A Study of Cognitive Load for Enhancing Student’s Quantitative Literacy in Inquiry Lab Learning

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Abstract. Students often find it difficult to appreciate the relevance of the role of quantitative analysis and concept attainment in the science class. This study measured student cognitive load during the inquiry lab of the respiratory system to improve quantitative literacy. Participants in this study were 40 11th graders from senior high school in Indonesia. After students learned, their feelings about the degree of mental effort that it took to complete the learning tasks were measured by 28 self-report on a 4-point Likert scale. The Task Complexity Worksheet were used to assess processing quantitative information and paper based test were applied to assess participants’ concept achievements. The results showed that inquiry instructional induced a relatively low mental effort, high processing information and high concept achievements.

1. Introduction
In the 21st century mathematical ability is needed in various activities such as when working, studying, even while doing daily activities. Current demands lead to the ability to understand, to apply and integrate numerical matters and data analyses in everyday as a habit of mind called quantitative literacy. Quantitative literacy is the ability to understand, to read and to describe quantitative information in everyday life [1] and the comfort of a person in operating and or processing numerical data [2]. QL involves responding to quantitative information presented verbally, graphically, or symbolic form [3]. Some researcher claimed that quantitative literacy is the most important skill for individuals [4,5,6]. Even [7] confirmed that quantitative literacy is more important than even high-level mathematics courses. Mathematics is The basic knowledge for mastering quantitative, but it does not mean quantitative literacy is imposed into the mathematics curriculum only. Students need to learn quantitative literacy from various other subjects.

Unfortunately, the quantitative literacy of high school students, Biology students, Biology education students and biology teachers in Indonesia is relatively weak [8,9]. This weak quantitative literacy is due to the fact that teachers have not developed quantitative literacy consciously in biology learning. In order to develop quantitative literacy, students need to get interesting experience and clear experimental activities so that students can feel the benefits of literacy Quantitative in the real world [10]. Students also need to be directly involved in generating quantitative data that can be interpreted [8], get more opportunities to make decisions that involve information-gathering and assessment, quantitative analyses, and communications about quantitative topics [10]. The students need to participate actively in scientific processes through research to acquire necessary knowledge in various fields [11].

An individual who has strong quantitative literacy skills has more ability to think and solve quantitative problems from various authentic contexts and situations in everyday life. Thus quantitative literacy is a tool of thought. Students can practice to solve quantitative problems by doing research in inquiry activities. In Inquiry Learning approach students can integrate laboratory activities,
where there are initial activities before the learning is to identify the problem of investigation, determine the purpose of an investigation, conduct the investigation in accordance with the problems made and make a scientific question [12]. Inquiry studies have a positive impact on the students’ independent in formulating and conducting an inquiry, able to measure the skills of the science process, make formulas and hypotheses, identify variables, experiment, interpret data, observe, measure, ask questions, communicate. And concluded [13], training students to overcome challenges, solve problems, test hypotheses, explain phenomena, or answer questions that are a method of a scientist [14]. These data are then analyzed to find relationship among variables. In inquiry lab Teachers helping students’ difficulties, but the primary responsibility for designing an experiment, collecting data, analyzing and interpreting data, and communicating the results is borne by the students.

Applying certain learning strategies to develop the quantitative literacy is affected by students’ working memory. Working memory goes consciously and it is able to process information quickly with its limited capacity [15]. The capability to analyze information (information processing) constitutes the process of information to be processed in order to produce learning result patterns [16]. Each person has limited and distinctive capacity for receiving information. That limited capacity will make someone hold something heavy and burdensome when he has to receive a lot of information. Such a issue has been described in the Cognitive Load Theory (CLT). Cognitive load theory aims at predicting the learning result by considering the capability and limitation of human cognitive conception [17].

According to the cognitive load theory, there are three types of cognitive load namely intrinsic cognitive load, extraneous cognitive load, dan germane cognitive load. It depends on a number of elements and its interactivity. Extraneous or ineffective cognitive load is generated by an ineffective learning design. All the irrelevant information processing with the learning objective illustrates the extraneous cognitive load. The relation between two cognitive loads elaborated by [15]. If intrinsic cognitive load is low, the level of extraneous cognitive load became less important since the total of cognitive loads does not burden the working memory capacity. Germane cognitive load is generated while the students have some deep cognitive processing and used for construction and automation of schemes.

Inquiry lab learning can be applied to improve the students’ capabilities for quantitative literacy. However, it is necessary to consider whether the addition for quantitative literacy in this inquiry lab learning will bring about cognitive loads for the students or not. Therefore, there should be some study concerning the cognitive loads that the students have when they implement the inquiry lab learning in an effort to increase their quantitative literacy.

2. Method

This descriptive research aimed to identify the cognitive loads consisted of intrinsic cognitive load, extrinsic cognitive load and Germane cognitive load in the inquiry lab learning that develops the Senior High School (SMA) students’ quantitative literacy. The participants in this research were 40 senior high school students of Grade XI for Natural Science (IPA) in Bandung, Indonesia (at the age of 16-17 year). The participants were the students studying by using inquiry lab learning.

