Measuring Components of Cognitive Load in Integrated Learning About Plant Structure and Function

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Abstract. Understanding how cognitive load is measured is a basic challenge in the cognitive load theory. This measurement is necessary when student receiving highly interconnected information which results in high cognitive load. Therefore, this study uses quasi experiment to measure student's cognitive load in learning plant structure and function. The subject of this study are 64 undergraduate students enrolling in plant anatomy course. The cognitive load is measured through information analysis skill (intrinsic load), attitude (extraneous load), and reasoning skill (germane load). The results shows that there is a significant correlation between the three components of cognitive load wherein students' information analysis skill is "sensitive" to intrinsic processing (developing prior knowledge) while attitude is sensitive to extraneous processing (developing attitude and positive developing attitude and positive perception). This is shown by the test result on reasoning skill. The result is also consistent with cognitive load theory stating that the component of cognitive load should be measured by different measure.

Keyword: Cognitive load measurement; integrated learning; plant structure and function

1 Introduction

Conceptual integration is important in optimizing learning process and outcome for students. This is in line with the objective of integrated learning applied by Indonesia's current curriculum, the curriculum 2013. It is stated that conceptual integration happens when there is continuous understanding of an idea through different level, breadth, and depth within discipline in specific learning domain, and integrated skill and concept understanding between different disciplines with similar characteristics [1]. Therefore, the conceptual integration is used to develop learning in holistic manner by relating ideas between different concepts. To ensure comprehensive integration, the integration should cover the wide and the depth and between disciplines [2]. The integrated learning material has a positive impact on student's understanding and knowledge and is deemed to be effective to lower students' cognitive load [3, 4]. Furthermore, it is asserted that the cognitive theory grows on the idea that learning happens when students actively construct knowledge representation within the limited working memory [5].

The main challenge in designing learning instruction especially in integrated learning is the sensitivity of cognitive load in learning process [6, 7]. The integration should specifically be measured in a way that the total cognitive processing needed does not exceed the capacity of

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students' working memory. Therefore, an integrated learning model is needed to facilitate students' cognitive process and keep the process within students' capacity. The integrated learning in this study uses nested type aiming to facilitate students in integrating social, thinking, and content-specific skills when discussing a topic. To measure students' cognitive load during learning process, an effective measurement is needed.

According to triarchic theory of cognitive load, there are three types of cognitive process during learning which contribute to cognitive load namely, extraneous processing which is the load irrelevant to the objective of learning, intrinsic load which is the load relevant to the process of understanding learning material, and germane processing which is the load related to a deeper cognitive process of organizing information and connecting knowledge [8, 9]. This study, therefore, analyze the way to lower extraneous processing by developing positive attitude and perception and lower intrinsic processing by utilizing prior knowledge when processing information. This study also analyzes the difference in students' germane load using reasoning skill test.

The process of developing positive attitude and perception as well as the utilization of prior knowledge is delivered through nested-typed integrated learning using Marzano instructional framework. This process aims to facilitate student in integrating plant structure and function using five learning dimensions of Marzano. The learning dimension is able to translate how a student learns and thinks (dimension of thinking) to a framework of performance (practical framework) leading to the development of students' reasoning skill [10]. Thus, the use of Marzano instructional framework is able to facilitate students in processing information in accordance with natural design of human brain function, thus, the cognitive processing does not exceed the capacity of working memory. Moreover, reasoning skill test is used to analyze the difference in germane processing due to the process of reasoning that involves mental operations such as concept construction, principle of construction, comprehension, problem solving, and decision making which are the projection of knowledge construction as a result from learning process.

