Developing Geometry Instruction Based on A Worked Example Approach

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Abstract

A set of worksheet of solid geometry for eight graders was developed based on a worked example approach to facilitate the acquisition of problem solving ability. This mixed method research using an embedded design was aimed to describe how to apply the principle of the worked example approach on developing worksheet and to describe its quality based on the validity of the content, the practicality of uses and the effectiveness of the impact. The development of the worksheet followed the ADDIE steps. The worksheet was consulted to worked example experts and revised several times before it was implemented in the trial classroom. A number of 31 eight graders from a junior high school in Tempel, Yogyakarta participated in the implementation of the worksheet. Quality on the implementation of the worked example approach into the instruction was developed further by revising and refining after trying-out. The result showed that the principle of the worked example approach can be applied in the worksheet that is by managing intrinsic cognitive load in accord with student's level of prior knowledge and complexity of the material, reducing extraneous cognitive load and maximizing germane cognitive load by presenting worked examples and isomorphic problem solving in a schematic manner. Based on supporting quantitative data, it was found that the validity (correctness of the content) was averaged 4.47 (content is very good) by the instructional experts and 4.31 (content is very good) by the media experts. The practicality was averaged 3.78 (very easy to follow) by the teacher and 3.14 (easy to follow) by the students. In the problem solving ability test, about 68% students in the trial class scored more than the minimum passing grade that was 70. This means the worksheet was effective to facilitate the problem solving ability.

Keywords: *worksheet, worked example, problem solving, mathematics, cognitive load theory.*

Introduction

Innovative efforts to improve problem-solving abilities should always be made. According Retnowati (2016), resolving problems effectively and efficiently requires conceptual / factual / declarative knowledge and procedural knowledge. Students who do not have sufficient prior knowledge to solve the problem will experience obstacles or difficulties for advancing their mathematical thinking such as to determe the solution of a given mathematics problem.

Sweller (1994) explained that students who do have limited prior knowledge will tend to use heuristic strategies (e.g., trial and error) that are considered facilitating students to learn problem-solving inefficiently. This might be caused that students just focus more on the final answer without necessarily understand the underlying mathematical knowledge solution of the problem. Thus, Sweller stated that heuristic strategies cause burden on cognitive process for students and could not lead students to form new knowledge. Sweller named the theory of instructional design that minimizes the load of thinking as Cognitive Load Theory (see Sweller, Ayres and Kalyuga, 2011). This theory has derived the principles of learning focusing on the acquisition of problem solving through various experiments in mathematics and the others. This theory explains that the effectiveness of learning might be determined by two aspects, intrinsic cognitive load (due to the natural complexity of the material) and extraneous cognitive load (which deals with the presentation of the learning material) (Sweller, et. Al., 2011; Retnowati, Ayres and Sweller, 2010). Instructional design should be presented to students with manageable intrinsic and extraneous cognitive load. According to this theory, if these cognitive load sources can be managed, students can optimize their cognitive ability to construct new knowledge.

Cognitive Load Theory suggests when students do not have sufficient prior knowledge to solve problems and learn the underlying knowledge, then students should be given an explicit instruction (Sweller, 1994). An example of explicit instruction is the worked example approach (Kirschner, Sweller & Clark, 2006). Atkinson (2000) summaries that a worked example consists of steps to solve the problem like the steps used by experts that are easy to follow and learn. As described by Hillen (2012: 90) that by studying worked examples, students can acquire problem-solving strategies. The worked example provides guidance that assist students to understand the problem and how the solution is represented. This approach is particularly effective for novice learners. The worked example provides novices knowledge base to understand what and how to do it. This knowledge is useful for enhancing their learning and problem solving (van Gog and Kester, 2012).

The effectiveness of worked examples in geometry learning has been shown by Retnowati, Ayres and Sweller (2010). The study compared the worked example and the problem solving approach when individual or group work settings are occupied. The worked example was composed by pairs of a worked example and similar problems. Students were asked to study the example and then complete the similar problem without seeing the example. In the problem solving approach, students were asked to learn the geometry by solving the given problems. Students in the Retnowati, et al.'s experiment were categorised as novices. The results showed that students in the worked example approach learned problem solving better than those in the problem solving approach. The author found that worked examples might reduce extraneous cognitive load and hence assist students to learn while doing problem solving. On the other hand, students in the problem solving approach failed to learn as much as their counterpart because they have limited capacity to understand the underlying concept and procedure while solving problems. Research indicated the effectiveness of worked example approach for facilitating novice learners to study compared to the problem solving approach in many domains (for more review, Atkinson, et al., 2000).

