Controlling cognitive load of high school student in biology class

Control de la carga cognitiva de estudiantes de bachillerato en la clase de biología

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Abstract

When the capacity of working memory is exceeded it leads to trouble in the cognitive process. The learning process will be more influenced by mental effort than by cognitive processing. In this situation students have a demandon their cognitive system termed cognitive load (CL). This study describes students CL both in a conventional biology class and after the integration of four CL controlling strategies in the conventional teaching strategy. The four CL controlling strategies were the framing technique, the stay and stray strategy, the didactical reduction of teaching material, and the stimulation of prior knowledge by watching videos. The level of cognitive load was described quantitatively based on the result of the statistical analysis of the correlation between the intrinsic cognitive load (ICL), the extraneous cognitive load (ECL), and the germane cognitive load (GCL). Student ICL was discovered by the ability of the student to process information gathered from a complexity worksheet. ECL was shown by the student's mental effort (ME) collected by questionnaire using a subjective rating scale. GCL was revealed through learning achievement (LA) measured by a paper and pencil test. The study was conducted in several high schools in West Java, including a state and private high school (SMA) and an Islamic high school (Madrasah Aliyah). The result demonstrated that during a conventional biology class student CL was at a high level. Integrating four CL controlling strategies into the conventional teaching strategy separately led to different levels of student CL. Three of the four CL controlling strategies, i.e. stimulating prior knowledge by watching video; the framing strategy, and the didactical reduction of teaching content, potentially lowered students' CL. The Integration of stay and stray strategy into a conventional class made no difference to the level of CL compared to that in a conventional class.

***Key words:** biology class, cognitive load, framing, stay and stray strategy, didactical reduction, prior knowledge.*

Resumen

La actividad de la memoria de trabajo que excede su propia capacidad provoca contrariedad en el proceso cognitivo y el proceso de aprendizaje será influenciado más por el esfuerzo mental que el procesamiento cognitivo. En esta situación, los estudiantes tienen una carga en su sistema cognitivo denominada carga cognitiva (CC). Este estudio describe la CC de los estudiantes tanto en una clase de biología convencional como después de la integración de cuatro estrategias de manejo de CC en la estrategia de enseñanza convencional. Las cuatro estrategias de control de CC aplicadas fueron la técnica del encuadre, la estrategia de dinámicas de grupo, la reducción didáctica de la materia de enseñanza, y la estimulación de conocimiento previo mediante exposición de videos. El nivel de la carga cognitiva se describió cuantitativamente basado en el resultado del análisis estadístico de la correlación entre la carga cognitiva intrínseca (CCI), la carga cognitiva extrínseca (CCE), y la carga cognitiva relevante (CCR). La CCI del estudiante se descubrió a partir de la capacidad del estudiante de elaborar información adquirida de una hoja de cálculo de complejidad. La CCE se mostró a través del esfuerzo mental (EM) del estudiante recopilado en un sondeo con una escala de calificación subjetiva. La CCR se expuso mediante los logros de aprendizaje (LA) calculado en una prueba de lápiz y papel. El estudio se llevó a cabo en diversas escuelas de educación media en Java Occidental, incluyendo escuelas de educación media (SMA) estatales y privadas así como una escuela de educación media islámica (Madrasah Aliyah). El resultado demostró que en una clase de biología convencional, la CC del estudiante estuvo en un alto nivel. La integración, por separada, de cuatro estrategias de control de CC a la estrategia de enseñanza convencional resultó en diferentes niveles de la CC del estudiante. La integración de la estrategia de dinámicas de grupo a la clase convencional no alteró el nivel de la CC con respecto a la de la clase convencional.

