The Effect of Project-Based Learning in STEM on Students’ Scientific Reasoning

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Abstract. Scientific reasoning is the ability to face competition in the 21st century, so students must have this ability. Project-based learning (PjBL) will train students to improve their scientific reasoning. This study aims to analyze the influence of PjBL in STEM on students’ scientific reasoning on fluid. This research was the quantitative method with the pretest/posttest control group design. The subjects of this study were 66 high school students of grade XI. Instruments for collecting data collection was the written test with a reliability coefficient of 0.87. The results of the study indicate that the scientific reasoning of students who are leaning through PjBL in STEM is higher than that of students who learn through regular learning. In designing the project, students also train to reason scientifically by considering the size of the products that are made to produce a product that can work well. However, the STEM integrated PjBL is still not optimal in improving aspects of probabilistic reasoning and controlling variables.

1. Introduction

Project-based learning (PjBL) is learning to answer the challenges of this century. PjBL engages students in real-world assignments, thus enabling them to acquire knowledge and skills to improve life [1]. PjBL involves the transformation and construction of new knowledge based on students' experiences in learning [2]. PjBL has been widely accepted as an effective approach for students in contextual and authentic learning environments. PjBL engages students in project design so that they can build and improve their scientific reasoning skills [3] [4]. Therefore the PJBL is learning under the demands of this century.

The latest educational development reinforces the need for STEM education. STEM Education facilitates student's scientific and mathematical concepts to solve ill-structured and open problems [5]. The integration of four disciplines, namely: science, technology, engineering, and mathematics into one unit of study, can produce more effective solutions [6] [7]. Thus, STEM education trains students to deal with real-world problems to produce effective solutions.

STEM integrated PjBL is useful for developing real-world problem-solving skills. This learning combines problem-solving abilities, creative thinking skills, and communication skills [5]. Besides, the integration of scientific and engineering practice with the core ideas and crosscutting concept can improve maximally students' learning content as well as their reasoning skills [8]. This instruction can improve the quality of life and can increase their interest and
performance in mathematics and science [3]. Thus, students can increase ownership of professional scientific knowledge so that it is useful for their future careers. Furthermore, the Integration of PjBL and STEM can improve the effectiveness and generate meaningful learning [9].

In solving real-world problems, students need to have scientific reasoning skills. Scientific reasoning is related to thought processes in problem-solving, higher-order thinking skills, and decision making [10], based on relevant information [11]. Students need the ability of scientific reasoning to understand and solve problems [12], so that problem solving becomes effective [13]. Moreover, middle and high school years are the fastest growing period in scientific reasoning skills [8]. The ability of scientific reasoning can help students in making decisions, interpreting evidence, or solving complex problems [14]. One possible approach is to include authentic science crosscutting concepts and core ideas of science [8].

Many researchers have reviewed scientific reasoning. Ding et al. measured students’ scientific reasoning in the natural science domain [15]. Osborne et al. assess students' scientific reasoning using computer-based platforms [16][12]. Germ et al. examines the influence of instructional frameworks on scientific reasoning and student argumentation in Biology [17]. Zhou et al. assessing students’ scientific reasoning through controlling of variables [18]. Hong et al. testing the influence of gender and hypothetic-deductive problem-solving models on students’ scientific reasoning skills [19][20]. In the field of physics education, research on scientific reasoning has been carried out, such as exploring how physics students make evidence-based reasoning and models for electricity and thermodynamics [21][22][23]. However, researchers have not done a study of the training of students’ scientific reasoning on the fluid through the STEM integrated PjBL.

Many researchers have done a study of fluid learning. Loverde et al. developed a module based on the inquiry of buoyancy for prospective teachers [24]. Profiles make multiple-choice diagnostic tests and interview guides [25][26]. Tutorial in Fundamental Physics assists students whose difficulties in identifying the force acting on the fluid and apply Newton's law on the fluid. Developing an assessment of research-based instructional materials designed to overcome the student’s difficulties in the pressure [24]. Development of teaching materials based on the 5E model to correct some mistakes in buoyancy [27]. However, researchers have not assessed the students' scientific reasoning skills in a fluid as a result of STEM integrated PjBL.