Worked example should be designed in accord with the principles of cognitive load theory, that it should present a low extraneous cognitive load (Sweller, et al., 2011). Based on the review of Retnowati (2012, 2016), it can be summarized that in order to create an effective worked example, at least these five principles should be followed: 1) creating pairs of similar worked example and problem solving, 2) using variation of problem contexts, 3) arranging level of complexity in order, 4) avoiding split attention effect and 5) avoiding redundancy effect. These five principles are proposed to minimize extraneous cognitive load. Nevertheless, instructional designers may improve the effectiveness of the worked example by managing intrinsic cognitive load and creating medium to stimulate germane cognitive load (Retnowati, 2012, 2016).

As discussed above, worked examples have been shown to be useful to present learning material to novice students. However, this approach is rarely found to be implemented at schools or trainings. Indeed, such efforts are needed to mediate research into practice. Therefore, it is necessary to develop a learning material based on the worked example approach. Furthermore, a learning material that is often required at mathematics classroom is namely a worksheet. A worksheet guides students to study a particular topic or to acquire a specific competency. A worksheet that is developed based on the worked example approach should have worked example instruction as the main activity to be followed by students. According to Suyitno (1997: 40), worksheet can help students to understand concepts and procedures if it can facilitate systematic learning activities.

Turning to the topic of geometry, according Safrina, Ikhsan and Ahmad (2014: 11) geometry is often difficult to learn. Geometry contains both abstract and concrete aspects. Similarly, Kariadinata (2010) argued that the geometry is difficult to learn because it requires students to understand abstract concepts through visualizations. Such manipulations or pictures might assist students to understand this, however, when the focus is problem solving ability, then more creative geometry problems that are suitable for the cognitive level of the students might be desired. This research is proposed to develop worksheet based on the worked example approach for facilitating problem solving ability and to improve the quality by validation, implementation and evaluation.

Method

This research may be categorised as a research and development activity where the developed product is student worksheet of geometry. The paradigm of this research is mixed method with embedded design (Creswell and Clark, 2010) where this research is largely a qualitative research while quantitative data used as supporting data of research results. The product was developed by following ADDIE procedure consisting of analysis, design, development, implementation and evaluation (Sugiyono, 2015: 39). A number of 31 students in a Junior High School in Tempel district participated in this research, during the implementation of the worksheet in May 2016.

The data are qualitative and quantitative data. The qualitative data obtained from each step of designing the worksheet by taking field-note to record all aspects of constructing the worksheet, including when discussing the design with the experts or teachers until it was decided that the principles of worked example designing have been implemented. For the analysis of qualitative data, data was acquired continuously, especially during development and learning by worksheet. Qualitative data analysis was used to describe how the development was done from the first step that was the analysis curriculum and students, then the designing and development, the implementation at school and eventually the evaluation of the product. Meanwhile, the quantitative data used to support the qualitative data was obtained from assessment forms that were prepared for looking at the validity of the content of the worksheet, and also the practical aspect of using the worksheet. These used five Likert's scale. A problem solving test (essay) was also used after the try-out (implementation in the classroom) to see the effectiveness of the worksheet. The final product was revised based on all suggestions of the qualitative and quantitative data. Some classifications (Widoyoko, 2009) were determined by the authors to decide the validity, practicality and effectiveness level, as can be seen in the Table 1 below.

Table 1. Qualification of Validity

Average Score	Classification
$\bar{X} > \bar{X}_i + 0,6 \times \text{sb}_i$	Valid
$\bar{X} \leq \bar{X}_i + 0,6 \times \text{sb}_i$	Invalid

Table 2. Qualification of Practicality

Average Score	Classification
$\bar{X} > \bar{X}_i + 0,5 \times \text{sb}_i$	Practical
$\bar{X} \leq \bar{X}_i + 0,5 \times \text{sb}_i$	Impractical

Table 3. Qualification of Efectiveness

Average Score	Classification
$\bar{X} \geq 51\%$	Effective
$\bar{X} < 51\%$	Ineffective

Note:

$\bar{X}$ = Average score

$\bar{X}_i$ = Ideal (theoretic) average score

$= \frac{1}{2}(\text{ideal max score- ideal min score})$

sb_i $= \frac{1}{6}(\text{ideal max score - ideal min score})$

Result and Discussion

The current research has developed a qualified set of worksheets for learning year eight geometry topics based on the worked example approach. The quality of the product was maintained during the development by applying the ADDIE procedures, as well as collecting the data of the validity, practicality and effectiveness both concurrently in qualitative and quantitative approach as described in the method section above. The main learning topic is three-dimensional figure, specifically cube, prisms and pyramid; which includes nets, surface area and volume.

