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Problem Solving Heuristic to Develop Scientific Reasoning

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Abstract

Scientific reasoning patterns of students formal operational base on the implementation of problem solving heuristic methods has been obtained. The aim of this research is knowing the influence of heuristic problem solving method that has been designed on practicum sheet of discovery learning model to develop scientific reasoning of students. The samples are 32 students in junior high school at 11-13 years old. The methods are CTSR test of scientific reasoning by Lawson and interview. The research design is one grup pretest-posttest. The results indicated that problem solving heuristic methods can be a factor to develop scientific reasoning of students. The lowest level of scientific reasoning (concrete reasoning pattern) is decrease 34,38%. The middle level of scientific reasoning (transitional reasoning pattern) is increase 31,25%. The highest level of scientific reasoning (formal reasoning pattern) is increase 3,13%. Heuristic methods helping students to develop scientific skills, such as setting hypotheses, modifying variables, and analyzing results of research. The scientific reasoning pattern can not be classified by age. People who has older of age has not impact in high scientific reasoning level than younger people. If someone fail on concrete aspect, it is not necessarily that person will be fail in formal aspect.

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INTRODUCTION

Physics introduced to Indonesia students in elementary school and high school. The results show that physics learning activity can not be able to facilitate the physics concept. It has an impact of students scientific reasoning level are low. The scientific reasoning aspects of correlational reasoning has no relationship category. It means that Indonesian students ability are weak to relate the answer and reason to solve a problem (Rimadani et al., 2017). The innovation of physics learning required to improve the quality of learning and student thinking skills (Azizah et al., 2015).

Learning strategies to develop student thinking skills was brought physics phenomena that can be observed, analyzed, and inferred directly by the students in discovery learning model (Robinson & Niaz, 1991). Discovery learning is involve the conscious reasoning process to find a new information that students have not been learned the problems (Taneo et al., 2015; Kurniasih et al., 2014). This model can encourage students to be active and competent in processing data or hypotheses, and summarizing problems (Dewey, 1997; Piaget, 1973).

The movement of "The Vision and Change" has emphasized to teach science as science doing. Learning of science not only focus the content of science, but also on scientific process (AAAS, 2011). The model of discovery learning is an example of constructivism theory that children constructs their knowledge with environmental interaction or experimental activity. The theory of constructivism more effective to develop conceptual understanding and scientific reasoning people than other learning theories (Howard & Miskowski, 2005; Jensen & Lawson, 2011; Minner et al., 2009).

Scientific reasoning has two reasoning patterns, there are concrete reasoning and formal reasoning. The examples of concrete reasoning pattern are class inclusion, conservation, serial ordering, and reversibility. Formal reasoning patterns include theoretical reasoning, combinatorial reasoning, functionality and proportional reasoning, control variables, and probabilistic, and correlational reasoning (Karpluss et al., 1997). The level of scientific reasoning does not depend on gender (Diehl, 1995; Al-Zoubi et al., 2009; Piraksa et al., 2014). Scientific reasoning is very important to acquire knowledge and decision making processes (Zimmerman, 2007; Wason & Johnson, 1972). Scientific reasoning skills are influence in successing mathematics skills, science, computer education, and adapt to informal learning environments (Al-Zoubi et al., 2009; Piburn, 1990; Gerber et al., 2001).

The discovery learning model has advantage to make independent learning activity and more actractive with all observations. The order side, some of students were not perform data analysis and conclude observation result (Syafi'i et al., 2014). All activities of learning in students responsibility and the teachers only as facilitators. It has an impact to students that can not relate the aim of observarion and theory. Heuristics is one of problem solving procedure but does not guarantee the right solution. Heuristics was only guides to find a solution (Schoenfeld, 1979). The Problem Solving Heuristic (PSH) method was improve students cognitive and self regulating abilities in discovery learning process (Veermans et al., 2006). The current study aimed to discribe the pattern of students scientific reasoning on implementation of heuristic method base on discovery learning model.

METHOD

The design of this research is One-Group Pretest-Posttest as shown Table 1. This design using experiment group only. The treatment is implementation heuristic method base on discovery learning model. The heuristic method was applied in student practicum sheet with Pressure physics chapter. Five types pressure practicum laboratory such as: pressure definition,

diffusion process, Hydrostatics Law, Archimedes law, and surface tansion were redesigned according to heuristic method and applied for 15 hours (3 weeks) in physics learning.

