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Developing Instructional Design to Improve Mathematical Higher Order Thinking Skills of Students

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Abstract. This study aimed to describe the instructional design to improve the Higher Order Thinking Skills (HOTS) of students in learning mathematics. This research is design research involving teachers and students of class X MIPA 1 MAN Yigyakarta III, Special Region of Yogyakarta, Indonesia. Data collected through focus group discussions and tests. Data analyzed by quantitativedescriptive. The results showed that the instructional design developed is effective to improving students' HOTS in learning mathematics. Instructional design developed generally include three main components: (1) involve students in the activities non-routineproblem solving; (2) facilitating students to develop the ability to analyze and evaluate (critical thinking) and the ability to create (creative thinking); and (3) encourage students to construct their own knowledge.

1. Introduction

Education has an important role in improving the quality of human resources in order to compete in the era of globalization and modernization. The law of the Republic of Indonesia Number 20 Year 2003 about National Education System [1] states that the national education serves to develop the ability and character development as well as a dignified nation's civilization in the context of the intellectual life of the nation. One of the efforts to achieve these goals is through the learning of mathematics.

Permendikbud Number 59 Year 2014 about Curriculum SMA/MA [2] mentioned that the mathematics courses should be offered to all learners from primary schools, to equip learners with the ability to think logically, analytical, systematic, critical, innovative and creative, as well as the ability to cooperate. In order to achieve these objectives, it is important in learning mathematics developed various aspects of skills, one of which is a higher order thinking skills (HOTS). This is in line with the views expressed by Yen & Halili [3] that HOTS is the skills that are needed by every individual in the educational environment.

Experts define HOTS with different approaches and viewpoints. Resnick [4] argues that HOTS is hard to define, but easily recognizable by its characteristics. Further, Resnick [4] revealed some of the characteristics of HOTS as follows: (1) non-algorithmic, meaning that the action steps can not be fully determined at the beginning; (2) tends to be complex, meaning that steps can not be seen or predictable directly from a certain perspective; (3) often produces a lot of solutions rather than a single solution; (4) involve disagreements (nuanced judgment) and different interpretations; (5) involves the application of multiple criteria, which are sometimes mutually contradictory; (6) often involve uncertainty; (7) involving self-regulationin the process of thinking; (8) involving imposing meaning,

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such as discovered the structure of the irregularity; and (9) requires effortfull. If examined closely, the general characteristics of HOTS above demonstrates the need for unusual thought processes or thinking that is more complex and requires an unusual effort anyway.

Thomas & Thorne [5] state that “higher level thinking is thinking on a level that is higher than memorizing facts or telling something back to someone exactly the way it was told to you”. Furthermore Thomas & Thorne [5] state that “higher level thinking requires that we do something with the facts. We must understand them, infer from them, connect them to other facts and concepts, categorize them, manipulate them, put them together in new or novel ways, and apply them as we seek new solutions to new problems”. In line with these opinions, Lewis & Smith [6] states that “higher order thinking occurs when a person takes new information and information stored in memory and interrelates and/or rearranges and extends this information to achieve a purpose or find possible answers in perplexing situations”. From the opinions that have been raised before it can be concluded that HOTS demand for more complex thinking in dealing with situations or solve a problem.

In connection with the framework of thinking skills, HOTS is often described as a cognitive activity or thinking skills at a high level. In this case, the term is usually contrasted with the term LOTS (Lower Order Thinking Skills). Saido, Siraj, Nordin, & Al-Amedy [7] states that the LOTS only require routine applications of information obtained previously as registering the information from memory beforehand and enter the numbers into the formula that has been studied before, while HOTS requires students to interpret, analyze, or manipulate information.

Some experts, including Fisher [8] classifies the cognitive process analysis, synthesis, and evaluation in Bloom’s taxonomy as HOTS, while cognitive process knowledge, understanding, and application as LOTS. While in the cognitive process by Krulik & Rudnick [9], explained that the critical thinking and creative thinking as HOTS, while recall and basic included in LOTS. As if it is associated with Bloom’s taxonomy revisions proposed by Anderson & Krathwohl [10], Liu [11] argues that the dimension of the cognitive process analyze, evaluate, and create as HOTS.

Based on some of these opinions can be concluded that HOTS is thinking skills that are more complex in solving various non algorhitmic problems that include critical thinking and creative thinking, As if it is associated with cognitive processes in Bloom’s taxonomy, HOTS involve students’ skills to analyze, synthesize, and evaluate, whereas if it is associated with cognitive processes in Bloom’s taxonomy revision HOTS involves the ability to analyze, evaluate, and create.

