Analyzing the extraneous cognitive load of a 7th grader mathematics textbook

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Analyzing the extraneous cognitive load of a 7th grader mathematics textbook

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Abstract. Based on a Cognitive Load Theory, there might be an extraneous factor should be considered when a learning material is presented such as in a textbook. Commonly, high school mathematics textbook contains abstract symbols, text, and pictures which might hinder learning if the presentation causes extraneous cognitive load. Unfortunately, textbook writers do not always consider this factor. Therefore investigation on textbooks used by students is required. This study purposely chosed the Year 7 high school mathematics compulsory textbook in Indonesia because the authors have had experience teaching year 7. The Cognitive Load Theory was used to analyze potential extraneous cognitive load presented in six units of the book. These are the introduction, observing, questioning, elaborating, associating, and communicating sections. The analysis framework was developed into four aspects: the split-attention, the redundancy of information, the lack of signaling, the incoherence, and the typing mistake. The analysis shows that about 18.43% of material presented in the textbook cause split-attention, 3.69% cause redundant information, 18,43% lack of signaling, and 3.69% is incoherence, and 11.6% is typing mistake. This finding reveals that the textbook contained some extraneous cognitive loads which may cause students' difficulty to understand the content. Accordingly, the book might require some revisions in order to support learning processes.

1. Introduction

Textbook is the most learning resource used. Even with the development of technology in this digitalization era, textbook is still used as the most dominant source of learning [1]. This statement is confirmed by the Trends International Mathematics and Science Study (TIMSS) survey results in 2011 [2] that teachers use textbooks more often as a primary in Mathematics learning than other learning resources (75% in grade 4 and 77% in grade 8). In Indonesia, 93% of schools use textbooks as learning and teaching resources [3]. Textbooks are used by teachers as a fundamental reference in learning and also for planning the lesson [4]. While students, as learner subjects, use textbooks as a source of learning, both on the command from their teacher and their own will [5].

According to International Association for the Evaluation of Educational Achievement, textbook is potentially implemented curriculum, they studied textbooks used in many countries to understand opportunity-to-learn that provided by the education system in the world [6]. The importance of textbook

also can be seen by the existence of the amount of research about mathematics textbook. There was a study that investigated its potency in constructing deep mathematic knowledge [7]. Moreover, a study conducted an investigation toward opportunity-to-learn context based tasks provided by mathematics textbook [8]. There was research that reviewed the language used in mathematics textbook [9]. Research about the way of the textbook used regarding in the instruction [10], or about the use of textbook by mathematics teacher both within and outside the classroom [11], and also how to analyse or review mathematics textbooks [12].

Textbook is seen as the most efficient resource to enhance students learning in low-income countries with large class sizes that usually have many unqualified teachers [13]. In such situations, a well-designed textbook and in sufficient quantity of use is the most effective way to support successful learning. Since the enactment of Curriculum 2013 (known as C-13), The Indonesian Ministry of Education and Culture published textbook to improve the efficiency and effectiveness of learning in Indonesia [14]. Each student has that printed textbook. C-13 is an applied curriculum in Indonesia education system which is the development of the previous curriculum with a rationale to face the current development challenges and to preliminaries, the competencies needed in the future. Mathematics textbooks published by The Ministry is the most resource used by students compared to three other mathematics textbooks sold on the market published by private publisher [15]. There have been several studies on this piblished textbook. Among of the research was focus in terms of writing [16], the problems from the cognitive aspect [17], the suitability of the presented material with the Bell's criteria [18], the conformity of the questions with the Program for International Student Assessment (PISA) framework [19], appropriateness of the textbook with the content, process and assessment standards listed in the C-13 document [15]. However, studies on that textbook have not considered about mathematics material presentation in terms of cognitive aspects. It is agreed that the representation in the textbook has a strong influent to the student conception [20]. In addition, as expressed by cognitive psychology view, learning involves schema construction process. Schema is memory structure that enables the learner to treat multiple elements of information as though they are a single element classified according to the way in which it will be used [21]. While learning, new information is processed in working memory forming schema, which is stored in long-term memory. One important factor that can affect this process is the way of material presented on the learning resource. Thus, the presentation in the textbook should be a focus of evaluation [22].