Table 1. One-Group Pretest-Posttest Design

Grup	*Pretest*	Treatment	*Posttest*
Experiment	O_1	X	O_2

This research was located at SMP Negeri 1 Margoyoso, Pati, Central Java. The study population are students of class VIII SMP Negeri 1 Margoyoso, with 32 students. The first research activity is pretest to know the level of students scientific reasoning before treatment. The end activity is posttest to measure and analyze the result of scientific reasoning base on implementation of heuristic method. The test instrument use Classroom Test of Scientific Reasoning (CTSR) by Lawson's with multiple choice and 12 questions (Ding et al., 2016). There are 9 questions CTSR test have been modified according to the Pressure physics chapter. The test instrument has been tested to obtain the standard of CTSR such as validity, reliability, and statistical test. The non test method of research is interview. Interview will be implemented after posttest as a cross check how student answer the test. The grid of measuring aspects of scientific reasoning CTSR as shown Table 2.

The impact of problem solving heuristicis determined by the average of pretest and posttest scores. If the average posttest score better than the average pretest score, it can be concluded that student scientific reasoning ability was increased. Another method that can be used to determine the impact of problem solving heuristicis is grouping the level of students scientific reasoning patterns. The level of scientific reasoning patterns from highest to lowest are formal pattern, transitional pattern, and concrete pattern.

Table 2. Grid Measuring Aspects of Scientific Reasoning (Lawson, 1995)

Number	Indicator of Scientific Reasoning
1	Conservation of weight
2	Conservation of displaced volume
3	Proportional thinking
4	Proportional thinking
5	Identification and control of variables
6	Identification and control of variables
7	Identification and control of variables
8	Isolation and control of variables, probabilistic thinking
9	Isolation and control of variables, probabilistic thinking
10	Isolation and control of variables, probabilistic thinking
11	Combinatorial thinking
12	Correlational thinking

RESULT AND DISCUSSION

The problem solving heuristic method has been implemented in discovery learning model. The results of scientific reasoning test show that average pretest experimental class is 39.00 and average posttest experimental class is 52.50. The average posttest is greater than average pretest. It can be conclute if problem solving heuristic method base on discover learning model can improve student scientific reasoning. The improvement of student scientific reasoning abilities are founded in ten numbers of CTSR, such as conservation of weight, proportional thinking, variable identification and control, separating and controlling variables, probabilistic thinking, and combinational thinking as shown in Figure 1. One aspect conservation volume is decreasing and one aspect correlational thinking has not changing.

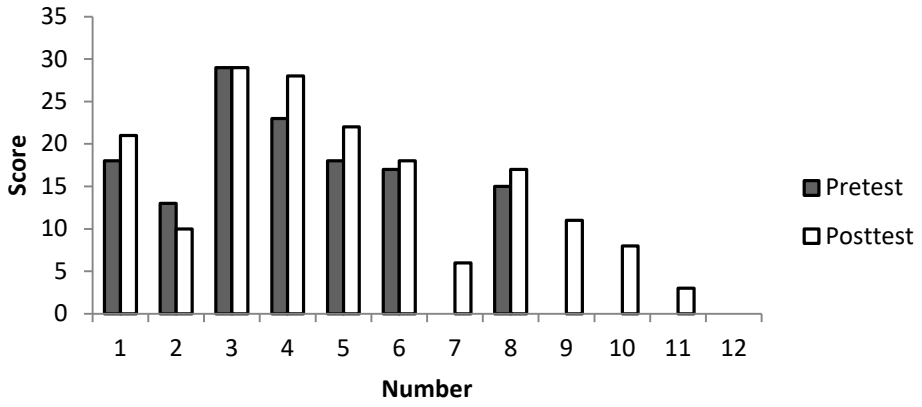
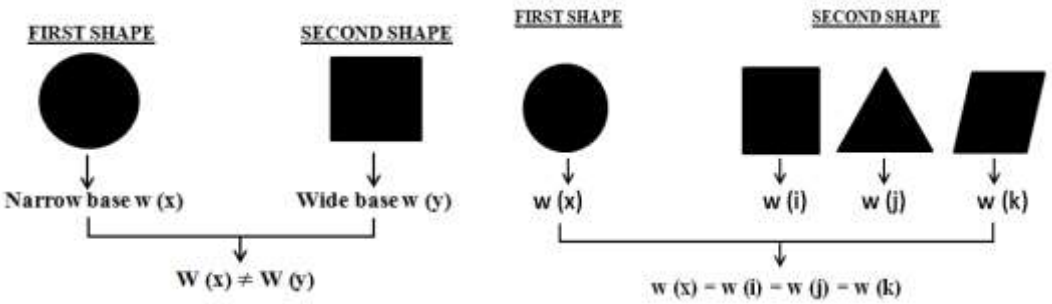