***Palabras clave:** clase de biología, carga cognitiva, encuadre, estrategia de dinámicas de grupo, reducción didáctica, conocimiento previo.*

INTRODUCTION

Teaching and learning in a school class is based on the need to develop and to train students' thinking processes. The thinking process relates to the activity of the working memory in which all cognitive processes occur when the student is learning. Working memory has only a limited capacity and can handle a limited number of interactions (Paas *et al*, 2003; Kalyuga, 2011). The capacity of a working memory depends on the student having a level of prior knowledge. If the working memory in a cognitive system has a little trouble the student will have difficulty in learning and the information delivered by the teacher cannot be taken in (Sweller *et al*, 1998; Paas *et al*, 2003). The student will be forced to mentally integrate information, a process that is unrelated to the construction of cognitive schema. In this situation the student has a demand on their cognitive system known as cognitive load.

Cognitive load (CL) consists of three components, intrinsic cognitive load (ICL), extraneous cognitive load (ECL), and germane cognitive load (GCL). ICL relates to the load of information processing received as any learning task is given. ICL has simultaneous interconnections with the working memory. The magnitude of ICL depends on the number of elements that must be simultaneously processed in the working memory and the prior knowledge that has been already absorbed by the learner. The load resulting from the interactivity of the elements varies among and within different subject areas (Moreno & Park, 2010). De Jong (2010) simplifies this by saying that ICL relates more to inherent characteristics of the content of subject matter. ICL cannot be changed by instructional treatments (de Jong, 2010; Moreno & Park, 2010). ECL is the load that student has and it is affected by the instructional system developed by the teacher. ECL is not necessary for learning because it does not directly contribute to learning or to the construction of cognitive schemas (de Jong, 2010). ECL can be eliminated by redesigning the instructional system (Moreno & Park, 2010; de Jong, 2010).Several factors which cause ECL are split attention, the modality principle, and the redundancy principle (Cerpa *et al*. 1996; Sweller *et al*. 1998; Sweller, 2010; de Jong, 2010;). GCL is the result of devoting cognitive resources to schema acquisition and automation rather than to other mental activities. GCL is the cognitive load associated with organizing the learner's knowledge. GCL is caused more by ICL than by ECL (Moreno & Park, 2010). De Jong (2010) stressed that the construction of cognitive schema involves several cognitive processes (e.g. interpreting, exemplifying, classifying, inferring, differentiating, and organizing) which occur when students process information contained within certain tasks of the instructional system. Consequently, instructional designs should stimulate and guide students to engage in schema construction and automation.

CL may be used as an explanation for the effect of the teaching strategy on psychological and behavioral changes which show learning achievement (Moreno & Park, 2010). CL can also be used to explain a level of student difficulty or student inability to construct schema of knowledge. Increased CL can be because of poor instructional design (Sweller *et al* 1998). According to CL theory a reduction of CL is purposed to give more space in the working memory and to give a place for processing new information. The reduction of CL can be done in order to keep mental effort at a minimum during the learning process (Moreno & Park, 2010). Teachers should, in their instructional design, pay attention to keeping a balance between ICL and GCL through altering the factors having an impact on ICL or ECL. De Jong (2010) and Kester *et al* (2010) described the way to reduce ICL and ECL to produce a better way for students to process the content of teaching, such as by activating student prior knowledge, minimizing the number of elements and their interaction, avoiding split attention and reducing redundancy of information, and, finally, enhancing students' learning modality systems. This paper describes the different impacts of the integration of several CL controlling strategies into the conventional biology class of various high schools.

METHODOLOGY

This study was conducted in 12 high schools in Bandung, Sumedang, and Ciamis of West Java Province of Indonesia including state and private high schools (SMA) and Islamic high schools (Madrasah Aliyah; MA). Four strategies to control student CL were integrated into the conventional teaching strategy that was usually used by the teacher, a teaching strategy adapted from the framework for guided inquiry class (Kuhlthau *et al*, 2012). The four CL controlling strategies were 1) the framing technique to avoid students' divided attention and to give a direction to what the students have to learn, 2) the stay and stray strategy to help student by giving peer coaching from outside the group, 3) the didactical reduction (simplification) of teaching material represented by a flow-chart to reduce the number of elements of content, and 4) stimulating prior knowledge by watching videos that shows concepts in a contextual mode and relate to the content that will be learned (see the Appendix for examples of these methods). Several topics of biology which had a different complexity, from very concrete to very abstract content, were chosen as the teaching content. These teaching topics included plant systems and diversity, the coordination system, and the excretory system.