All the students attended two-week inquiry lab learning in group. The class began by watching video regarding free diving, then continuing by formulating the research questions in the experimental activity. The theme of first-week practical work was respiratory tidal volume in a human adult. Every group decided the research variables and experimental designs in order to answer their questions. The variable observed by the students had to be in the form of quantitative data. Subsequently, they made research in lab guided by the teacher. As a result of their activities, the resultant quantitative data were could be used to practice the students’ quantitative literacy. At the end of every learning, each student was given 8 questions functioned to guide them developing their quantitative literacy, namely: 1) How much the average of vital capacity and complementary air as well as the frequency does the insect breathe in the practical work? 2) How is the determined factors effects for the lung vital capacity? Add the supporting quantitative proof! 3) How is the determined factors effects for the lung supplementary air? Add the supporting quantitative proof. 4) Is there any
relation between the determined factors and the lung vital capacity volume? Explain! 5) Is there any relation between the determined factors and the lung supplementary air volume? Explain! 6) Are the determined factors the most influential ones? Compare with other groups results using other factors. 7) Based on the observation, what does it means with the change of water volume contained in the bottle? 8) Based on the obtained observation data, change the table data into the graphical form. On the second-week learning activity, the students were doing inquiry lab activities with the theme of insect respiratory frequency.

The data collecting of cognitive load component is implemented during and after every inquiry lab learning taking place. Intrinsic Cognitive Load (ICL) is assessed using Task Complexity Worksheet given in the form of worksheet contained 16 questions to measure the students’ capabilities of receiving and processing information during the learning process in the subject of respiratory system. The Subjective Rating Scale questionnaire is given every time the learning process to measure the mental efforts (ECL) completed during the learning process. There are 28 questions in the questionnaire sheet illustrating the compatibility between the learning strategy and the teaching material and also the students’ difficulties in processing information (ICL) at the week 1 and 32 questions for the week 2 using 4-point Likert scale. Germane Cognitive Load (GCL) is measured by 20 multiple choice concerning the respiratory concept and 10 essay regarding the quantitative literacy with indicator by [18]. A non-parametric correlation test (Kendall’s tau) taken to figure how strong the relation between each cognitive load component. Data of Germane Cognitive load collected after and before inquiry lab learning. Normalized test-gain (N-gain) of GCL calculate and categorize by Hake formula [19].

3. Result and Discussion

3.1 Intrinsic Cognitive Load dan Extrinsic Cognitive Load

Table 1 shows the ICL presented by mental effort score and the ECL presented by the students' processing information score in inquiry lab learning 1 and 2.

| Cognitive Load Component | Inquiry 1 | Sd   | Inquiry 2 | Sd   | Mean | Sd  |
|--------------------------|----------|------|-----------|------|------|-----|
| Processing Information   | 83,61    | 6,38 | 85,27     | 7,49 | 84,44| 5,63|
| (ICL)                    |          |      |           |      |      |     |
| Mental effort (ECL)      | 46,16    | 8,47 | 44,45     | 9,14 | 45,81| 8,19|

Based on Table 1, it is found out that the illustrated ICL by the capability to process information during the learning process fall into the high with the score of 83.61 (inquiry lab 1) and 85.27 (inquiry lab 2). This result presents the evidence that the inquiry lab is suitable for the quantitative information processing. ICL can be changed by natural change from what has been studied or by their own learning action [20]. It means that the changing that the students naturally have themselves will change the cognitive scheme in their memory. Therefore, the high capability to process information (ICL) is not enough to proof the low cognitive load that the students have, and it should be followed by the results of mental effort (ECL). If the students feel more difficult in or tired of the implemented learning process, it means Extraneous Cognitive Load will be higher. In this research, it is found out that the Mental Effort score (ECL) that the students have is low, and the students tend to be able already to cope with the experienced difficulties and able to accept the learning process by using inquiry lab (44.45). A good instructional design is learning design that provides tasks that can achieve sufficient and not excessive levels of ICL, can decrease ECL, and improve GCL [21].

In Table 1, the mental efforts (ECL) are not distinctive from inquiry lab 1 (44.16) to inquiry lab 2 (44.45). The considerable mean of the students’ mental efforts based on Table 1 is 44.80 (relatively low). This finding shows that the implemented inquiry lab does not burden the students’ working memory. The National Research Council has recommended the effort to improve the quantitative
literacy for biology curriculum through interdisciplinary approach including stressing for the use of mathematics and statistics [22]. In the learning attended by the students, they make their own data, then make calculation, representation, interpretation, and communicate the data in order to understand the respiratory concept [13].

The important finding from this research is that there are ICL data inversely proportional to the ECL. It means that, there is no cognitive load, the inquiry lab learning strategy helps the students in obtaining and processing information (teaching materials). The mean of students’ cognitive load shows that the students’ learning achievement and the processing information capability are higher than the mental efforts. Strategy of learning is effective when the extraneous cognitive load as low as possible during the learning process [15]. The students’ learning results are directly affected by the capabilities to receive and to process information, so that if the students have less burden in receiving and processing information, then they will tend to have less burden also in constructing the cognitive scheme. So, the good learning results from the students shows that they have less burden in learning the respiratory system using the inquiry lab learning strategy. However, the mental effort remains to have contribution to forming the cognitive scheme.

