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Problem-based learning: effects on student's scientific reasoning skills in science

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Abstract. This research aimed to develop instructional package of problem-based learning to enhance student's scientific reasoning from concrete to formal reasoning skills level. The instructional package was developed using the Dick and Carey Model. Subject of this study was instructional package of problem-based learning which was consisting of lesson plan, handout, student's worksheet, and scientific reasoning test. The instructional package was tried out on 4th semester science education students of Universitas Muhammadiyah Sidoarjo by using the one-group pre-test post-test design. The data of scientific reasoning skills was collected by making use of the test. The findings showed that the developed instructional package reflecting problem-based learning was feasible to be implemented in classroom. Furthermore, through applying the problem-based learning, students could dominate formal scientific reasoning skills in terms of functionality and proportional reasoning, control variables, and theoretical reasoning.

1. Introduction

Today in 21st century, students need a repertoire of knowledge and skills that are more diverse, complex, and integrated than any previous generation. In order to prepare students to be successful and powerful generation, they should have some abilities or skills that can help them facing the challenges of 21st century. Such skills later is known as 21st century skills.

There are five 21st century skills that appeared valuable across a range of jobs, from low-wage service work to professional work: adaptability, complex communications/social skills, non-routine problem solving, self-management/self-development, and systems thinking [1]. In the context of science education, these skills have been named recently as strands of scientific proficiency which addresses the knowledge and reasoning skills that students must eventually acquire to be considered fully proficient in science [2]. In other words, reasoning skills is one of the 21st century skills expected to be taught in science classes in order to prepare students to succeed facing the challenges of globalization.

Scientific reasoning is the cognitive ability of students to interpret, analyze, evaluate, reason, solve problem related to science. These skills will help students to be better in understanding and evaluating scientific knowledge [3]. In other words, scientific reasoning skills correlate with students' ability to learn content knowledge [4]. There are two patterns of scientific reasoning skills, namely, concrete and formal reasoning. Some examples of concrete reasoning patterns are class inclusion, conservation, serial ordering, and reversibility. Formal reasoning pattern refers to the extent to which students can use logical and mathematical relationship rather relying primarily on familiarity and experience. The formal reasoning patterns include theoretical reasoning, combinatorial reasoning, functionality and proportional reasoning, control variables, and probabilistics and correlational reasoning. Previous research showed that students who were possess greater formal reasoning ability showed much larger gains on a concept knowledge test [5].

Scientific reasoning skills are required to be taught. However, the skills still do not receive much attention from educators, especially lecturers in Science Education Program, Universitas

Muhammadiyah Sidoarjo (UMSIDA). The results of diagnostic tests on scientific reasoning showed that 87% of students are still at the level of concrete scientific reasoning and 13% of students are at the formal scientific reasoning level. This is not in accordance with the theory of Jean Piaget who states that formal scientific reasoning occurs in children aged 11 or over. Children at that age, have more complex operations and capable of abstract thinking [6]. Students who are supposed to be at the level of formal scientific reasoning have difficulty in determining experimental variables. They are also unable to interpret the data that present unpredictable variables and recognize the relationships among them.
The main factor causing students' inability to reach their true potential is that students are not yet accustomed to complete tests or problems related to science process skills that are a major part of scientific reasoning skills. Some lecturers have used practicum methods to teach the scientific process. However, they still use paper and pencil tests that do not emphasize on the science process skills at the evaluation.

One of the learning models that are expected to help students improve the students' scientific reasoning skills from the concrete level to the formal level is the Problem-Based Learning (PBL). PBL is an instructional model that challenges learners to learn learning, work together in groups, and find solutions of real problems [7]. The PBL helps students to develop flexible knowledge, effective problem-solving skills, self-directed learning, effective collaboration skills, and intrinsic motivation [8]. All problems in problem-based learning come from the initial questions of students about a problem situation [9]. The problem is used to engage student's curiosity and ability to analyze the subject matter. Through PBL, students can develop the 21st century skills, because the model facilitates the students to reflect their works, contribute, negotiate, listen, and welcome other group members' ideas [10, 11].

Based on the descriptions, this research will focus on developing instructional package reflecting problem-based learning to improve students' scientific reasoning from concrete to formal level.

2. Method

This study was carried out to gain information about the student's scientific reasoning after the implementation of instructional package of problem-based learning. The research design was adopted from Dick and Carey Model. The first step was identifying the instructional goals. The second one was conducting instruction analysis, and writing learning objectives. The third step included developing scientific reasoning test, and instructs strategy and materials. The instructional instruments then were tried out to get suggestions. Finally, the results of the try out were analyzed and used to revise the instructional package to produce quality instructional learning.

The object of the study was the students of 4th semester majoring in science education. The instruments used were validation sheets and scientific reasoning test. Tryout was conducted by using the one-group pre-test post-test design. The data were then analyzed using an N-gain test to determine the effectiveness of problem-based leaning on students' scientific reasoning.

3. Results and Discussion

3.1. Validity of instructional package

The instructional package of problem-based learning was validated by two expert judgments. The expert assessed the instructional instruments in terms of content and construction. The results of the validation can be seen in the table 1.

Table 1. The results of validation

The instructional Package	Expert Judgment		Average	Category
	V1[a]	V2[b]		
Lesson Plan	3.5	3.4	3.4	Valid
Student's worksheet	3.3	3.5	3.4	Valid
Handout	3.3	3.3	3.3	Valid
Scientific reasoning test	3.2	3.4	3.3	Valid

[a]the first validator [b]the second validator

Based on the table 1, it can be described that the lesson plan is valid and appropriate to be implemented in classroom to foster scientific reasoning of students. However, there were some parts of the lesson plan which need to be revised based on the experts' suggestions. Some terms were not appropriate. The learning objectives and indicators should be stated operationally according to the scientific reasoning test.