In this study, the sensitivity of the three cognitive load components is tested based on students' ability to analyze information during learning, mental effort in understanding learning material, and reasoning skill after conducting learning. The measurement of information analysis skill using information analysis test which is equipped with performance objective aiming to analysis plant structure in relation to its function, analyze plant adaptation strategy by relating plant structure and function, interpret data on plant structure and function, and design an experiment within a time frame. The students' mental effort in comprehending learning material is attributed to teaching model measured by attitude scale. The main aim of this study is to determine whether the three measurements of cognitive load component are sensitive to the difference in strategy to lower student cognitive load, comparing integrated learning with nested model with the conventional nested model. The three measurement is deemed as sensitive if the three components of cognitive load has significant correlation with one another.

2 Method

This study uses quasi experimental method with nonequivalent control group design. The subject of the study were 64 undergraduate students taking Plant Physiology Subject in the academic year of 2019/2020. The 33 students learned with nested type integrated learning with Marzano instructional framework, while the other 33 students participated in conventional integrated learning as a control group. In collecting the data, this study uses three instruments for measuring each component of cognitive load. The intrinsic load is measured using a test covering the task to analyze the conceptual information of plant function. The tasks are (1) identifying the plant structures which are relevant to function (2) integrating the concept of plant structure to the function (3) applying relations between plant structure and function (4) designing an experiment. Meanwhile, the extraneous load is measured using attitude scale to obtain the data of students' mental effort while understanding the learning material and the germane load is measured with 30 test items of multiple choices with reasons covering students' reasoning skill in analytical, causal, and proportional reasoning. The result of the tests was analyzed to obtain the information of students' cognitive load during the implementation of 2 types of integrated learning.

The conventional nested typed integrated learning applied to control group is a learning strategy that integrate multiple skills in achieving the learning objective. The skills being integrated in this study are social, thinking, and content specific skills. The steps of conventional nested typed integrated learning are:

a. Delivering problems related to relation between plant structure and function to facilitate thinking skill. The problems delivered are always related to natural phenomena in order to stimulate students to think speculatively and to recognize the pattern between plant structure, plant function, and plant habitat.
b. Delivering learning material with contextual theme to facilitate students' content specific skill. The contextual theme in this study is defined as how student construct their knowledge about plant physiology by integrating it with the knowledge about plant anatomy which is previously learned and kept as cognitive schemes.
c. Providing chances for students to complete their tasks by collaboration to facilitate students' social skill.

Meanwhile, the nested typed integrated learning with Marzano instructional framework applied to experimental group is a learning strategy based on a way the brain works when processing information to understand learning material. This strategy is conducted by integrating social skill emphasizing on teacher and students' interactions in classroom discussion, thinking skill, and content specific skills. By using Marzano instructional framework, the learning process is expected to be able to facilitate students in learning and thinking. The principles of this learning strategy are:

a. Creating conducive learning environment by maintaining interactions between lecturer-students and among students
b. Delivering problems and solutions to the problems aiming to facilitate students in developing thinking process
c. Providing chances for students to complete their task by collaborating to enhance students' optimum development zone and increase students' optimism in learning
d. Providing an objective performance guidance covering the operational verbs to direct students' performance in integrating plant structure and function in order to ease the information processing in working memory
e. Utilizing prior knowledge in long term memory to construct the concept of plant structure in relation to topic being delivered, leading to knowledge assimilation.

The strategy to measure the three components of cognitive load are described in the following subsections.

2.1. Measuring Intrinsic Load

Measuring intrinsic load aims to obtain data about students' ability in analyzing information. The test on information analysis skill is applied on the concept of transpiration and photosynthesis. The test items demand students to write down their answer in a paragraph to obtain students' information analysis skill on the aspect of identifying components of plant structure which are relevant to its function, integrating plant structure to function, applying the principles of correlation between plant structure and function, and designing an experiment.

Furthermore, the analysis is carried out using tasks and a rubric. There are nine tasks given to the students to gain data about their information analysis skill. Meanwhile, the rubric is provided to analyze the completeness of components used in analyzing information with 4 scale from 1 to 4. The aspect measured by the rubric of information analysis skill is adapted from a rubric developed by Marzano [11]. The further detail about the tasks and rubric are shown in Table 1 and table 2.