The overall procedure of developing the worksheet based on the worked example approach followed the ADDIE that can be described below. In the first step, analyze, the reserchers collected detailed information on the proposed subject (Year 8 students) who would utilize the worksheet. Since the subject uses a national curriculum, it may be assumed some prior knowledge they have possessed. For the proposed users of the worksheet, they should have learned about three dimensional figures in primary school. Detail information of how much they have learned was explored through the curriculum and also by asking relevant teachers and students. It was concluded that at year eight, students should be able to focus their learning of three dimensional figures on more challenging problem solving. Therefore, the worksheet contains higher level of problem solving about nets, surface area and volume of cube, rectangular prism and pyramid.

In the design step, researchers applied the principles of worked examples as discussed above. It was designed that in every topic, learning was facilitated from less to more complex. These learning phases are named the *introduction phase*, *understanding phase* and *enrichment phase*. In the introductory phase, students can activate their prior knowledge and have induction for the new problem solving. In the following phase, students learn new (novice) problem solving by worked example approach. In the last phase, students enhance their learning by more challenging problem solving. Key answers are provided in the worksheet but students are instructed to clarify their results after making some attempts during learning. Figure 1 below shows a page in the worksheet describing the three phases.

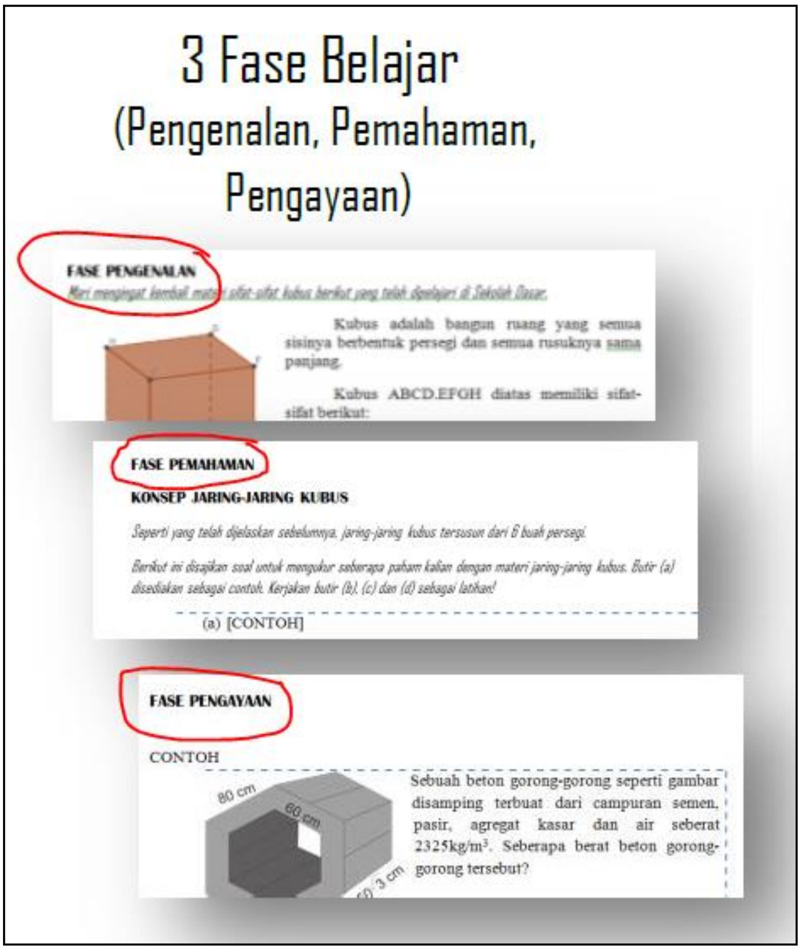

Figure 1. Worksheet Phase

The worked examples were designed using a strategy of pairing. As can be seen in Figure 2, the position of pairs of example [contoh] and problem solving [soal] is varied, depending on the length of the to-be-learned problems. It was noted that the most important is that the design of the pairs was isomorphic and the level of difficulty increases from low to high. By this design, the extraneous cognitive load caused by the presentation of the problem may be lower and hence improve germane cognitive load.