The level of cognitive load was described qualitatively, based on the result of the statistical analysis of correlation among three components of CL. Student ICL was revealed by the student's ability to process information delivered by the teacher or by the tasks of instructional design (IP; information processing). IP was gathered by a complexity worksheet given to the student alongside the teaching process. ECL was shown by the student's mental effort (ME) collected by the questionnaire on a subjective rating scale. GCL was revealed by learning achievement (LA) measured by a paper and pencil test conducted at the end of the teaching. All instruments used to measure student CL were developed as described by Brünken *et al* (2010). The relations among three components of cognitive load are asymmetric (Moreno & Park, 2010), levels of ICL or GCL are shown in another way, through the score of the student's IP or LA whereas the level of ECL is equal to the score of ME. CL was assumed to be at a lower level when IP-LA has a significant positive correlation whereas both IP-ME and ME-LA have a significant negative correlation.

RESULTS AND DISCUSSION

The biology classes of high schools in some districts of West Java are conventionally conducted by the teacher using a teaching strategy adapted from the framework for guided inquiry class (Kuhlthau *et al*, 2012) with common teaching methods such as teacher presentation complemented by a slide power point, questioning, discussion, practical activities, and student presentations. To enhance student motivation and stimulate a student's prior knowledge apperception was commonly stimulated by questioning, asking about the content delivered in previous lesson. Interpretation of statistical correlation on student CL components revealed that the CL of the students commonly stayed at a high level (Table 1). Teaching strategies in a conventional biology class could not yet yield a level of ICL that could reduce the level of ECL because the negative correlation of IP-ME was not significant (Table 1). In some cases, such as in SMA Ciamis, correlation of IP-ME showed a positive value of coefficient correlation indicating that some students used their ME to develop final cognitive schemas. All these teaching strategies when employed in a conventional biology class in all schools showed a positive impact on decreasing ICL and had a positive effect on GCL as indicated by a significant positive correlation of IP-LA (Table 1). However, the GCL was also imposed by ECL because the negative correlations of ME-LA were not significant. The result means the students have difficulty in constructing a schema using their cognitive system. They used much mental effort to gather the concepts or information delivered by the teacher while the teaching process was going on. It was shown by the explanation of de Jong (2010) that if the load is imposed by mental activities that interfere with the schemas' construction or automation it will have negative effects on learning. Moreno & Park (2010) stressed that the purpose of instruction is to keep mental effort at a minimum during the learning process.

Table 1. Correlation among CL components showing a level of student CL in biology classes of high school without integration of CL controlling strategy. Cells with gray shading indicate a significant correlation (p<0,05).

CL Components	SMA Bandung	SMA Sumedang	SMA Ciamis	MA Bandung
IP – LA	0,664; p=0,000	0,512; p=0,001	0,171; p=0,334	0,485; p=0,007
IP – ME	-0,208; p=0,237	-0,221; p=0,183	0,010; =0,956	-0,094; p=0,620
ME – LA	-0,295; p=0,090	-0,047; p=0,786	-0,023; p=0,897	-0,290; p=0,120

The integration of CL controlling strategies into conventional biology classes of high schools brought a better student CL level compared to the conventional teaching strategy alone (Table 2). The use of video in the apperception phase to stimulate student prior knowledge and the use of framing during the teaching process separately gave a significant negative correlation of IP-ME and a significant positive correlation of IP-LA (Table 2). These results show that CL controlling strategies integrated into the conventional strategy could reduce student ICL and positively contribute to decreasing student ECL. These show that two strategies have a potential effect on reducing the level of student CL. We predict that the use of tables and dichotomous diagrams containing keywords or clues act as a kind of framing, directing students to what they should do while they are doing the instructional task. Keywords or clues mean it is easier for the student to construct schema, thus they can finish the task better. A dichotomous diagram with keywords or clues gives a basic schema in a concrete manner. Gibney & Lengel (1968) explained that the need of concrete learning experiences is inversely proportional to intellectual capability. A student with less intellectual capability needs more concrete examples. On the other hand, stimulation of student prior knowledge using video has the advantage of reducing student CL because the information conveyed in a video is un-fragmented and enclosed in an audio-visual organization. The un-fragmented information means that elements of information are delivered in an interconnected way, a method that means it is easier for students to recall the knowledge they already have. In this situation working memory will have more space for information processing and assimilation will proceed more efficiently.

