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The Effects of Generative Concept Map on Science Learning Achievement and Cognitive Load*

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This study investigated the effect of generative concept maps according to learning achievements and cognitive load. A total of 78 students in the first grade of middle school participated in this study. Before the experimental treatment was implemented, students had to fill out a questionnaire assessing prior knowledge. The study was designed where all the students were presented the same learning contents regarding photosynthesis; however, the two experimental groups were provided with different concept map methods: a learner-generative concept map (GCM) and an instructor-provided concept map (PCM). GCM students were asked to make a concept map by themselves in small groups while they are reading material. PCM students were instructed to study in small groups in order to read the material; however, they were provided a concept map developed by their teacher. The control group (CG) had the teacher present the learning contents in traditional lecture format with no accompanying concept map. The results show that there were significant differences in the achievements among the groups. CG showed higher achievement than both the experimental groups. There was also a significant difference in cognitive load. Although the GCM group did not obtain higher achievement than the other groups, the GCM group showed higher mental effort and lower physical fatigue than the other groups. The GCM group might have invested more effort to find and connect ideas when drawing their concept map with peers which is unlike the conditions for the PCM group and CG. In conclusion, we should consider applying GCM in teaching and learning design in order to increase learning achievement and decrease extraneous cognitive load.

Keywords : Generative learning, Learner-generative concept map, Instructor-provided concept map, Cognitive load

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Introduction

One important learning strategy is to provide opportunities for students to participate in the learning process and to encourage students to accomplish their own learning objective. Learners' generative learning process may be more effective than taking information passively from teachers. Students who engaged in generative learning processes, such as learner-generated questions, generative-drawing, and concept mapping, show a deeper level of understanding (Ainsworth, Prain, & Tytler, 2011; Berry & Chew, 2008; Schmeck, Mayer, Opfermann, Pfeiffer, & Leutner, 2014; Wittrock, 1974).

One of the basic assumptions of Wittrock, the founder of generative learning, was that learners are not passive recipients of information, they are active participants in the learning process, working to construct meaningful understanding of information found in the environment (Wittrock, 1974). The term generation means that learners actively construct their own interpretation of information and draw inferences from them. Generation is the process of actively producing relations among knowledge and experience (Wittrock, 1974, 1989, 1991, 1992). In the construction of new schemata, generation can result in assimilative learning and also in accommodative learning. When students are asked to read text material, they must exert mental effort to adapt or to change their existing knowledge structures. Teachers can also lead students to generate connections between nodes of information. For example, students can learn to generate their own summaries or explanations as they work on their learning materials (Wittrock, 1994).

This model of generative learning has been studied in the teaching of science, reading comprehension and various subject areas (Berry & Chew, 2008; Schmeck et al., 2014; Wittrock, 1974). These results show that generative learning processes play an important role in learning and understanding these subjects.

Schmeck and his colleagues (Schmeck et al., 2014) tested the effects of having eighth grade students draw pictures relevant to a scientific text that they were currently reading. The results showed that students who were asked to draw pictures while reading scored higher on a comprehension test than students who only read. To study scientific text, drawing is a very important learning strategy to enhance engagement, to show conceptual reasons, and to clarify ideas (Ainsworth et al., 2011).

Wittrock (1974) implemented an experiment to verify the generative process in reading text material. The participants in the study were 366 fifth and sixth-grade elementary school students. They were assigned to one of three different group types for reading: organizers group, generative group and control group. The organizers groups were given one or two word organizers at the top of each text paragraph, and the generative groups were asked to write a summary including the meaning of each paragraph. Performance was the highest with the generative groups.

Berry & Chew (2008) reported the effect of student-generated questions and concept maps for college students studying psychology. In the first experiment, they asked students to make three questions per week concerning the course material. Lower performing students who participated in this study improved further than students who did not participate. In the second experiment, students generated concept maps regarding the course material. Generating concept maps significantly improved performance.