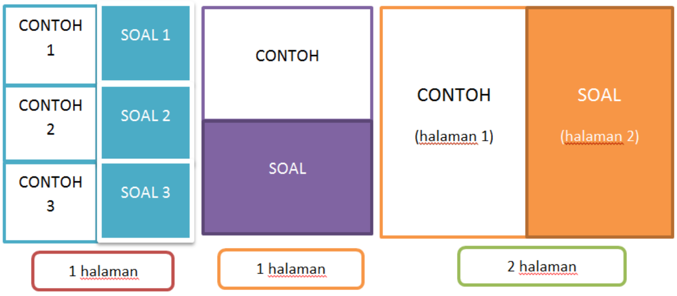

Figure 2. The format of writing a couple of examples and problems

During the development step, researchers consulted the on-progress results to the experts in order to obtain data of validity, practical and effectiveness. Focused discussions were conducted many times (part-by-part of the worksheet) to see whether the development of the worksheet has been in accord with the principle of the worked example approach. Through the discussion, it was found that applying the principle of avoiding split attention and redundancy effects was the most critical. For an example, the previous design of net problem solving was as can be seen in Figure 3 below which was agreed that such design may cause a split attention. The split attention lies on the star, shaded area and the written instruction explaining these symbols. This design was then revised as can be seen in Figure 4 and assumed that this has minimal extraneous cognitive load. In this design, the star and written instruction were removed and replaced by a shaded area and the written explanation in the area. By this way, students would be easily grab the information and learn from the worked example and isomorphic problems more efficient.