Facts in the field indicate that HOTS of students in Indonesia is still [12]. Low HOTS of students in mathematics can be seen from the results of the study Trends in International Mathematics and Science Study (TIMSS) organized by the International Association for the Evaluation of Educational Achievement (IEA). TIMSS data in 2011 [13] shows that on cognitive dimension, Indonesia was ranked 38 out of 42 participating countries.

Low students’ HOTS in Indonesia is caused by many factors. Results prasurvei the author of the 10 high school math teachers showed that only 2 teachers (20%) who have applied mathematics learning oriented to development students’ HOTS. Besides other findings also show that teachers' understanding about HOTS is also lacking, even exist high school math teacher who is unfamiliar with the term of HOTS. Based on these findings, it is necessary to develop an instructional design to improve students’ HOTS in mathematics learning. This article aims to descriptionan instructional design to improve students’ HOTS in mathematics.

Method

This study using design research approach aimed to design and develop an intervention (such as programs, teaching-learning strategies and materials, products andsystems) as a solution to a complex educational problem as well as to advance our knowledge about the characteristics of these interventions and the processes to design and develop them, or alternatively to design and develop educational interventions (about for example, learning processes, learning environments and the like) with the purpose to develop or validate theories [14].The subject of research involving teachers and students of class X MIPA 1 MAN Yogyakarta III, Special Region of Yogyakarta, Indonesia. Data collection was done through Focus Group Discussions (FGD), instructional design trials and tests. The effectiveness of instructional design was analyzed by quantitative descriptive, by seeing an increase in scores pretest-posttest of students.

2. Result and Discussion

Based on the review of the theory and FGD, instructional design to improve student HOTS as follows: (1) learning objectives lead to the development of critical thinking skills (characterized by the ability to analyze and evaluate) and creative thinking are characterized by their ability to create; (2) the inducement activities of teachers by asking the question “why” and “how”, which serves as a stimulus for students to develop HOTS; (3) using the problems that generate many answers or many ways of solving (4) content in worksheet have connectivity between the material and concepts; (5) worksheets that are used to build the concept leads to the discovery and investigation activities adjusted to the characteristics of the material; (6) worksheets that are used for the application of the concept using creative problem that demands a lot of answer and or a lot of ways to solve the problems; (7) problems associated with the real world context and have irregular structure (ill-structure); and (8) There are the reflection to find the reasons why students choose or use a particular method or concept in solving the problem.

Saido, Siraj, Nordin, & Al-Amedy [7] stated that the strategy can be used to improve students’ HOTS is through problem solving activities. It is become a demand for math teachers to have the skills to provide the problems that can develop students’ HOTS. Here is one example of the use of problem oriented students’ HOTS in mathematics quoted from PISA [15].

Problem 1:
“A pizzeria serves two round pizzas of the same thickness in different size. The smaller one has a diameter of 30 cm and costs 30 zeds. The larger one has a diameter of 40 cm and costs 40 zeds. Which pizza is better value for money? Show your reasoning.”

The discussion of the problem is as follows:
Discussion:
Smaller Pizza (diameter 30 cm):

Area = $\pi \times \frac{30}{2} \times \frac{30}{2} = 225\pi\ cm^2$

Area of each one Zed = $\frac{225\pi}{30} = 7{,}5\pi\ cm^2$

Larger Pizza (diameter 40 cm):

Area = $\pi \times \frac{40}{2} \times \frac{40}{2} = 400\pi\ cm^2$

Area of each one Zed = $\frac{400\pi}{40} = 10\pi\ cm^2$

Based on the calculation above shows that with 1 Zed earned $7{,}5\pi\ cm^2$ smaller pizza and $10\pi\ cm^2$ larger pizza. It can be concluded that a larger pizza (diameter 40 cm) cheaper than the smaller pizza (diameter 30 cm)

In the above problem, the student is required to understand the meaning of the problem, then able to calculate the extent or magnitude of the pizza, pizza magnitude obtained with 1 Zed price or price per cm2 pizza in units Zed. Furthermore, students are required to conclude the pizza which are cheaper and why. For students who are accustomed given routine matter will be difficulties in translating the intent of the question. As if the problem is converted into a regular math problems would read as follows:

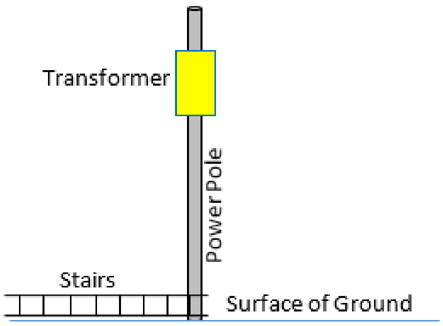
Problem 2:
Routine mathematics mathematics:

A pizzeria provides two choices of pizza with the same thickness and different sizes. The smaller pizza has a diameter 30 cm is sold at a price of 30 Zed. Pizza with a larger size that has a diameter 40 cm for 40 Zed. Determine the price to pay if you buy two smaller pizza and theree larger pizza.