Previous studies of the generative process represented by learner-generated activities have shown that students improve their understanding and transfer of content. Generative activities help learners' cognitive and metacognitive processes and facilitate a deeper understanding of the learning materials (Wittrock, 1989, 1992).

Our current study was designed to examine the effects of concept map types on the performance of middle school science class students. To enhance the students' reading comprehension and problem solving, concept maps were used in class (Burrows & Mooring, 2015; Chang, 2007; Chawla & Singh, 2015; Kinchin, Hay, &

Adams, 2000; Wu, Krajcik, & Soloway, 2001). Previous concept map studies have provided the roles of concept map as a strategy to facilitate comprehension, to help organization, to retain information, and to activate recall and retrieval. Although some results failed to show the effects of concept maps on learning (Redford, Thiede, Wiley, & Griffin, 2012; Stull & Mayer, 2007), many previous studies did show that concept maps facilitated understanding and decrease cognitive load (Amadieu, Van Gog, Pass, & Tricot, 2009; Oh, Kim, Jung, & Kim, 2009; Van Gog, Kester, Nievelstein, Giesbers, & Paas, 2009; Verhoeven, Schnotz, & Paas, 2009).

Current Korean Concept map researches mainly used concept maps as advanced organizers (Heo & Kim, 2003; Oh & Kim, 2006; Oh et al., 2009; You & Kim, 2008) and summary strategies (Chung & Lee, 2003). In addition, concept map studies have yet to identify learner-generated concept mapping and instructor-provided concept map activity. Therefore, there is insufficient data to analyse and better understand the difference between learner-generated and instructor-provided concept map activities. The study of Kim & Oh (1995) was very similar to ours in applying student-centered and teacher-centered concept mapping in middle school biology. The teacher-centered concept map of Kim & Oh study was made by the teacher and students during class activities, but the PCM in our study was only to use the concept map provided by their teacher while they were studying. This study focused on to investigating the benefits of learner-generative concept map as opposed to expert-provided concept map.

Grabowski (2004) distinguished learner-generated and instructor-provided activity in the generative learning model. When teachers try to use generative activities, they should select a learner-generated or instructor-provided activity according to students' prior knowledge and other individual differences. An instructor-provided concept map may limit students' deep and active elaboration of cognitive processes. A learner-generated concept map requires students to make a spatial overview of semantic organization and learners have to identify the main concepts from the learning contents and organize them in a coherent manner by themselves (Amadieu et al., 2009).

Cognitive load theory presents three components: extraneous cognitive load, intrinsic cognitive load and germane cognitive load (Kirschner, 2002; Merriënboer, Schuurman, De Croock, & Paas, 2002; Merriënboer & Sweller, 2005; Sweller, 1988; Sweller, Ayres, & Kalyuga, 2011). Extraneous cognitive load is an unnecessary cognitive process that is not related to learning, and is caused in part by ineffective instructional design. Intrinsic cognitive load is determined by the inherent complexity of the material. Germane cognitive load is a generative process to adapt new schemata and to change existing knowledge structures. This form of cognitive load helps learners to engage in deeper cognitive processing such as organizing and integrating the ideas and knowledge from the learning material.

Although many researchers investigated generative activities, there are rarely any comparative studies performed (Stull & Mayer, 2007) between instructor- provided concept maps (PCM) and learner- generative concept maps (GCM). Therefore, this study investigated the effects of PCM and GCM on learning achievement and cognitive load.

Generative activities such as paraphrasing and summarizing reading materials, generating-questions and concept mapping have been shown to decrease cognitive load (Swanson, Moran, Bocian, Lussier, & Zheng, 2013). Yet, other studies have found that concept mapping has the benefit of increasing student understanding of learning contents, but it also demands a higher cognitive load (Gurlitt & Renkl, 2010; Stull & Mayer, 2007). Learner-generated activities may create a higher amount of extraneous cognitive load during the generative process when compared to instructor-provided conditions. The complexity of learner-generated activities may produce an overwhelming burden of extraneous cognitive load instead of producing any potentially beneficial germane cognitive load (Stull & Mayer, 2007).