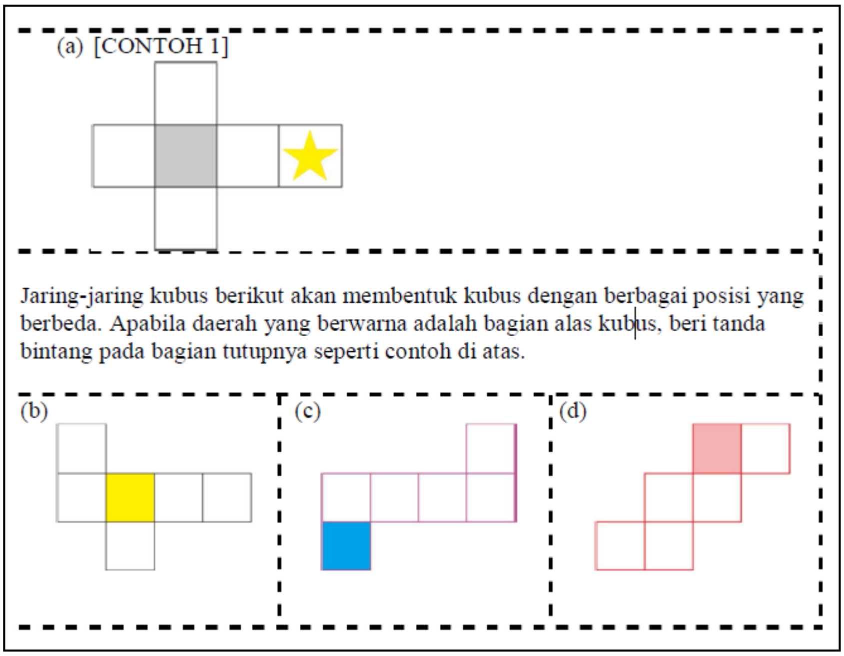

Figure 3. Example of *Split-attention*

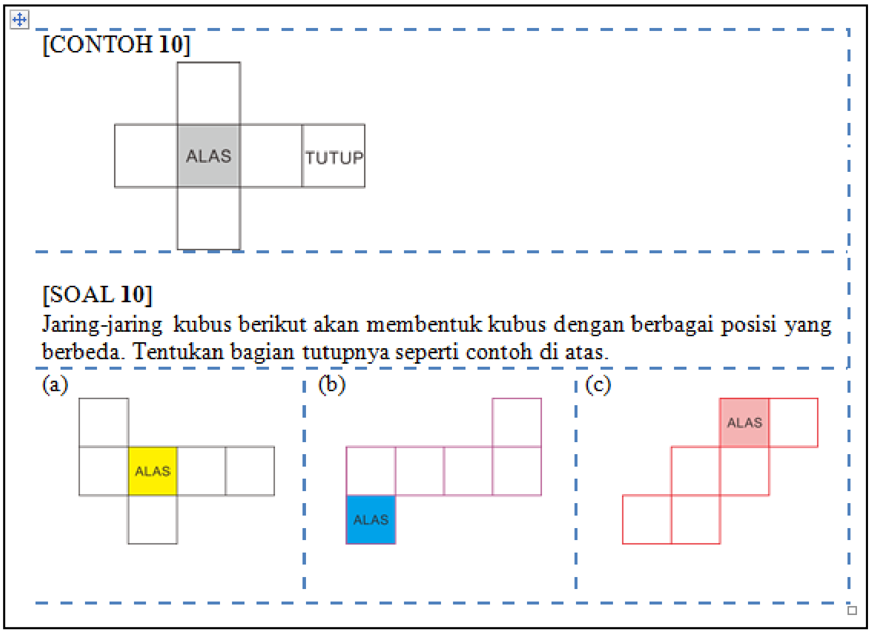

Figure 4. Example of well integrated worked example.

Discussions to reach the quality aspect of the worksheet were done continuously to explore whether the worksheet has been developed following the worked example principles. This also included the level of complexity of every material, the context choices, variation of the problem solving, lay-out and figures. After some confidence was gained by revising the developed worksheet according to the discussion results, the implementation step followed. There were two batches of implementation. In the first one, several students were involved to give information whether the instruction in the worksheet is easy to follow. During this implementation step, the researcher also collected some quantitative data using assessment sheets. These instruments were used to assess the validity and practicality aspects. Questions in the validity assessment were about whether the problem context, level of complexity, sequence of the topics and variability of the problem solving have been relevant to the learning outcome. As well as whether the principle of worked example approach has been applied accordingly and hence possibly lower cognitive load during learning using the worksheet. The results showed that the geometry experts scored 4.47 of the maximum score of 5 (criteria contents valid), and the media experts scored 4,31 of the maximum score 5 (criterion media valid).

As described by Plomp and Nieveen (2013), a product is practical when it provide convenience and usefulness. Attractiveness was added in the practical component. Questions in the practicality assessment were about the appearance, readability, print-out of figures, color, lay-out, distractions and strategically aim to achieve learning outcome. The results showed that an average score 3.14 of the maximum score of 4 (practical) from the students while an average score higher that is at 3.78 out of a maximum score of 4 (practical) from the teacher. A product was considered effective if it can facilitate the learning process to give a good result in order towards the goal (Plomp and Nieveen, 2013). Specifically, effectiveness of the worksheet to facilitate problem solving skills would be reach if students are able to acquire conceptual and procedural knowledge from the worked example instruction. The effectiveness of worked example can be achieved if the worked example do not impose high extraneous cognitive load (Retnowati, 2012). Through discussions during the design and development steps, researchers attempted to minimize cognitive load may be caused by the material in the worksheet. To support this data, a problem solving test was given to thirty one students in the second implementation step. Before completing the test, the students were asked to study the worksheet accordingly. The result showed that 68% of students could score above seventy (of the maximum score of 100).

In the evaluation step (the last step of the ADDIE), the researcher made some little adjustment to the worksheet to improve the quality. Through consultation and discussion with the expert, the final worksheet was produced. This is maybe an early conclusion however it could be said that the developed worksheet has been able to assist students managing their cognitive load during learning, as can be supported by both qualitative and quantitative data.

Conclusion

This research yields a qualified worksheet based on the worked example approach following the ADDIE procedure. Qualitative research was conducted to explore the design and development by discussions part-by-part with experts, teacher and also the subject user, the student. The learning material was geometry for year eight in Indonesia and focused on the acquisition of problem solving skills. The worked example approach was applied by: 1) creating pairs of similar worked example and problem solving, 2) using variation of problem contexts, 3) arranging level of complexity in order, 4) avoiding split attention effect and 5) avoiding redundancy effect. Quantitative data was collecting for assessing the quality of the overall worksheet. The data support the discussion and revision results in the development of the worksheet. This worksheet may be an exemplary educational product that was developed based on cognitive load theory, and hence suggested to be implemented at educational setting. Furthermore, similar research is very useful to assist the implementation of instructional theory into practice.

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