Cognitive Load Theory (CLT) provides a framework for analyzing instructional design with respect to suitability in supporting learning processes [23, 24]. CLT is a learning and instructional theory that describes the implications of instructional design from human cognitive architecture that the limits of working memory capacity must be considered in the learning procedure [25, 26]. According to the human cognitive architecture, working memory organizes information during learning by connecting with those from long-term memory [27]. Learning should result in an organized schema stored in long-term memory [28]. Based on CLT, the limitation of the working memory capacity and its effectiveness is determined by the complexity of essential material (intrinsic cognitive load), the way of material presentation (extraneous cognitive load) and the cognitive used in schema construction (germane cognitive load) [26, 29, 30]. The cognitive capacity of the working memory is easily overload [31]. If the demand for working memory resources caused by intrinsic cognitive load and extraneous cognitive load exceeds the working memory capacity then the learner may not be able to engage in essential processing for schema construction [26]. Therefore learning process becomes less optimal because it takes a longer time and greater effort [31]. As a result, the expected learning objectives may not be achieved.

For supporting mathematics learning process, it is necessary to analyze the design of learning that refers to CLT [32], especially on some materials that have complex and difficult characteristics or that are new for students [26]. Textbook analysis in this study focused on the way of mathematics material presentation based on extraneous cognitive load (ECL). Although the textbook analyzed in this study only used in Indonesia, the results of this study can provide a framework for analyzing textbooks in accordance

with ECL on a wider scale. Moreover, this study gives insight for mathematics educators and mathematics textbooks author about the material presented in such a way that can optimize learning process.

2. Method

2.1. The Mathematics Textbook

Mathematics textbook of C-13 published by The Ministry was chosen to be analyzed in this study. This textbook was selected because it is widely used for supporting the achievement of the mathematics competencies expected in the C-13. Therefore, this textbook had a strong influence in supporting the schema construction during student learning process. The Ministry provides the textbooks for all education level, starting from elementary to high school students. This study purposely chose the book for Year 7 because the authors have had experience teaching year 7 and the authors probably will use it. Additionally, this textbook has not been analyzed based on ECL before. Moreover, due to the limitations of the study, it was focused on the last edition book of the first semester because this textbook has been revised many times more than the other mathematics textbook published by The Ministry.

Based on preliminary observations, this textbook was first published in 2013, then revised in 2014, 2016 and 2017. In the last print, this textbook is 25 x 17.5 cm2 which contain 338 pages. It consists of 4 chapters: numbers, sets, algebraic form, equality and inequalities of one linear variable. Each chapter contains a sub-chapter that explains more specific mathematics topic. For instance, chapter 2 (the set topic) consists of 3 sub-chapters, i.e. the set concept, the set properties, and the set operations. According to the researcher's observations, the textbook has a consistent presentation style. Each chapter consists of keywords, expected competencies list, learning experiences list, a concept map, narrative mathematician, student tasks (including the explanation, worked example and exercise), project assignments, summaries and competency tests. The main mathematics material in the textbook is included in the student tasks. The structure of the main student task presentation follows scientific learning approach steps, namely introduction, *Ayo Kita Amati* (observing), *Ayo Kita Menanya* (questioning), *Ayo Kita Menggali Informasi* (elaborating), *Ayo Kita Menalar* (associating), and *Ayo Kita Berbagi* (communicating).

Table 1. The analysis framework for textbook analysis.