Table 1. Information analysis tasks

	Identifying components of plant structure relevant to its function
1	Choosing the plant tissues on a specific organ structure which are suitable to compare
2	Identifying similarity and differences of plant tissues on an organ
3	Explaining and categorizing plants based on the characteristics of organ tissues
	Integrating the concept of structure with function
1	Integrating knowledge about plant structure and function
2	Analyzing the "mistake" in relating the plant structure and function to adaptation strategy in plant habitat
3	Constructing supporting details by providing proof of the difference between the plant structure with its adaptation strategy
	Applying the principles of correlation between plant structure and function
1	Applying the principles of plant structure and plant function
	Designing an experiment
1	Hypothesizing
2	Designing an experiment based on plant structure and the principle of process in plant physiology

The score of students' information analysis skill follows categorization by Arikunto [12] explained as follow:

Table 2. Categorization of information analysis skill

Score	Category
3,2 – 4,0	Excellent
2,7 - 3,1	good
2,3 - 2,6	Fair
1,7 - 2,2	Unsatisfactory
0,0 - 1,6	Very low

2.2. Measuring *Extranous load.*

Measuring extraneous load aims to collect the data on the mental effort needed to understand a certain learning material. A rubric is used to obtain the data with 5 level of Likert scale (1) very easy (2) easy (3) medium (4) hard (5) very hard. The lower the average score achieved by the students, the lower the mental effort needed to understand learning material.

The aspects measured by the instrument of extraneous load are on identifying components which are relevant to the plant function integrating the structure and function of plant, and integration scheme of function and application of the principles of correlation between plant structure and function

3 Reasoning skill test (*Germane Load*)

The method to obtain data about students' ability to develop cognitive schemes by organizing knowledge and relating newly learned knowledge with the knowledge kept in the long-term memory is done by using reasoning skill test. It is assumed that if a student has a good reasoning skill, they would have a good concept mastery [13, 14]. The instrument is arranged in multiple choices with reasons. The student reasoning skill is measured covering the inductive and deductive reasoning with the aspects of causal, analysis, and proportional reasoning [15]. These reasoning aspects are chosen following the statement form Marzano stating that reasoning is thinking process which covers concept construction, principles construction, comprehension, problem solving, research, decision making and thinking process skill which are needed in learning plant physiology [16]. The categorization of students' reasoning skill is adapted from previous study [17] explained in the Table 3.

Table 3. Reasoning Skill Categorization

Score	Categorization
75 - 100	Excellent
61 - 74	Good
51 – 60	Fair
35 - 50	Less satisfactory
25 - 34	Very low

The instrument for reasoning skill developed in this study is also used to measure students' concept mastery based on the taxonomy of processing level developed by Marzano [11, 18]. The level of processing used to measure concept mastery are generalization, decision making, problem solving, and experimenting. The five processes developed in germane load instrument is in accordance with the demand of Indonesian qualification framework for undergraduate level in Biology subject, which are applying biological concept to contextual setting, solving problems, adapting to dynamic situations, formulating procedural solution for problems, and performing decision making based on data and information.

The data would then analyzed quantitatively on the components that lower cognitive load by conducting T-test on the average decrease of cognitive load between experimental and control classes, correlation test between the components of cognitive load on experimental and control classes and regression test between the component of cognitive load to obtain the information about which component influences students' reasoning skill. The statistical measurement is done with the aid of *Statistical Package for Sosial Science* (SPSS) *for Window* 20. The final step of data analysis is the triangulation analysis by interpreting the result qualitatively and quantitatively to ensure whether the data support or "against" one another [19].