The discussion of the problem is as follows:
Discussion:
Known:
Smaller Pizza (diameter 30 cm) = 30 Zed;
Larger Pizza (diameter 40 cm) = 40 Zed
Asked:How the price of 2 smaller pizza + 3 larger pizza?
Solution: 2 (30 Zed) + 3(40 Zed) = 180 Zed.

Problem 2 shows that to solve the problem is given, students simply apply the concept of multiplication and addition. Forms of problem like this clearly do not require students to use HOTS.
As other examples of problems that can train students to think critically is as follows.

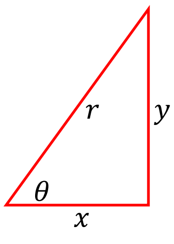
Problem 3 [16]



A technician will repair the transformer contained in one of the power poles using astairs, as shown in the illustration above. If the height of the transformer is 5 meters from the ground, what is the minimum required length of stairs so that technicians can repair the transformer?

To solve problem 3, students should know the concept of a minimum of what is needed to solve the problem, facts or information known, and what alternative solution to the problem. The above problem is not a problem that only requires the application of a concept, but students are asked to analyze in advance the concept of what it takes to solve the problems. The discussion of problem 3 is as follows.

If the height of the transformer is exemplified by y and the length of the stair is exemplified by r, it will be obtained illustrated the problem as follows.



In beside picture, it appears that the problem can be solved by using a comparison trigonometry in a right triangle, where x is distance of end stair with a power pole. The problem is to determine the length r, then it takes a great corner between the stairs to ground level (θ), but on the problem the angle size θ is unknown.
Based on the above illustration angle size θ is between 0° to 90°. In this case the alternatives that can be chosen by selecting special angle which are quadrant I.

If $\theta = 30°$, *then* $\sin 30° = \frac{y}{r} \Leftrightarrow \frac{1}{2} = \frac{5}{r} \Leftrightarrow r = 10$ *meters*

If $\theta = 45°$, *then* $\sin 45° = \frac{y}{r} \Leftrightarrow \frac{1}{2}\sqrt{2} = \frac{5}{r} \Leftrightarrow r = 5\sqrt{2}$ *meters*

If $\theta = 60°$, *then* $\sin 60° = \frac{y}{r} \Leftrightarrow \frac{1}{2}\sqrt{3} = \frac{5}{r} \Leftrightarrow r = \frac{10}{3}\sqrt{3}$ *meters*

All of the above alternatives is correct, but it should be considered whether the angle chosen will produce the safest slope of the stair. Based on these three alternatives, the safest slope of the stair is when θ = 60°, so the length of the *stair is required is* $\frac{10}{3}\sqrt{3} \approx 5{,}77$ *meters.*

Based on discussion of problem 3, it appears that students are required to be able to make an illustration of the problem, it indicates that it needed the ability to create. In addition, students are also required to be able to identify important facts and information that is relevant to formulate the desired solutions, in this case the student is required the students skill to analyze. On the other hand, to find the best solution or the most reasonable solution of the above problems, it is necessary their students' ability to evaluate of each solution were found.

3.1 The effectiveness of instructional design

Before the instructional design applied in the classroom, students are given a pretest that aims to identify early students' HOTS. The next after implementation instructional design that has been developed, students are given a posttest to determine the impact of the implementation of the instructional design. Pretest and posttest mean score of students is presented in Figure 1.

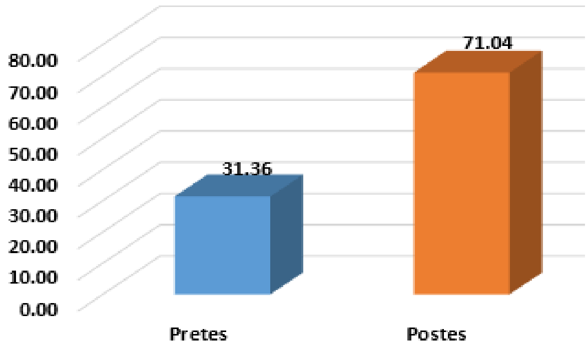


Figure 1. The Enhancementof Mean Score of Students' HOTS

Figure 1 shows that the score of students' HOTS has increased significantly. This shows that the implementation of instructional design provides a positive impact on the enhancement of students' HOTS. The performance score HOTS each student is presented in Figure 2.