Cause of ECL	Descriptor
The split-attention	a. Contain images, graphics, or textual information that should be processed simultaneously but serve separately. b. Contain material that should be processed simultaneously but separated by page.
The redundancy of information	Contain the same information that is presented in multiple forms or it is unnecessarily elaborated.
The lack of signaling	a. Contain the narration that lack of signaling (i.e. bold, italic, underline, color, heading, numbering etc.), but actually its part is important information. b. Contain the material that lack of guidance to the activity that must be student do. c. Contain the material that lacks clues about new mathematics term for the student.
The incoherence	a. Contain adding images or words that only for interest but do not need directly for the learning b. Contain lengthy text information c. Contain the material that is presented in obscure language.
The typing mistake	Contain typing mistake that may affect students' understanding of the information.

2.2. Textbook Analysis Procedure

To analyze the textbook, six units of analysis were determined, i.e. introduction, observing, questioning, elaborating, associating, and communicating. These were selected based on the structure of the textbook.

For the purpose of the analysis, it was assumed that the book is studied independently by students, in their own study pace, regardless the fact that the book is often used in the classroom for mathematics instruction. An analysis framework (see Table 1) drawn based on literature about presented material that causing ECL [26, 30, 31, 33-35].

2.3. Coding Procedure

The presentation of material in a textbook was coded using an analytical framework that has been described in table 1. Prior to use, its authenticity was proved through content validity. Besides the authors, there were independent external coders who analyse the textbook to investigate the inter-coder agreement. They were mathematics teacher that has more than 10 years of experience in teaching and have understood the ECL. The coding process was as follow: (1) Read thoroughly each unit of analysis then put code when ECL appears; and (2) Created a matrix to display all finding. Then, the researcher: (2) Counted frequency of occurrence of each ECL; (3) Summarized; and (4) reported.

3. Result

The finding showed that the textbook contains 18.43% split-attention, 18.43% lack of signaling, 11.06% typing mistake, 3.69% redundancy of information and 3.69% incoherence. In total, there were 40.55% of overall the textbook contains ECL. This percentage was not derived from adding up the percentage of each ECL indicator contained in the book, but from summing up any information that contains the ECL, since one information may contain more than one ECL aspect. For example, worked example demonstrated in Figure 3 is lack of signaling and also contain typing mistake, so this worked example is calculated to contain one ECL. Overall, the finding from the analysis is summarized in Table 2.

Table 2. The result of analysis.

Unit of Analysis	N	Cause of ECL									
		The Split-Attention		The Redundancy of Information		Lack of Signaling		The Incoherence		The Typing Mistake	
		N	%	N	%	N	%	N	%	N	%
Introduction	5	0	0.00	0	0.00	1	20.00	2	40.00	0	0.00
Observing	59	12	20.34	3	5.08	9	15.25	2	3.39	4	6.78
Questioning	18	0	0.00	0	0.00	3	16.67	0	0.00	0	0.00
Elaborating	35	13	37.14	0	0.00	13	37.14	0	0.00	14	40.00
Associating	82	15	18.29	5	6.10	14	17.07	4	4.88	6	7.32
Communicating	18	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Total	217	40	18.43	8	3.69	40	18.43	8	3.69	24	11.06

An example of material presented in the textbook that includes a requirement to split-attention are shown in Figure 1. It is the worked example that provides a guide to the learner in presenting a Venn diagram. This kind of information was first introduced in the textbook so that students do not have sufficient prior knowledge about it. As seen in Figure 1, information in the form of words (on page 126) is separated from the diagram (on page 127), but the two neither source of information makes sense without the other. The diagram provides no given information and the word information is unintelligible without the diagram. To understand this worked example, learners will have to locate the given information on the diagram. It might be expected that the cognitive resources will need to be devoted to splitting attention between the disparate sources of information and mentally integrating them [35].