Figure 1. Prestest-Posttest CTSR Test Score

Discovery learning with heuristic methods would be able to train problem solving of students to illustrate the concept of size, shape, and mass. The increasing of weight conservation aspect is 9,38%. The pattern of student reasoning base on weight conservation aspect shown in Figure 2a and Figure 2b. The problem solving in Figure 2a show that a cube has larger base surface than sphere. The large of cube surface has impact on pressure. The weight of cube will be decrease too. Another reasoning process as shown in Figure 2b. It show that an object has "one" mass. The mass will not change althought the shape of the object changed.



(a) (b)

Figure 2. Reasoning Pattern of Weight Conservation: (a) first type, (2) second type

The aspects of conservation volume show that 13 students in pretest solve with correct answer, and 10 students in posttest solve with correct answer. Students have ambiguity to define about "volume" and "weight" as shown in Figure 3. If an object dipped to tub full of water, the weigh of water that spill is equal to weight of object. The concept is not appropriate because the volume transferred by water will be equal to volume of dying object. Description: both of objects dipped in a sinking state so the density of objects has no effect.

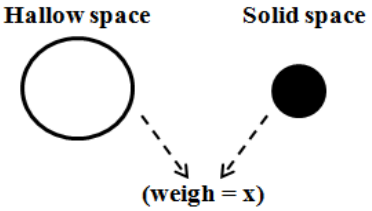


Figure 3. Reasoning Pattern of Conservation Volume

The level of proportional thinking and advanced proportional thinking get the highest score toward all aspects of scientific reasoning. Students solve the problems through the principle of proportion. Based on Figure 1, the pretest score of numbers 3 and number 4 are high. The score almost reached in maximum at posttest. Student use simple way to solve problems as show Figure 4.

$$\text{If} \rightarrow 50\,n = 20.000$$
$$n = 400$$
$$\text{So} \rightarrow 2{,}5\,n = 2{,}5 \times 400 = 1.000$$

Figure 4. Reasoning Pattern of Proportional Thinking

The aspect of identification and control variables has three questions with two different types. Problem number 5 and number 6 are relate to practicum activities, number 7 relate of practicum observations data. Correct answer of problem number 5 increase 12.50%, number 6 increase 3.13%, and number 7 increase 18.75%. The increasing of three aspects are not to high. it suggests that student have disadvantages of choosing the right variables, determining of relation among variables, designing experiments, formulating conclusions from experiments, and interpreting experimental results (Jong & Joolingen, 1998; Kuhn, 2007; Boudreaux et al., 2008).

The aspect of separating and controlling variables, probabilistic thinking has two types with three questions. One question is separating and controlling variables, and two questions are probabilistic thinking problems. The significant increases aspect occur probabilistic thinking problems. Students solve the probability concept appropriately. Students have two strategies in probabilistic thinking, there are through result approach and the heuristic method (Konold et al., 1993). The result approach that student are not identifythe problem to determine probabilities as the answer.

The aspect of combinational thinking is not substantial improvement. Students do not correct combination. They solve a problem with heuristic method or trying some solutions to get a result. The aspect of correlational thinking would not solved by all students. They are not understand the concept of correlation. Students only comparing the quantity and would not compere ratios as a conclusion.