4 Result and Discussion

4.1. Instrument to measure Information Analysis Skill

The validity of information analysis skill instrument (intrinsic load) using factor analysis with SPSS 20 for Window shows the score of 0,612 – 0,741. This score shows validity of the instrument only if the coefficient correlation is greater than α 0,05 (22) = 0,413. The result then shows that all items in the information analysis skill instrument has bigger coefficient than α 0,05, indicating that the instrument is valid. Furthermore, the reliability test using Cronbach's alfa statistical test shows the result as below:

Table 4. *Output* of reliability test on information analysis skill instrument

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.711	.700	8

Table 4 shows that the value of Cronbach alfa is 0.711. Following the credibility criteria [20], it can be concluded that the instrument has high reliability with the score of 0.60 – 0.79. Thus, it can be concluded that the instrument has significant reliability and validity and is appropriate to measure students' information analysis skill.

4.2. Instrument to measure mental effort in understanding learning material

Ensuring the validity and reliability of the instrument measuring mental effort needed in understanding learning material is needed to have a reliable and valid information about students' mental effort when learning with integrated learning approach. The result of validity test shows the score of 0.732 – 0.780. This score shows the high validity of the instrument only if the coefficient correlation is greater than α 0,05 (22) = 0,413. The result then shows that all items in the mental effort instrument has bigger coefficient than α 0,05, indicating that the instrument is valid indicating a high validity of the instrument. Furthermore, the reliability test using cronbach's alfa statistical test shows the result as below:

Table 5. *Output* of reliability test on mental effort instrument

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
.711	.700	8

Table 5 shows that the value of cronbach alfa is 0.765. Following the credibility criteria by Sujana (2002), it can be concluded that the instrument has high reliability with the score of 0.60 – 0.79. Thus, it can be concluded that the instrument has significant reliability and validity and is appropriate to measure students' mental effort.

4.3. Instrument to measure reasoning skill

The validity and reliability of reasoning skill instrument is measured using item analysis with product moment correlation technique conducted by Anatest program. The result of validity test shows the score of 0.72 while the reliability score is 0.84. This indicates that the instrument is valid and reliable to measure students' mental effort, thus the instrument is appropriate to be used in this study. In addition, the instrument is also tested by item difficulty test, which generated score between 0.00 – 0.83. The definition of difficulty percentage category is shown in table 6.

Table 6. Percentage of item difficulty on Mental effort instrument

Score	Pecentage	Category
0.00 – 0.30	24 %	Low
0.30 – 0.70	72%	Medium
0.70 – 1.00	8%	High

The result shows that 4% of the items in mental effort instrument are considered hard, 6% is medium, and 32% is easy.

The students' cognitive load in this study is analyzed based on their ability to analyze information for intrinsic load, mental effort in understanding learning material for extraneous load, and reasoning skill for germane load. Students' intrinsic load is considered as low when they obtain high score in information analysis. On the contrary, the extraneous load is considered low when they have low mental effort. Meanwhile, the germane load is considered low when students obtain high score in reasoning skill.

The result of statistical analysis on cognitive load in control and experimental classes shows that students in experimental class have lower cognitive load than students in the control class. The result is shown in Table 7.

Table 7. Cognitive load in Experimental and Control Class

Cognitive Load	Experimental Class	Control Class
Information analysis skill (intrinsic load)	3.2	2.5
Mental effort (extraneous load)	0.28	0.32
Reasoning skill (germane load)	68.2	59.4

The Table 7 shows that the experimental class attain higher scores in information analysis skill and reasoning skill, indicating that the student in experimental class have lower intrinsic and germane load compered to students in control class. Likewise, the extraneous load of the experimental class is lower meaning that students in experimental need less mental effort than students in the control class to understand the same learning material.

The low the cognitive loads are attributed to the nested typed integrated learning with Marzano instructional framework which not only emphasis on thinking process but also create supportive learning environment for students to be involved in learning process. This specific characteristic of the learning approach leads to the low students' cognitive loads when integrating plant structure and function. Furthermore, this study also combining the specific characteristics of the learning approach with a strategy that considering the natural design of students' cognitive structure that is the limitation of working memory and the system of long-term memory that store information as cognitive scheme [21, 22].