Formal learning can affect how students develop scientific reasoning [8]. Regular learning can still be improved to develop scientific reasoning. Therefore, this study examines the STEM integrated PjBL process and its impact on students' scientific reasoning in fluids.

2. Method

2.1. Research design

The research design used was a non-equivalent control group design. The experimental group learned through STEM integrated PjBL, and the control group learned through regular learning for six weeks. Then the two groups did pre and post-test of scientific reasoning at the beginning and end of the treatment.

2.2. Research subject

The subjects of this study were 66 students of class XI of Natural Sciences at SMAN Malang, 33 students as the experimental group, and 33 students as the control group.

2.3. Research instrument

The research instrument was a scientific reasoning test. This scientific reasoning test adopted similar tests developed by Goszewski et al. (2013). This scientific reasoning test consisted of 8 items in four aspects: proportional reasoning, controlling variables, probabilistic reasoning, and correlational reasoning with a reliability coefficient of 0.87.
2.4. Data analysis
The data analysis used the ANCOVA test. This analysis technique was carried out because the prior scientific reasoning influences scientific reasoning skills so that the prior scientific reasoning needs to be controlled as covariables. Also, a student's response be analyzed qualitatively.

2.5 Student activities in STEM Integrated PjBL

| STEM Integrated PjBL                                                                 | Scientific Reasoning         |
|-------------------------------------------------------------------------------------|------------------------------|
| **Phase 1: Start with an essential question**                                        |                              |
| • Students face the problem that the community needs tools that function to increase | Proportional Reasoning       |
|   the speed of water flow at a low cost.                                            |                              |
| • Students watch a video about waterjet free energy                                  | Variable Controlling         |
| • Students discuss the design of waterjet free energy (Science and engineering)      |                              |
| **Phase 2: Design a plan for the project**                                          |                              |
| • Students plan the waterjet free energy project collaboratively; make a design      | Proportional Reasoning       |
|   and choose materials to support the completion of the project                      | Probabilistic reasoning      |
|                                           | Correlational Reasoning      |
| **Phase 3: Create a schedule**                                                      |                              |
| • Students and teachers collaboratively draw up a schedule of events in completing  | Probabilistic reasoning      |
|   the project. Schedule project implementation for one month and set targets for    | Correlational Reasoning      |
|   each meeting.                                                                      |                              |
| **Phase 4: Monitor the students and the progress of the project**                    |                              |
| • Students start working collaboratively                                             |                              |
| **Phase 5: Create the project**                                                     |                              |
| • Students design waterjet free energy (engineering) and determine the tools        | Probabilistic reasoning      |
|   needed to design projects based on knowledge of physics (science)                  | Correlational Reasoning      |
| **Phase 6: Evaluate**                                                               |                              |
| • Students measure the achievement of standards, evaluate the progress of the       | Correlational Reasoning      |
|   waterjet free energy project, provide feedback on the project.                    |                              |
| • Students present and explain the projects they have done (science, technology,    | Variable Controlling        |
|   and engineering)                                                                  |                              |
| • Feedback and improvement of the project                                           |                              |
3. Result and Discussion

3.1. Description of Scientific Reasoning

The scientific reasoning of the two groups shows a different tendency. The average score of the scientific reasoning pretest of the experimental group was 16.25 and 11.71 for the control group. While the average score of scientific reasoning posttest of the experimental group was 77.92 and 45.45 for the control group. These results indicate that from the beginning, the two groups showed that reasoning skills tended to be different. Table 2 shows in detail the students' scientific reasoning skills.

Table 1. Statistics Descriptive of students' pretest and posttest of scientific reasoning.

| Statistics         | PjBL-STEM | Regular |
|--------------------|-----------|---------|
|                    | Pre test  | Post test | Pre test | Post test |
| Number             | 33        | 33       | 33       | 33        |
| Mean               | 16.25     | 77.92    | 11.71    | 45.45     |
| St dev             | 12.99     | 23.51    | 10.17    | 20.57     |

A comparison of each aspect of students' scientific reasoning for the group implementing STEM integrated PjBL with the group implementing regular learning is shown in Table 2.