Students in 11-13 years old are informal operational stage (Piaget, 1950). They are attainable parts of scientific reasoning like rational thinking, stochastic thinking, combinational thinking, and correlational thinking (Lawson, 1995). This results is not accordance with the mapping of concrete operation stage by Piaget. He suggest that people in concrete operation stage be able to identify six types of conservation reasoning, namely conservation of numbers (6-7 years), material conservation and immutability (7-8 years), immense conservation (8-9 years), conservation of weight (9-10 years), and conservation of volume (11-12 years).

The students ability on conservation weight aspects (number 1) is not experienced a significant increases as shown in Figure 1. The aspect of conservation volume (number 2) that should be controlled by students at 11-13 years old is decline. In interview, students understand the meaning of question and understand the devinition of volume. The problem solving is fail because student relate conservation of weigth with conservation of volume. People fail in problem solving process with many conditions, such us the frontal lobe maturation is lack or the physics concept and social experience is low (Lawson, 2004). The students highest reasoning abilities is proportional thinking. Students perform are better in numerical contexts than real life contexts (Zhou et al., 2016). Proportional thinking is a part of formal reasoning pattern (Fah, 2009). If a person has constraints in concrete reasoning pattern, they are can solve problem in formal reasoning aspect.

Scientific reasoning ability can be developed with implementation of heuristic methods on discovery learning models. The results of this study is like other studies that the level of reasoning can be improved by learning activities with testing hypothesis or theory procedures (Lawson, 2004; Erlina et al., 2016; Wu et al., 2016; Novia & Riandi , 2017). Scientific reasoning patterns of experimental group show Figure 5. The student scientific reasoning ability was change after implementation the treatment. The pattern of students scientific reasoning before treatment is concrete reasoning pattern 62,50% and transitional reasoning pattern 37,50%. After the implementation of heuristic methods, the student scientific reasoning are concrete reasoning pattern

28,13%, transitional reasoning pattern 68,75%, and formal reasoning pattern 3,12%. It mean that concrete reasoning pattern is decrease 34,38%, and transitional reasoning pattern increase 31,25% and students formal reasoning pattern increase 3,13%.

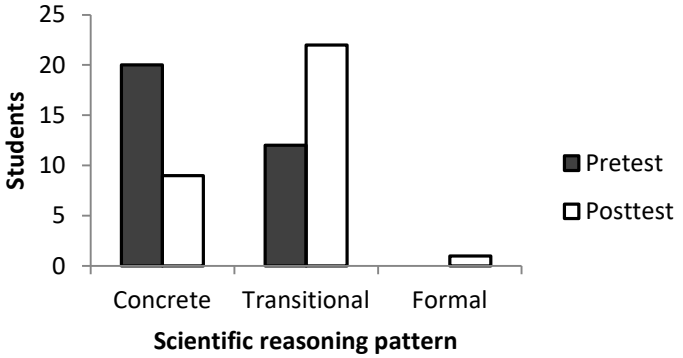


Figure 5. Pretest-Posttest Scientific Reasoning Patterns

Student reasoning in 11-13 years old is transitional reasoning pattern. It is transition between concrete reasoning pattern and formal reasoning parttern. The students scientific reasoning ability can not be determined on Piaget's cognitive stages that developed by age (Irawati, 2016). The ability of scientific reasoning does not necessarily evolve in 100%. People reasoning pattern can stop in concrete or transitional pattern, or will not be able to reach the formal level in their lifetime (Nur & Rahman, 2013).

Tabel 3. The Structure of Heuristic and Without Heuristic in Discovery Practicum Sheet

No	Heuristic	Without Heuristic
1	The purpose of practicum	The purpose of practicum
2	Materials	Materials
3	Procedure	Procedure
4	Table of observations	Table of observations
5	Main problem	Discussion
6	Hypothesis	Conclusion
7	Hypothesis development	
8	Graph of observasion	
9	Graph information	
10	Repeat practicum	
11	Change variables	
12	Table of observations	
13	Graph of observations	
14	Conclusion	

The heuristic method can be a factor to develop scientific reasoning although in limit proportions. Heuristic can develop scientific reasoning pattern because it can be assist someone to solve problems with several stages. The structure of heuristic in discovery practicum sheet as show Table 3. The students trying to complete all heuristic steps, one by one. The heuristic steps can be construct students knowlegde as a solutions of problem without teacher assistance. Heuristic methods helping students to identifying hypotheses, testing hypotheses, analyzing data, repeating hypothesis with new procedures or chaging variables, drawing a graphic and estimate the extreme values so the practicum analysis can be easier (Veermans et al., 2006).