For our study, we hypothesized that the control group would produce a lower amount of germane cognitive load (Plass, Moreno, & Brünken, 2010; Paas, Renkl, & Sweller, 2003) to comprehend text material than GCM and PCM groups. In this study, CG students received information directly from the teacher's lecture; however, the students from the GCM group had to draw a concept map to connect relevant ideas, use their prior knowledge to assimilate new ideas, and change their existing knowledge structure to accommodate novel concepts. PCM students were expected to perform similar activities as the GCM group except they were supplied with an instructor-provided concept map. We predicted that the cognitive load of the PCM group would be lower than the GCM group because they did not have to draw a concept map. Therefore, the GCM group would demand the highest germane cognitive load among the three groups. And the germane cognitive load of the PCM group would be higher than the control group.

For the PCM group, the middle school science teacher provided the concept map to the students while they read the textbook in small groups. For the GCM group, the students drew a concept map while they read the text material in small groups. We expected the GCM group would have a higher learning achievement and a higher germane cognitive load than the PCM group. Students who were instructed to make a concept map had to read the text material, elicit the text meaning, and draw the concept map. We hypothesized that more mental effort would be needed from the GCM group than from the PCM and control groups. The more mental effort that students invest, the higher the learning achievement.

This study examined the different effects between learner-generated concept mapping activities and instructor-provided concept map learning in middle school science class. We analysed science learning achievement and cognitive load according to the type of concept map utilized. In order to achieve these purposes, we have drawn the research problems as follows:

First, could learner-generative concept mapping affect science learning achievement more than instructor-provided concept map?

Second, could learner-generative concept mapping affect cognitive load more than instructor-provided concept map?

Methods

Subjects and groups

A total of 80 students in the first grade of middle school participated in this study. Two students were excluded from data due to their incomplete and missing information. Of the 78 remaining students, 37 (47.4%) were female and 41 (52.6%) were male. The students were assigned to one of three groups which were CG, the GCM group and the PCM group. GCM students were expected to collaborate in small groups to develop a concept map while they read the textbook material. PCM students studied in small groups as well, but they were provided a concept map from the teacher. CG students participated in a conventional class in which the teacher gave a traditional lecture. All students studied the same contents on photosynthesis in plants.

Learning material and measurement instruments

Learning material

Learning content was based on the photosynthesis of plants which is one of the science course topics for students in the first grade of middle school. The unit on photosynthesis deals with carbon concentrating mechanisms, light-independent reactions, and respiration. In the course of study, the unit of photosynthesis usually requires approximately six hours of class time.

Prior knowledge test and post achievement test

A pretest was implemented to check learners' prior knowledge relevant to photosynthesis in plants. The test was composed of 14 multiple-choice items. The reliability was $\alpha = .72$. There was no significant difference in prior knowledge among the groups ($F=1.238$, $p=.296$). After the experiment, students had to complete a posttest assessment of learning achievement. This test consisted of 16 items and reliability of the test was Cronbach α .73.

Cognitive load test

This study measured cognitive load using the Jung and Kim's instrument (2012) which was a validated collaboration load as well as individual load. The cognitive load instrument was appropriately revised for middle school students and face-to-face learning environments. The instrument is composed of six components such as physical efforts, mental efforts, task difficulty, self-evaluation of process, self-evaluation of outcome, and flow. Physical efforts involve physical fatigue and physical strength in the collaborative process to perform tasks. Mental efforts involve the learners' perceived amount of mental activity during the learning task. Task difficulty is the degree of understanding according to the learning task. Following the cognitive load theory, the physical efforts, mental efforts and task difficulty are constructs of intrinsic cognitive load, extraneous cognitive load and germane cognitive load. Also, the self-evaluation of process, self-evaluation of outcome, and flow indicate degrees of learner satisfaction, fulfillment and attention experienced in the collaborative learning process.