Table 2. Correlation of CL components showing a level of student CL in biology classes of high school with integration of CL controlling strategies. Cells with gray shading indicate a significant correlation (p<0,05)

CL Components	Stay & Stray	Framing	Didactical reduction	Stimulating Prior Knowledge by Video
IP – LA	0,632; p=0,000	0,475; p=0,003	0,635; p=0,000	0,420; p=0,021
IP – ME	0,106; p=0,558	-0,338; p=0,023	0,003; p=0,985	-0,574; p=0,0009
ME – LA	0,133; p=0,462	-0,078; p=0,652	-0,465; =0,004	-0,348; p=0,0598

In other situations, the use of didactical reduction of teaching material gave a different result compared to the two strategies mentioned above. Didactical reduction represented by a flowchart gave an insignificant correlation of IP-ME (Table 2) meaning there is no clear connection between IP and ME. This statistical correlation indicated that during the teaching process there was no necessary relationship between ICL and ECL. When student's ICL is lower, ECL can stay either at a lower or higher level. In this situation, however, the decreasing ECL level affected the level of GCL as shown by a significant negative correlation of ME-LA. Student GCL was more affected by ICL because the correlation of IP-LA leads to a significant positive correlation. These results revealed that didactical reduction had a potential effect for reducing student CL, even though the cognitive processing during the teaching process was quite disturbed by ECL. This potential effect of didactical reduction on reducing student CL probably come from the depiction effect of teaching content delivery using a flow-chart. A flow-chart is a kind of visualization of teaching material changing the text into a visual format. A flow-chart contains a reduced number of information elements and shows how those elements interact with each other giving a mode in which the student will acquire the content easier than a text. Haslam &Hamilton (2010) found that visualization facilitated the student to develop a mental representation of the concept. Additionally, Sweller (2005) specified that visualization or a picture as a kind of representation helps the student to understand the content more easily. Mayer& Moreno (2003) noticed that visualization of a concept has an advantage for the student with poor prior knowledge.

The use of the stay and stray strategy gives students more opportunities to help each other during the teaching process, especially when students acquire new information. In the stay and stray strategy students of one group can go to another group to ask for information and an explanation of that information. Unfortunately, the integration of the stay and stray strategy in the teaching process had less potential to reduce student CL because only IP-LA correlation yielded a positive value of coefficient correlation and occurred significantly. The IP-ME and ME-LA correlation led to an unexpected relationship (Table 2). Both IP-ME and ME-LA correlations were positive and insignificant; this condition shows that the stay and stray strategy could not expressively reduce student ECL. It means that to come to a high level of LA student needs more ME rather than LA. Stay and stray strategy cannot manage student ECL as yet. It may come from the impact of the student visitation step, in which students could visit another group to complete their observation but the visited group was not ready to give explanations to the visiting group. We found that the visited group could not give an accurate explanation to the guest group because students in the visited group had difficulty processing the information delivered by instructional tasks, such as from their observation. We guessed two possible explanations for this situation: *first*, students had no sufficient prior knowledge to assimilate new knowledge (Mayer & Moreno, 2010), and *second*, the information that students collected from their observations was too complex; having a large number of interacting elements that students needed to process in their working memory. A high interactivity content by its nature consumes more of the available cognitive resources (de Jong, 2010).