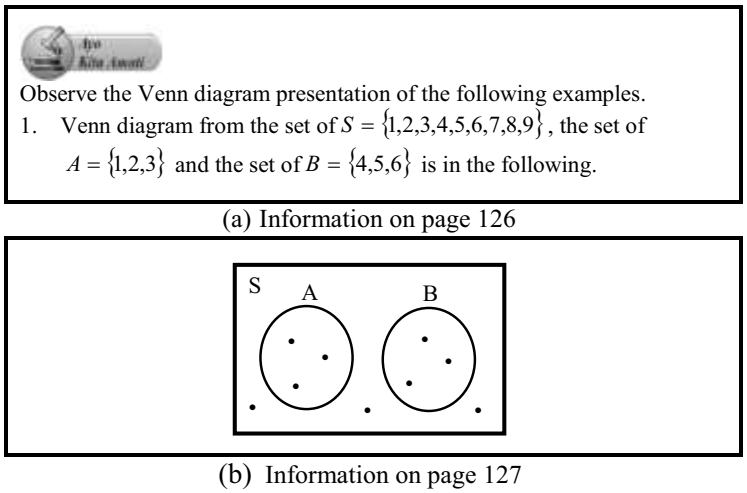

Figure 1. A worked example with split-attention (Original language is *Bahasa Indonesia*, p.126-127).

Figure 2 demonstrates an example of worked example that lack of signaling. This information aims to provide an example in solving the problem in the set topic. These steps of completing involve the knowledge to solve linear equations of one variable, whereas the material has not been studied by seventh-grade students and it will be studied only after the material of the set and algebraic form. Therefore, in studying this worked example students should look for clues on explanation at each step of the solution. In addition, Figure 2 also provides an example of worked example that contains a typing mistake. In the third step, it should be $35 = 22 + 15 - x + 3$ but in the textbook it is written as $35 = 22 + 15 + x + 3$. It seems likely that this mistake is not intended since there is no instruction about learning from the presented errors. Indubitable, this kind of error will have a negative impact on the students learning process.

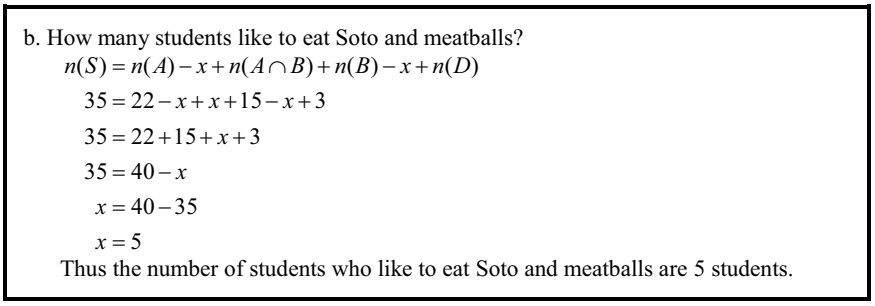

Figure 2. A worked example that lack of signaling and contain a typing mistake (Original language is *Bahasa Indonesia*, p.152).

Figure 3 is an example of the material presented that contains redundancy of information. In the Pascal triangle has been given its descriptions, but in the next section, the textbook provides the explanations in the form of textual in same meaning. In this case, the image of Pascal triangle is self-contained (i.e., can be understood on its own). It does not need both text and pictures as information sources because the image provides all the information required for understanding the number of subsets. This additional source of information in the textual might occupies working memory capacity for processing information that less likely lead to better comprehension. This redundant information is not necessary.