The development of strategy in nested typed integrated leaning with Marzano instructional framework follows the statement that a thinking skill program is an approach designed in a structured manner and identical with cognitive learning development [23]. The development of learning attitude and engagement would motivate students to be actively involved in learning process, thus, students would feel at ease in understanding learning material because the topic is meaningful for solving everyday problems. The students would understand that learning about plant structure is helpful to support them in learning plant function resulting in better learning attitude and greater interest. Furthermore, the utilization of prior knowledge has significant impact on lowering intrinsic processing for three reasons.

First, students are facilitated to organize information about plant structure which is relevant with the plant function, thus, students are challenged to relate their learning process with the knowledge they have previously learnt leading to the construction of cognitive schemes in students' long-term memory. Second, the process of constructing cognitive scheme by relating plant structure and function leads to integrated comprehension of the learning material as the students now understand that the knowledge about plant structure is important in learning about plant structure. Lastly, the learning process deliberately develops cognitive schemes because students are facilitated to relate the newly learned information with the knowledge stored as schemes in the long-term memory, leading to wider and deeper knowledge gained in understanding plant physiology topic [2]. For instance, after students relating plant structure and function, they are led to connect their knowledge with the influence of plant environment on plant adaptation. This process follows the notion that prior knowledge does not only influence the process of learning new concept but also influence students' perception and engagement in learning [24].

To further understand the relation between the three components of cognitive load, a correlational test is conducted which result is shown in Table 8.

Table 8. Correlation test of the component of cognitive load

No	Correlation	Correlation coefficient (r^2)		P value
		Experiment class	Control class	
1	*Intrinsic load* and *germane load*	0,899 r = 0,95	0,785 r = 0,89	p= 0,00*<0,01
2	*Extraneous load* and *germane load*	-0,684 r = 0,83	-0,825 r = 0,91	p= 0,00*<0,01
3	*Intrinsic load* and *extraneous load*	-0,837 r = 0,91	-0,689 r = 0,83	p= 0,00*<0,01

The result shows that the three components of cognitive load have significant correlations with value of p = 0.00*<0,01. The correlation of germane load in experiment class is greater influenced by intrinsic load (r^2 = -0.899) than by the extraneous load (r^2 = -0.684). Meanwhile in the control class, the germane load is greater influenced by extraneous load (r^2 = 0.825) than by intrinsic load (r^2 = 0.786). This positive correlation between intrinsic and germane load implies that information analysis skill is proportionally related with reasoning skill. On the contrary, the negative correlation between extraneous load and germane load indicates that the students' reasoning skill is inversely related to mental effort. Likewise, the negative correlation between intrinsic load and extraneous load shows that the lower student mental effort, the better their ability in analyzing information.

Furthermore, the determination coefficient (r) between intrinsic and germane load in experimental class is 0.95, while in control class in 0.89. This shows that 95% of students' reasoning skill in experimental class is influenced by information analysis skill, whereas in the control class, the influence is at 89%. Likewise, the determination coefficient between extraneous load and germane load in experimental class is 0.83 compared to 0.91 in control class. This indicates the mental effort is influence 83% of students reasoning skill in experimental class and 91% in control class due to the learning approach. Moreover, the determination between intrinsic and extraneous load in experimental class is 0.91 while in control class in 0.83. This means that 91% of students' information analysis skill in experiment class and 83% in the control class is influenced by students' mental effort emerged due to the learning approach. Thus, it can be concluded that intrinsic load and extraneous load effect the development of students' reasoning (germane load) because the cognitive capacity of students enabling them to invest their knowledge about relation between plant structure and function in their cognitive schemes. The students with low reasoning score have high mental effort as well as low information processing skill. On the contrary, students with high reasoning skill have low mental effort and high information analysis skill.