ECL that presented through the students’ mental efforts has a little more mean compared to the ICL that presented through processing information capability (Table 1). Good GCL is obtained as a result of the contribution of more capability to Receiving and Processing Information (RPI) by the students compared to the Mental Efforts (ECL) [23]. In this case, based on Table 1, the ICL score is higher than ECL so that it enables the students to produce the good Learning Results (GCL) for them too.

3.2 Germane Cognitive Load

Table 2 demonstrate the score of the Germane Cognitive Load component

| Component of GCL | Mean | Sd  | Normalized gain |
|------------------|------|-----|-----------------|
| Content          | 67   | 9,05| 0,62            |
| Quantitative literacy | 90   | 9,05| 0,55            |

In Table 2, there is content mastering score for respiratory system and the ability of quantitative literacy. The high germane cognitive load can be affected by ICL or ECL. Intrinsic cognitive load has direct effect to the GCL forming, whereas ECL does not directly affect to the GCL forming. Normalized gain content achievement score and quantitative literacy fall into the moderate score category [19] that shows that the students still have the difficulties in understanding the two aspects of GCL.

| No   | QL Indicator | %  |
|------|--------------|----|
| 1.   | Interpretation | 73 |
| 2.   | Calculation   | 74 |
| 3.   | Analysis      | 73 |
| 4.   | Representation| 89 |

Based on Table 3, it seems that from the measured four indicators during the inquiry lab learning, the students’ representation capabilities tend to be higher (89%) of the students answering right compared to the other three quantitative indicators that is interpretation, calculation and analysis. The students’ calculation capability score also has the adequate percentage value (74%). The calculation capability involved is the ability to perform average calculations. The students are capable of answering the calculation questions easier because this capability has already been taught since the elementary school. On the other hand, the indicator for the interpretation and analysis quantitative data has the lowest percentage compared to other two indicators (73%). The interpretation and analysis
capabilities is at the lowest in percentage where the students answering right though. In order to find out the cognitive loads that the students have, the measurement is not adequate just from the high or low score for every cognitive load components obtained by the students, it has to observe also the relation among the cognitive loads respectively [24].

Table 4. Normality test of ICL, ECL adn GCL

| Data   | N  | Mean | Sd  | Sig. value | Summary |
|--------|----|------|-----|------------|---------|
| ICL    | 43 | 84.44| 5.57| 0.513      | Normal  |
| ECL    | 43 | 44.80| 8.20| 0.876      | Normal  |
| GCL    | 43 | 74.65| 6.30| 0.110      | Normal  |

Table 5. The result of correlation test

| Variabel          | R   | sig. Value |
|-------------------|-----|------------|
| ECL terhadap ICL  | -0.097| 0.372>0.05 |
| ICL terhadap GCL  | 0.065 | 0.576>0.05 |
| ECL terhadap GCL  | -0.033| 0.772>0.05 |

Based on Table 5, it can be described that the correlation results from each components of students’ cognitive loads. The variable value for Mental Effort (ECL) to the capabilities in Receiving and Processing Information (ICL) is negative; not significant (r=-0.097). It means that there is not any contribution from the mental efforts to the capabilities to receive and to process information clearly, but capable of describing that the reducing of mental efforts can improve the capabilities to receive and to process information. The students still have cognitive loads during the learning process even it is a little. On the other hand, the correlation of information processing capability (ICL) to the Learning Result (GCL) is positive; not significant (r=0.0065). It means that the contribution (ICL) to the Learning Result (GCL) tends to be uncertain. Apart from it, the correlation of Mental Effort (GCL) shows negative value; not significant (r=-0.033). It can mean that the contribution for the reducing of mental effort to the learning result is uncertain, it is possible that the students still have cognitive loads even it is a little. Cognitive load theory is concerned with techniques for managing working memory load in order to facilitate the changes in long term memory associated with schema construction and automation [15]. The results of the study show that students do not yet have quantitative literacy as the ability stored in long-term memory. Based on the overall correlation results, that the relation among the components respectively can be confirmed uncertain, it is shown by the unavailability of significant result from the correlation test. The important finding from this research is that the inquiry learning can practice the students’ quantitative literacy shown by the students’ percentage which is relatively high in answering right the quantitative literacy test. In this case, the measurement resulting quantitative data constitutes the initial step in developing quantitative literacy [25].

4. Conclusion
Inquiry lab learning improved the quantitative information processing with relatively low mental efforts. In the applied inquiry lab, the determination of quantitative variables by the students, continued by making measurement and analysis for quantitative data succeed in training the students to develop their quantitative literacy capabilities especially representation. However, there are still cognitive loads found in developing it. Unfortunately, the limited research is carried out in two sessions. Quantitative literacy is habits of mind, it is need to continuous practice until it becomes a habit.

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