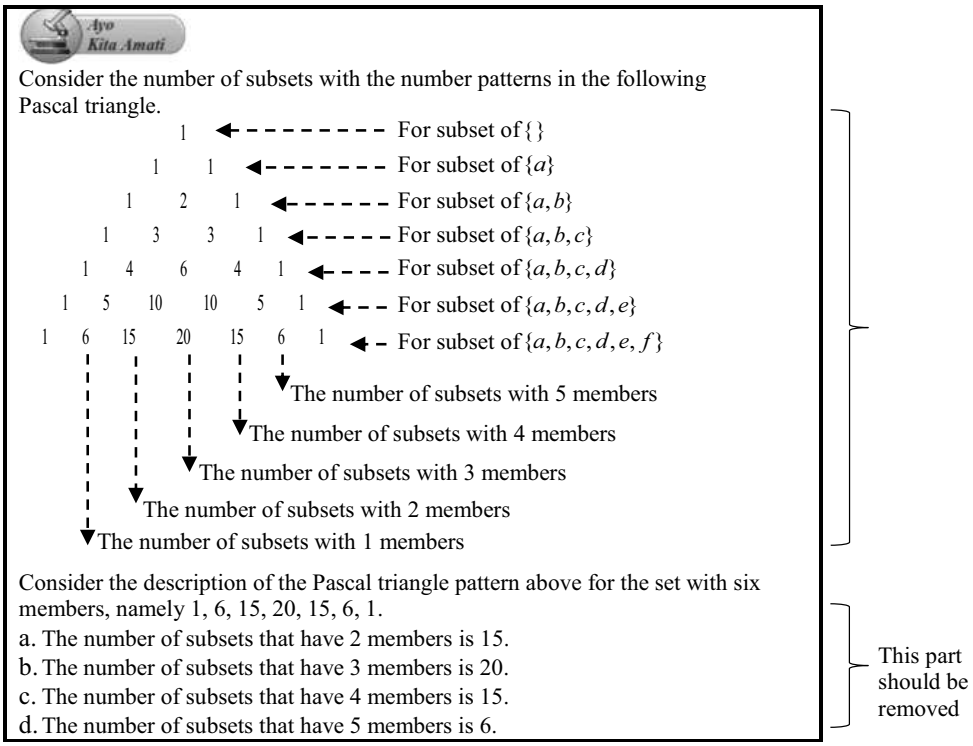

Figure 3. An explanation that contains redundant of information (Original language is *Bahasa Indonesia*, p.142-143).

Problem 2.4 cited in figure 4 is affixed with the picture of the students of class VII A (Captioned in Figure 2.3). In fact, the picture is not relevant to the instructional goal. It seems to be used for making up the textbook appearance. This could distract the students, especially students with low prior knowledge who might think this kind of figure is relevant to the learning material. This picture is an example of the incoherence material that should be eliminated.

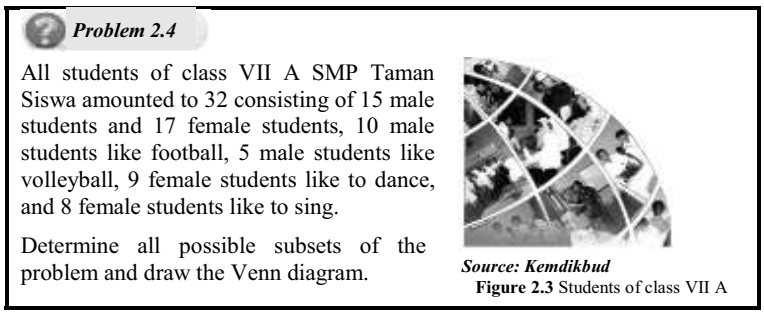

Figure 4. A worked example that incoherence (Original language is *Bahasa Indonesia*, p.153).

4. Discussion

According to the CLT, much of the cognitive processing which occurs in working memory required for constructing a meaningful learning. Three important feature of working memory are (a) dual channel, that is separate channels for pictorial and verbal processing; (b) limited capacity, that is severe limits on the amount of processing that can occur in each channel at any one time; and (c) active processing, that is meaningful learning requires engaging in cognitive processing such as selecting, organizing, and

integrating [35]. This capacity is affected by ICL and ECL. When ICL (that is required to understand the essential material in a material presentation) and ECL (that required to process extraneous material or to overcome confusing layout in a material presentation) exceeds the cognitive capacity, fully understanding may not attain [31]. Consequently, the ECL must be excluded from the learning resources.