The intrinsic and extraneous load significantly influence germane load [5]. The regression equation between the three components of cognitive load in experimental class is $\hat{y} = 49.4 + 9.1\ x1 – 3.95\ x_2$, meanwhile in the control class is $\hat{y} = 60.4 + 11.3\ x_1 – 9.76\ x_2$. The regression equation in the experimental class shows that the comparison between information analysis skill (x_1) and mental effort (x_2) has greater comparison compared to the control class. Therefore, in the experimental class, the increasing complexity of learning material which influence mental effort and intrinsic processing in working memory has insignificant effect to germane load because students already have cognitive schemes which lower load in working memory while processing information. On the contrary in control class, the increasing complexity of learning material significantly influence mental effort due to the process of cognitive scheme construction which relies greatly on the lecturers' explanation rather than active involvement of students. This results in overcapacity in working memory in processing information due to the lack of synergy between working memory and long-term memory [25, 26]. The graph of regression equation of the experimental and the control classes are shown in Figure 1.

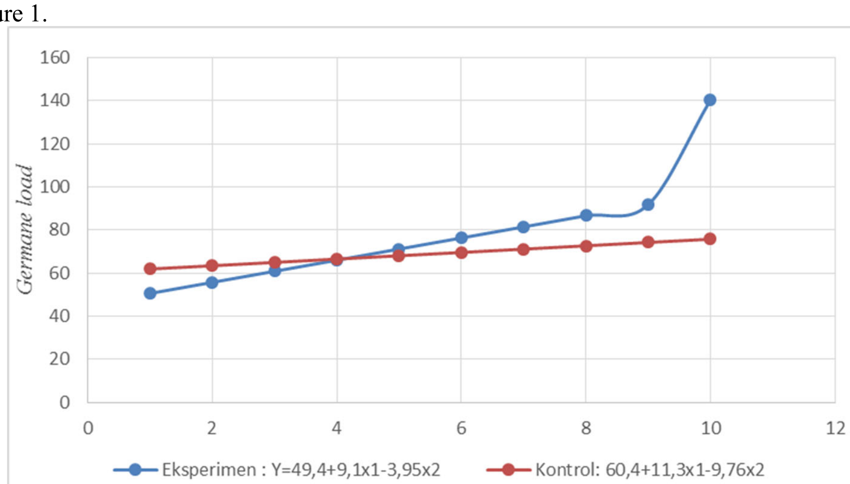

Figure 1. Regression graph of experimental and control classes

On the Figure 1, it can be seen that students reasoning skill is influenced by information analysis skill and mental effort. In regards to the data in table 2, the germane load in experimental class is influenced greater by intrinsic load (r = 0.95) than by extraneous load (r = 0.83), while in the germane load in control class is greater influenced by extraneous load (r=0.91) than by intrinsic load (0.89). This means that the decrease in germane load is better to be influenced by the decrease in intrinsic load than the decrease in extraneous load. This explains why the construction of students' cognitive schemes is better when being influenced by information analysis skill than mental effort. This finding is supported by regression test shown in Figure 1. The regression graph for the experiment class shows the existence of a significant increase in information analysis skill compared to that in the control class.

Moreover, in the experimental class, it is clearly observed that as students' information analysis skill develops, the students' reasoning skill is also increasing. However, it is not the case for the control class showing that the decrease in mental effort does not positively effect students' reasoning skill.

5 Conclusion

The This study of measurement of cognitive load components shows that the measurement of information analysis skill is sensitive to the method of lowering intrinsic processing (utilization of prior knowledge) and the attitude scale is sensitive to the method of lowering extraneous load (development of positive attitude and perception) which are reflected in the result of reasoning skill test. According to the data analysis, it is also discovered that the difference in the measurement of cognitive load has a significant correlation to one another. This finding is consistent with triarchic theory of the cognitive load wherein the different aspects of cognitive load should be treated with different method of measurement.

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