The cognitive load test uses indirect and self-reported questionnaires to measure a student's mental effort invested in understanding the learning materials. In addition, it is composed of 24 items using a 7-point Likert scale (7 = highly difficult, 1 = very easy). The reliability was α = .86.

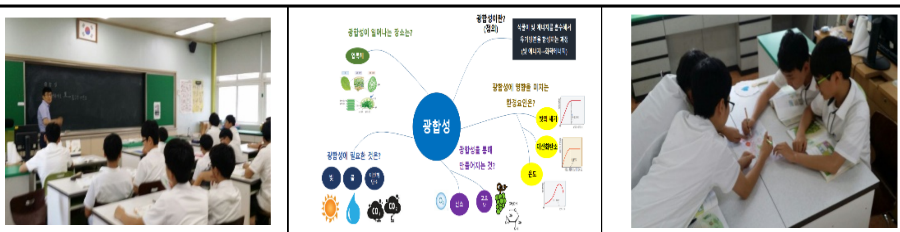
Procedures

This study was implemented during the second semester of 2014. The learning content was about photosynthesis in plants as designed in the science textbook for first grade middle school students. The science class for this study was designed for three hours per week. The unit of photosynthesis usually requires approximately six hours-class time to study. Therefore, this experiment was implemented in totality for two weeks, six hours total. Two weeks prior to the experiment, students were informed of the upcoming study. For the first 45 minutes, the science teacher explained the purpose of the study, the instructional methods to be used and the procedures of the experiment. In order to decrease the cognitive load in making a concept map, during the last 45 minutes, students were given the opportunity to practice drawing a concept map and learn how to read and connect the concepts written on the map. The instructor assigned homework for students to draw another concept map for feedback. During the following class period, the teacher checked the students' concept map homework and presented comments as to what was considered a good and bad concept map example. Actually, almost all students in the study already knew how to draw the concept map and how to use it through the other extra-curricular activities.

Table 1. Procedure for the experiment

Group	Before experiment	Experiment • 6 classes: 3 times per wk, 2 wks • each learning time: 45 mins	After experiment
CG	Prior knowledge test & explication about the experiments/ Instruction for the concept map	Lecture class	Achievement test & cognitive load test
PCM		Small group learning + Reading text and discussing the contents using the concept maps (35-40mins) + Mini lecture(5-10mins)	
GCM		Small group learning + Reading text and generating the concept map while reading the textbook + Mini lecture(35-40mins) + Mini lecture(5-10mins)	

Before the actual learning, students had to fill out a questionnaire regarding prior knowledge on the photosynthesis in plants. Except for CG students, who studied in a traditional lecture environment, both the PCM and GCM students studied in small group collaborative learning environments for 45 minutes, three times a week. PCM students read the text and discussed the contents using the teacher-provided concept map. GCM students also read the text and they collectively generated a concept map. As a result, the students had to summarize the meaning and organize the relationships between concepts. The teacher gave a short lecture to summarize the contents for 5-10 minutes at the end of the PCM and GCM class time. Measurements were taken every ten minutes during class in order to check cognitive load, and at the end of the experiment, student learning achievement was measured with a 40-45 minute posttest.



CG	PCM	GCM

Figure 1. Example of group activities

Results

Science achievement according to the types of the concept maps

The achievement of CG students outperformed both experimental groups. There was a significant difference in the achievement among the groups (F=5.665, p=.005). These differences were between CG and GCM, and CG and PCM. It was an unexpected finding that CG achievement outperformed other groups. We predicted that the GCM group would have superior achievement when compared to CG and the PCM group.