In light of this, an analysis of the mathematics textbook from ECL view is a fruitful means for raising the question about textbooks for promoting schema construction. Referring to the literature, this study identifies inappropriate presentation that may lead to ECL. The framework of analysis is summarized into 5 aspects of ECL and each aspect is defined to one or more descriptor that served to give depth and detail. It was applied to analyze a textbook that is commonly used in the seventh grader published by Indonesian Ministry of Education and Culture.

According to the analysis, almost half of material presented in the textbook contains ECL, particularly ECL caused by the split-attention and the lack of signaling. The split-attention occurs when attention must be separated from multiple sources of visual information that are all essential for understanding [21]. For example, a geometric diagram and its associated statements. The two sources intentionally cause the learner to split their attention while they must be mentally integrated to be understood. This process might increase extraneous cognitive load [21, 35].

There were also many material presentations that lack of signals on the book. Whereas, the signaling principle indicated that learning may be improved if the learner's attention is focused on the critical aspects of the learning task or the presented information. It reduces the need for visual search and frees up cognitive resources that may be devoted to schema construction and automation, with the positive effect on test performance [36]. In addition, people learn more deeply when guidance is provided for directing the learner's attention to the essential material [31, 37].

Moreover, the textbook also contains some redundancies of information that typically has a negative impact on learning. Most people think that the presentation of the same information in a different way will make understanding is easily obtained. However, learners have to process all redundant information repeatedly, which is a cognitively demanding process that hinders learning [36]. For example, the textbook provides both textual and pictures information that have the same meaning. In this case, adding a picture to a written text or adding a written text to a picture means adding unneeded information. If the learners have the high prior knowledge, they frequently do not need both information as sources, because one source provides all required information to be understood. As a result, although one of the two information sources is not needed, the eye wanders between the two sources. Thus, the learner loses time and mental effort with the search for redundant information [38].

The textbook also contains the material that is incoherence. Actually based on empirical research, adding extraneous information in the form of seductive graphics and stories, or lengthy text can depress learning [39]. Based on the theoretical rationale for coherence, weeding out the irrelevant material enabling the learner to use all available cognitive capacity for learning [31]. In addition, the analysis found that the textbook also makes some unintended typing mistake. This mistake should not be made because it can lead to misunderstanding and confusion for the students.

As described before, this study involved six units of analysis: introduction, observing, questioning, elaborating, associating, and communicating. The provided introduction is meant to give overview of the material to be discussed in the following sections. This introduction section is only a few in the textbook, which is on some sub-topic only. But it contains some lack of signaling and incoherence. In the next unit, the observing section is intended to provide a learning experience by observing mathematical objects with regard to the topic that will be studied. However, the analysis showed that some ECL exists in this part, especially the split-attention. It will be effected to the further task since this section is a stepping stone to the next section.

In the questioning section, the textbook provides sample questions to direct the students to ask self-question about the things that they have been observed. In this part, there are only a few inappropriate

presentations that cause the ECL. It may not have much effect on the student's learning process. The next section is elaborating. It can be regarded as the most important part of the presented material in the textbook. Based on the direction of the teacher's book, this section presents the main information that serves directly and indirectly. Direct information is intended to give information that can immediately understand. Whereas indirect information is presented by inviting students to perform a task that leads to achieve the information. Hence, this part should be presented in a good way, yet the analysis showed that it contains the most cause of ECL compare to the other units, especially for the split-attention, lack of signaling, and typing mistake. Thus, it may attack the student to get full understanding and govern the student's performance in associating task which presented in the next section.