CONCLUSIONS

Student CL during the teaching process in high schools' conventional biology classes was considered to stay at a high level. Integrating four CL controlling strategies into the conventional teaching strategy separately lead to different levels of CL. The use of video to stimulate student prior knowledge, framing, and didactical reduction of teaching content took the teaching process into a lower level of student CL. Integrating stay and stray strategy into the conventional class gave no better student CL level, in other words, the students still had difficulty processing the information meaningfully. We suggest that to control student CL in biology class teachers should pay attention to several factors affecting students' CL rather than only one factor. Teachers may use a minimum of two or more CL controlling strategies simultaneously integrated into their instructional design.

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APPENDIX

Teaching steps of conventional teaching strategy and integrating controlling cognitive load strategies in conventional teaching of Biology Class of Senior High School

Stage	Conventional Strategy*	Controlling Cognitive Load Strategies			
		Stay & Stray	Framing	Didactical Reduction	Stimulating Prior Knowledge by Video
Apperception (Open & Immerse)	Asking student’sexperiences relating to teaching contents and to the current problem, to open student’s mind.	Asking student’sexperiences relating to teaching contents and to the current problem, to open student’s mind.	Asking student’sexperiences relating to teaching contents and to the current problem, to open student’s mind.	Asking student’sexperiences relating to teaching contents and to the current problem, to open student’s mind.	Asking student’sexperiences relating to teaching contents and to the current problem, to open student’s mind. Watching videos relating to teaching content, such as how the kidney works, the influence of hormones on other coordination organs, and plant biodiversity, to stimulate or elicit prior knowledge
Explore	Teacher presents teaching content using a slide power-point. Student works in a group to search out all information relating to teaching content, from text books or internet.	Teacher presents teaching content using a slide power-point. Student works in a group to search out all information relating to teaching content, from text books or internet.	Student works in a group to search out all information relating to teaching content, from text books or internet, using table and dichotomous diagrams containing keywords or clues (as a framing from the teacher)	Teacher presents teaching content using a flow-chart (a didactical reduction of teaching content from text book to flow-chart)	Teacher presents teaching content using a slide power-point. Student works in a group to search out all information relating to teaching content, from text books or internet.
Identify	Student works in a group to identify the important information and formulates questions	Student works in a group to identify the important information and formulates questions	Student works in a group to identify the important information through answering several questions already written in the worksheet.	Student works in a group to identify the important information and its relationships from the flow-chart. Student formulates questions	Student works in a group to identify the important information and formulates questions
Gather	Student works in a group to collect the data through observation. Data should be used to answer the question.	In one group: One or two students visit another group to ask for the important data relating to their question (stray). Others members stay in the group to receive visitors from another group and answer the questions from the visitors (stay).	Student works in a group to collect the data through observation, however she/he should pay attention to the table, dichotomous diagram, or questions prepared by the teacher in the worksheet	Student works in a group to collect the data through observation. Data should be used to answer the question.	Student works in a group to collect the data through observation. Data should be used to answer the question.
Create & Share	Student discusses in a group the answer to the question, using data and presents (shares) the results in the class. Student concludes whether the question is answered or not.	Student discusses in a group the answer to the question, using the data that they collected in the group and that they obtained from other groups. Student presents the data and shares the results in class. Student concludes whether the question is answered or not	Student discusses in a group the answer to the question, using data and presents (shares) the results in the class. Student concludes whether the question is answered or not.	Student discusses in a group the answer to the question, using data and presents (shares) the results in the class. Student concludes whether the question is answered or not.	Student discusses in a group the answer to the question, using data and presents (shares) the results in the class. Student concludes whether the question is answered or not.
Evaluation	Student answers the teacher’s question about teaching content and process.	Student answers the teacher’s question about teaching content and process.	Student answers the teacher’s question about teaching content and process.	Student answers the teacher’s question about teaching content and process.	Student answers the teacher’s question about teaching content and process.

*Note: the framework of conventional teaching strategy was adapted from the framework of guided inquiry class (Kuhlthau et al, 2012)

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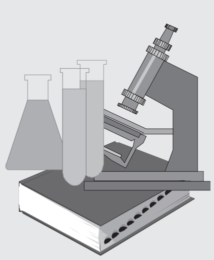

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