Table 2. The difference of achievement among groups

Groups	N	Achievement		F	p	*Post hoc*
		M	SD			
GCM	27	9.26	2.63			
PCM	25	9.16	2.94	5.665**	.005	③>①, ②
CG	26	11.35	3.71			
Total	78	9.92	3.31			

**p<.01

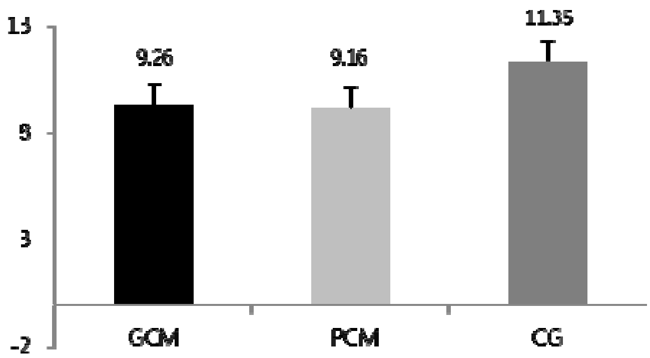


Figure 2. Mean and standard deviation on learning achievement

Cognitive load according to the types of the concept maps

The physical effort of CG students was higher than both the GCM and PCM groups. There was a significant difference in physical effort among the groups (F=6.337, p=.003). Our results show that the GCM group felt the least amount of physical fatigue among all the groups. The mental effort of the GCM group was higher than CG and the PCM group. These differences were statically significant among all groups (F=3.153, p=.048). In order to understand the text, GCM students exerted more mental effort when studying than the other groups.

The task difficulty under CG conditions was the highest, and task difficulty under GCM conditions was the lowest. However, these differences were not significant (F=2.799, p=.067). There were no significant differences in self-evaluation of the process (F=.789, p=.458), self-evaluation of the outcome (F=1.379, p=.258) and flow (F=.874, p=.422) among the groups. Although these results were not statically significant, the mean values of the PCM group were the lowest among all three groups. In addition, mental effort of the PCM group was the lowest. These results can be explained as the students not using the instructor-provided concept map effectively.

Table 3. The difference of cognitive load among groups

Cognitive Load	GCM①	PCM②	CG③	F	p	*Post hoc*
	M±SD	M±SD	M±SD			
Physical effort	2.58±1.49	2.98±1.38	4.01±1.61	6.337**	.003	③>①, ②
Mental effort	5.40±1.15	4.70±1.07	4.74±1.17	3.153*	.048	①>②, ③
Task difficulty	2.96±1.36	3.60±1.28	3.75±1.23	2.799	.067	
Self-evaluation of process	4.53±1.34	4.19±1.08	4.54±0.95	.789	.458	
Self-evaluation of outcome	4.81±1.33	4.25±1.42	4.39±1.07	1.379	.258	
Flow	4.35±1.36	3.92±1.14	4.27±1.17	.874	.422	