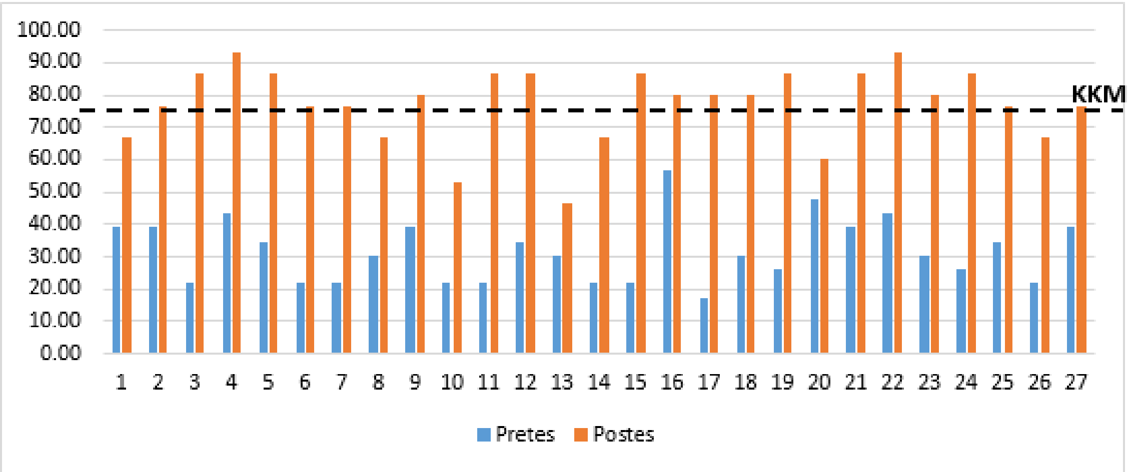


Figure 2. Graph of Enhancement of Students' HOTS

Based on Figure 2 shows that each score HOTS students when the pretest increased after the implementation of instructional design developed. Although not all students achieved a Minimum Completeness Criteria score, these achievements clearly indicate that the developed instructional design can improve each students' HOTS. Thus the implementation of instructional design that has been developed effective to improve student HOTS.

3.2 Discussion

The results of data analysis showed that the instructional design developed is effective for improving students' HOTS. This is due to the filing of an open question (creative problem) through worksheet make students more challenged to explore the various possibilities of ideas that can be used to solve the problem. Loewen [17] suggested that with the filing of creative problems can generate awareness for students that not all the problems have only one correct solution. This is what can trigger and train the students' creativity in mathematics learning, and creativity are part of HOTS.

Another factor which led to increased student HOTS is presence of meaningful learning activities, where students are actively involved in the discussion process to construct knowledge and utilize various relevant sources to explore the knowledge desired. This is in accordance with the opinion raised by Bohan & Bohan [18] that the learning process that involves the active participation of students to solve various problems can present meaningful learning activities for students.In addition, students become enthusiastic because they feel challenged to a given problem. This of course could improve students' motivation to learn. This is in line with the opinion of Loewen [17]which states that the presentation of creative problems challenging can increase students' interest and motivation to learn. Thus the increased interest and motivation to learn students become a determining factor for the increase students' HOTS.

3. Conclusion

Based on the result and discussion can be concluded that HOTS in mathematics learning is important. It aims to develop students' ability to analyze, evaluate, and create, so that students have the critical power and creativity that can be used to solve problems in everyday life. Some efforts should be made to improve students' HOTS in mathematics, namely: (1) engaging students in the activities of non-routine problem solving; (2) facilitate the students to develop the ability to analyze and evaluate (critical thinking) and the ability to create (creative thinking); and (3) encourage students to construct their own knowledge, so that learning becomes meaningful for students.

Based on the findings in this study suggested for teachers to apply instructional design that has been developed in this research in mathematics learning. To ensure that the instructional design can be implemented properly, teachers should provide various non-routine problems close to the everyday life and train students the ability to ask "why" and "how".To assist in making problem-oriented HOTS, teachers can adapt and modify the questions TIMSS and PISA

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