Regarding to the validation results, the student's worksheet is categorized valid. To improve the quality, the student's worksheet was revised according to the expert's advice that to facilitate students who have no prior knowledge about determining and defining variables, the definition and the example of the variables should be provided in the student's worksheet.

Furthermore, the handout is also valid. But, it needs a little bit improvement based on the evaluator's suggestions. The handout should support student to reason, so that it must be provided blank space for students to write their reasons after questions. Some terms and typewritten which are still inappropriate should be corrected.

Although such test instrument is considered valid and reliable, some items need some revision based on the evaluator's suggestions. Firstly, item 1, 3, and 4 need revision in terms of language and typewritten. Secondly, Item 2, 5 and 9 are slightly not appropriate with the indicators. After some revisions, the developed scientific reasoning test then can be administered to students to know their scientific reasoning skill.

3.2. Effectiveness of instructional package

The analysis results of N-gain score of individual student are presented in the Table 2. The gain score describes whether the problem-based learning of instruction has an effect on fostering student's scientific reasoning skills.

Table 2. N-Gain score of students

Student	Pre-test	Post-Test	N-Gain	Category	Student	Pre-test	Post-Test	N-Gain	Category
1	15	63	0.56	Medium	10	20	80	0.75	High
2	20	68	0.60	Medium	11	5	60	0.58	Medium
3	25	80	0.73	High	12	10	69	0.66	Medium
4	15	58	0,51	Medium	13	10	80	0.78	High
5	25	95	0.93	High	14	15	47	0.38	Medium
6	20	60	0.50	Medium	15	20	72	0.65	Medium
7	10	50	0.44	Medium	16	15	72	0.67	Medium
8	15	65	0.59	Medium	17	20	75	0.69	Medium
9	15	83	0.80	High	18	15	56	0.48	Medium

The results of scientific reasoning test describe the degree to which the students master topic of biogeochemical cycles and scientific reasoning skills. The test was performed two times, pre-test before the students getting treatment and post-test after the implementation of problem-based learning to the students. Regarding to the pre-test and post-test results presented in Table 2, it can be seen that the problem-based learning has medium affect in helping students mastering formal scientific reasoning skills. Moreover, the formal scientific reasoning of students can be seen in the figure 1.

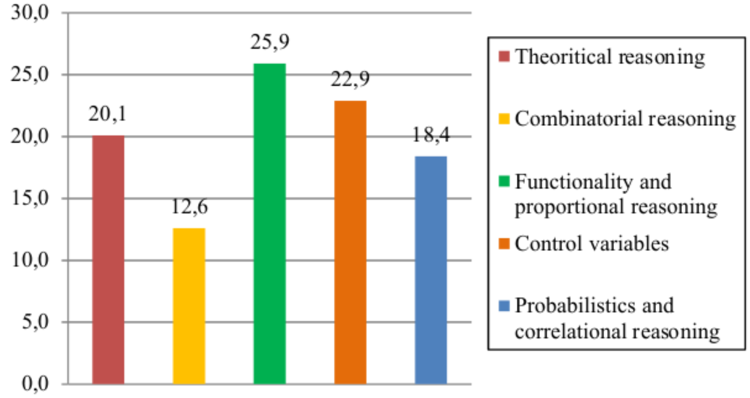

Figure 1. Student's mastery of formal scientific reasoning

As presented in the figure 1, it can be described that the students dominate the formal scientific reasoning skill in term of functionality and proportional reasoning, control variables, and theoretical reasoning. Arguably, this fact happened since students have been trained scientific reasoning skills through the implementation of the problem-based learning. In the learning, students self-evaluate their own projects, efforts, motivations, interests, and productivity levels. Students become critical friends by giving constructive feedback to each other, which helps them become aware of their own strengths and improve on their interactions with each other.

The fact that the problem-based learning can effectively facilitate students' proportional reasoning, control variables, and theoretical reasoning skills can be explained for two main reasons. Firstly, in the problem-based learning, the students were encouraged to do scientific process skills, such as formulating hypothesis, posing and defining variables, determining procedures, gathering data, discussing data analysis and drawing a conclusion. All of skills fostered the ability to think, work and behave scientifically as an important aspect to developing science and technology, and to solve problems in everyday life. Secondly, in the presenting artifacts and exhibiting phase of the PBL, students were asked to share their work with others. Consequently, the students were forced to provide rational explanations regarding the results of their work that are inconsistent with other work outcomes. PBL has shown a positive impact on students' abilities to apply basic science knowledge and transfer problem-solving skills in real-world professional or personal situations [12].

However, the students lack of combinatorial reasoning, and probabilistic and correlational reasoning. The possible explanation for the fact was that most of the students still got difficulties to consider all conceivable combinations of tangible or abstract items. The students were unable to interpret observations that show unpredictable variability and recognizing relationships among variables. Therefore, the teacher has to provide intensive guidance to students in their groups and familiarize students to solve problems of combinatorial reasoning, and probabilistic and correlational reasoning.

In the classrooms where problem-based learning model is used, the student learn new knowledge by providing the problems to be solved, so that some attitudes of students, such as problem-solving, thinking, group works, communication, information acquisition and information sharing with others are affected positively by implementation of problem-based learning [13]. Through PBL, the students also could understand the tentative nature of scientific knowledge and the role of creativity implicit in scientific endeavor [14]. PBL is an effective way to help students who work to build basic science skills in various domains or curricular areas [15].

4. Conclusion

PBL is an instructional model that provides real world problems, in which the students are encouraged to use their scientific reasoning skills to solve the problem. Based on the results of this study, the developed instructional package of PBL is declared valid or feasible to use. The PBL support the students to possess functionality and proportional reasoning, control variables, and theoretical reasoning.

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