The heuristic method has unusual or opposite steps with algorithm techniques. Heuristic method can develop scientific reasoning pattern because it helps student to develop more solutions such as relating problem with physics concept, conditional thinking, make a simple equation,

proportional thinking, and drawing the base problem to get conclusion as. The step of heuristic problem solving in scientific reasoning test as show Figure 6.

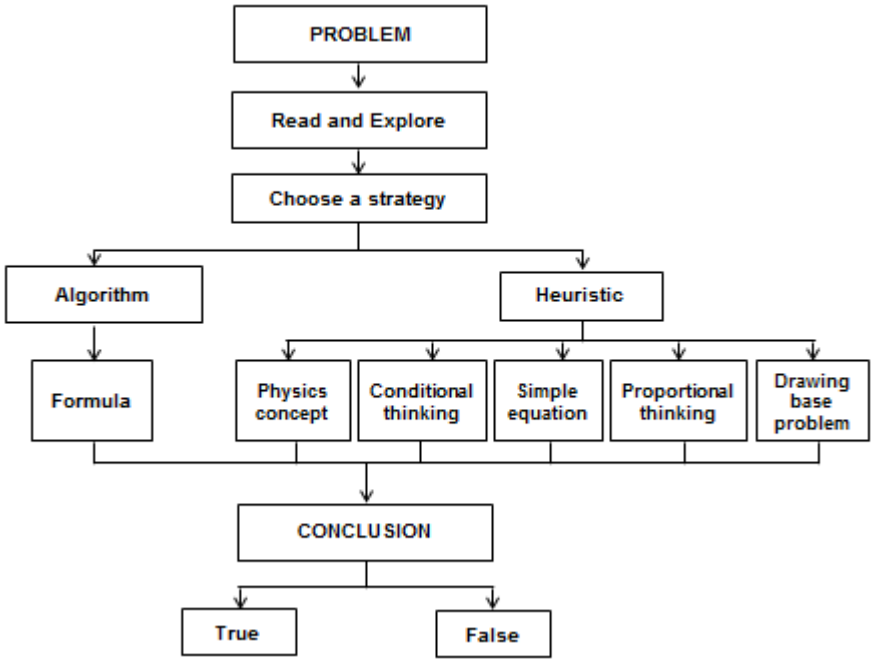


Figure 6. Student Poblem Solving in Scientific Reasoning Test

The students ability to solve scientific reasoning problem in posttest score are more varied than pretest score. The students who using physics formula (algorthm) are less than using heuristic problem solving. It means that the problem solving pattern of students more focused on trial activity based on the experience in discovery learning. The example that students using heuristic problem solving on posttest is the fourth number. More student use the principle of comparison than Pascal's law. The principle of comparison is one parts in heuristic problem solving as show Figure 6. Student was applying the principle of comparasion and the conclusion is correct.

The results of interviews on the respondents show that modified worksheets according to heuristic methods can help students to improve their thinking skills. Students not only practice the practicum, but also doing the experiment like science in generaly. Students will be change some variables and carry out the laboratory according to their hypothesis or their desires. Learning activity base on scientific reasoning development does not regrad how students solve the problem successfully (using algorithms or heuristics), but focus on understanding the value and benefits of producing reliable knowledge; development of some basic competencies, and appreciate the cognitive and cultural development adopted (Osborne, 2016).

CONCLUSION

Heuristic method was applied in discovery learning. The influence of the heuristic method are founded in posttest-pretest score and the pattern of scientific reasoning skill. The average posttest is greater than the average pretest and the students scientific reasoning pattern is incresing from concrete pattern to transitional pattern. If someone fails in concrete pattern aspect, it is not necessarily that person will be fail in formal reasoning aspects. The people ability of scientific reasoning could not be classified by age. The theory of scientific reasoning by Piaget's is applied in generally people, but in reality everyone has different thinking skills. A person in the formal operational stage would have a failure in the concrete aspects of thinking even though in theory the ability of that aspect has been passed by that person.

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