In the associating section, the textbook presents some problems that are intended to be answered by students after they do the observing to elaborating task. Through the problems, the students are expected to get answers, statements, or conclusions. Unfortunately, all the five aspects of ECL is founded in this section. Almost the same as the other units, the most type of ECL in this section is the split-attention and lack of signaling. This poor presentation may cause students difficulties in getting the answer and conclusion. Thus, the learning process becomes inefficient. In the last unit, communicating section gives the command to students for conveying the results of the tasks or conclusions in the classroom. Based on the analysis, only this section is free from the ECL. However, this part does not play an important role in individual student learning.

In sum, the analyzed textbook would appear to be limited to promote meaningful learning. Then the textbook needs to be improved. Accordingly, there is a major challenge for the instructional designer to compose instructional messages that are sensitive to the characteristics of the human information-processing system in which the amount of required processing in each channel of working memory does not exceed the learner's cognitive capacity [31]. Fortunately, in this case the CLT provides guidance to design instructional resource which is compatible for the student based on empirical research.

The split-attention can be avoided by creating an integrated presentation format in which the picture and textual information are physically integrated obviating the need to search for relations between them [40]. It has proven that this technique has a positive effect on the learning [36]. If a picture and a textual information cannot be presented simultaneously, present it in close spatial proximity to the pictures [31, 38]. For example, the diagram and the textual information in Figure 1 should be presented on one page. The instructional designer also can make each textual information in the same color as the corresponding part of the picture [41]. These techniques provide cues that direct the learner's attention such that it will reduce the effort that must be involved in visually scanning the page [31].

The designer should avoid presenting the same information in a different way. For example, in figure 3, the textual information what is meant to give explanation can be eliminated because the picture is self-explain. Moreover, sometimes a learning resource contains words and/or pictures that are irrelevant to the instructional goal. A straightforward solution to this ECL is to exclude the words and/or pictures that are interesting but irrelevant from the textbook [31]. This technique will reduce processing of extraneous material [31, 38]. For example, the figure students of class VII A in the worked example in figure 4 should be eliminated, because it is not required directly in understanding the problem.

Another solution to the problem of having too much ECL in a learning resource is to insert cues that direct the learner's attention toward the essential material. Also, provide cues that show the learner what to attend to and how to organize it [31]. The signals or explanation do not add any new information but rather highlight the essential material in the lesson to direct the learner's attention, thus eliminating the need for processing extraneous material [31]. The instructional designer can add an outlining sentence that lists the main steps, headings, numbering and the other signals. For example, in the worked example in figure 2, the designer should add explanation how to solve the equation in each step. Such explanations will guide students to understand the problem and how it is solved by following the step-by-step the solution [41]. Thus, the instructional designer should note that students who learn the worked example

may have lack of prior knowledge relevant to the to-be-learned problem-solving [41]. According to the empirical research, these techniques reduce visual search and have a positive effect on learning outcome [36].

5. Conclusion

In sum, the findings showed that the most appeared ECL in the analyzed textbook are the split-attention (18.43%) and lack of signaling (18.43%). Then, the typing mistake (11.06%), redundant information (3.69%) and incoherence (3.69%). According to the CLT, these might hinder understanding. This suggests that the textbook should be revised by considering the cognitive load may be imposed when students learn it [42]. Furthermore, the analysis found that the elaborating section contains the most ECL, then followed by associating and observing section. While the other three sections are less. This indicates that composing mathematics textbooks, especially in the main section is not easy. The writer should pay more attention on this section. Moreover, this study also provides teachers with insights into the strengths and weakness of the textbooks, and suggest enable them to make effective decisions about the selection of textbooks. Although the analyzed textbook is only one and used in Indonesia, the analysis framework can be applied to mathematics textbooks in most locations. However, this study took the content level only without determination of the actual use of this textbook in the mathematics classroom. In fact, teachers and the environment may have an influence on the use of textbooks [1]. This became a limitation in this study. Besides, this study does not consider how the factual effect of the textbook presentation for students. Accordingly, for earning a more convincing result, further analysis that investigates the relationship of the textbook presentation in ECL view to students learning process and their achievement need to be carried out.

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