*p<05, ** p<.01

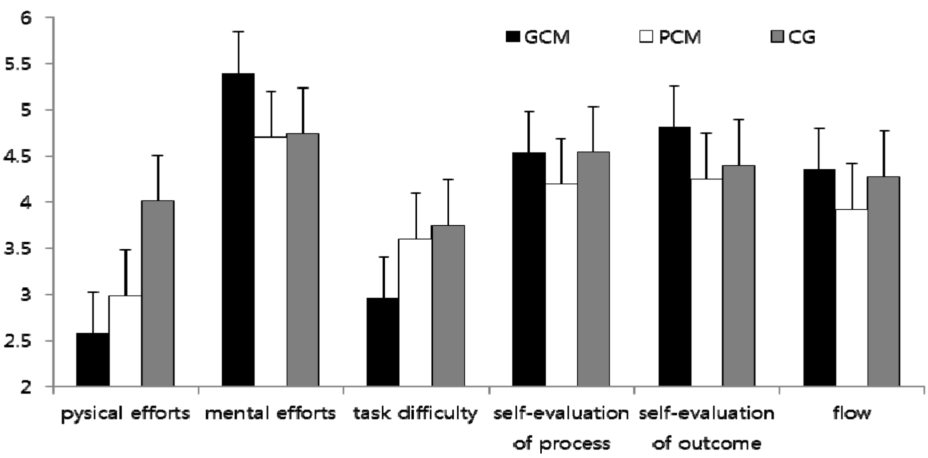


Figure 3. Mean and standard deviation on cognitive load

Discussion

The purpose of this study was to investigate the effects between learner-generated concept map activities and instructor-provided concept map activities on learning achievement and cognitive load. Firstly, there was a significant difference on the learning achievement among the groups. The achievement of CG students was higher than both experimental groups. These differences were between CG and the GCM group, and CG and the PCM group. We expected the GCM group would have superior achievement compared to CG and the PCM group. Previous studies showed the use of generative learning activities such as paraphrasing and summarizing text material, generated-question, and concept mapping helped enhance comprehension and achievement (Berry & Chew, 2008; Wittrock, 1974, 1989, 1992). We expected that the active engagement from GCM learners would enhance comprehension and learning achievement. However, our results showed the superiority of traditional lecture during middle school science class. CG students might have benefitted in higher learning achievement because the teacher directly taught students so they could just receive knowledge while students participating in the experimental groups had to acquire their knowledge by themselves.

Secondly, we analyzed cognitive load among the groups. The physical effort of CG was very high compared to the GCM and PCM groups. There was a significant difference between the groups. The results showed that the CG group felt more physical fatigue than the GCM and PCM groups. The students who passively listened to their teacher's lecture felt higher physical fatigue than the GCM and PCM groups who had to participate in their own small group work. The mental effort of the GCM group was higher than CG and the PCM group. These differences were statically significant from the other groups. To understand the text, GCM students tried to study harder than the other groups. It can be interpreted that the GCM group who constructed a concept map while reading the text invested more mental effort than the teacher-centered environment of CG and the teacher-provided concept map of the PCM group. This study showed that although the GCM group did not acquire the highest learning achievement compared to the other groups, the mental effort of the GCM group was higher in terms of invested identifying, connecting, and drawing knowledge and ideas.

Another important part to look into is that these results showed that teacher lectures produced a strong effect on learning achievement. In addition, students participating in teacher lectures did not invest much mental effort and felt the highest physical fatigue compared to the other groups. Although the GCM group's achievement was not higher than CG, students invested more of their mental effort compared to other groups. The result of the PCM group showed lower achievement and generally high cognitive load. This result can be interpreted as meaning that the instructor-provided concept map does not effectively facilitate learning; and instead it may contribute to confusion. Therefore, it's not completely effective to just provide concept maps. Teachers need to give enough explanation and guidance on how to produce and use concept maps meaningfully.

We can conservatively infer that the short learning period and the complexity of the concept map activity affected our results. This experiment was performed for a short duration of only three times per week for a total of two weeks. There was not enough time to acclimatize middle school students to effectively participate in small group learning activities. In addition, the process of the GCM group was relatively more complicated and thus increasing the amount of total comprehension necessary to achieve the same learning as compared to teacher's lecture. These results were consistent with the study of Stull & Mayer (2007). They described that learner-generated activities could create more extraneous cognitive load in the generative process than under the instructor-provided condition. Although, the GCM activity provided generative learning, students were influenced by extraneous cognitive load rather than germane cognitive load.

Due to the results of our research, we have created suggestions for further studies. Firstly, we should consider having a longer duration of GCM and PCM conditions. The longer the generative learning process, the more students will be accustomed to the GCM and PCM conditions and the potential for achievement under GCM and PCM conditions are likely to rise. Secondly, studies should be administered or conducted with either high school or college students in different subject areas to confirm the effects of the GCM condition. Thirdly, instructional designers should consider the degree of generation activity for learning. We should consider the variety of personal factors, learner-generated activities and instructor-provided activities that may depend on the students' self-regulated learning capabilities (Lim, 2009; Lim, Lee, & Grabowski, 2009) and interests on the subject, preference of small group learning, and other relevant factors. Finally, to decrease the extraneous cognitive load of the GCM group when making concept mapping, teachers should provide enough practice time and guide students on how to use the concept map. Therefore in further studies, we should consider the degree of cognitive load relative to drawing concept map using a reliable standard test before the experiments.

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