Table 2. Comparison of aspects of students' scientific reasoning between the PjBL-STEM and Regular instruction

| Aspek Penalaran Ilmiah | Nomor Soal | Rata-rata | Standar Deviasi |
|------------------------|------------|-----------|-----------------|
|                        | PjBL-STEM  | Regular   | PjBL-STEM       | Regular |
| Proportional Reasoning  | 1,2        | 95.6      | 63.8            | 9.94    | 8.18 |
| Controlling Variable   | 3,4        | 79.8      | 54.5            | 22.2    | 19.9 |
| Probabilistic reasoning| 5,6        | 53.9      | 21.2            | 15.9    | 6.08 |
| Correlational Reasoning| 7,8        | 82.3      | 42.3            | 21.6    | 13.3 |

Table 2 shows that the average score of aspects of students' scientific reasoning in the STEM integrated PjBL group is higher than that of the regular group. On the aspect of proportional reasoning, students in the group of STEM integrated PjBL obtain the highest average score, and on the aspect of probabilistic reasoning, students in the regular group obtain the lowest average score. Tables 1 and 2 indicate that the application of the STEM integrated PjBL model affects students' scientific reasoning.

3.2. Hypothesis Testing

An ANCOVA test for the scientific reasoning difference between the experimental group and the control group was carried out with controlling the prior scientific reasoning.

Table 3. Tests of Between-Subjects Effects

| Source             | Type III Sum of Squares | df | Mean Square | F    | Sig. |
|--------------------|-------------------------|----|-------------|------|------|
| Corrected Model    | 19177,140               | 2  | 9588.570    | 1793.061 | .000 |
| Intercept          | 12768,626               | 1  | 12768,626   | 2387.731 | .000 |
| Prior SR           | 1789,616                | 1  | 1789,616    | 334.658 | .000 |
| Treatment          | 9711,177                | 1  | 9711,177    | 1815.989 | .000 |
| Error              | 336,899                 | 63 | 5.348       |       |      |
| Total              | 270651,563              | 66 |             |       |      |
| Corrected Total    | 19514,039               | 65 |             |       |      |

Covariance analysis yields $F = 1815.989$ with $p = 0.000$. Because $p < 0.05$, it can be concluded that the null hypothesis is rejected. The rejection means that the scientific reasoning skills of the
experimental group than that of the control group. After controlled by the prior scientific reasoning skills, the average score of scientific reasoning skills of the experimental group was 75.281, while the control group was 48.090.

The result shows that scientific reasoning skills can develop and increase through training and practice [28]. Student-centered learning through an inquiry process leads to the improvement of scientific reasoning skills [29] [30] [31].

Analysis of student responses shows that two aspects of probabilistic reasoning and controlling variables have not been well developed. This result is because students do not consider all the possibilities to resolve a problem. Students have not systematically considered the functioning of the product. In the context of the task of deductive reasoning, students often fail to consider alternative explanations [32]. In controlling variables, students often test all variables, even though they are not related to problems. Besides, students test the wrong variable or focus on just one variable. Most students do not have the skills needed to handle multi-variate causality [33]. Students understand the meaning of the "dependent" and "independent" variable, but they do not know how to identify the variables in different contexts [34].

3.3. Discussion

STEM integrated PjBL is more successful in influencing students' scientific reasoning than regular learning. STEM integrated PjBL invites students to learn through inquiry, work collaboratively to research, and create projects that reflect students' knowledge [35]. Students can work in teams and acquire skills in synthesizing information, planning, using technology, problem-solving, time management, communication, and producing products. Project water jet that is done allows the interrelationships among knowledge, social contexts, environmental, and financial. STEM integrated PjBL allows the development of scientific reasoning skills [36]. The instruction improves student achievement, authentic problem solving, and scientific reasoning skills [37]. There is a big difference between knowing everything through reading versus having experienced it herself [38]. This difference experience causes STEM integrated PjBL resulting in better students' scientific reasoning than regular learning.

STEM integrated PjBL emphasizes the importance of teamwork and communication between friends when solving complex challenges [38]. That STEM integrated PjBL begin activities with the main questions that help students connect the relevance of the content to be studied with the reasoning skills and solve the main question successfully [39]. Next, students collaborate in groups to build a variety of perspectives from the question. This kind of learning can improve student understanding and higher cognitive skills because it develops knowledge construction and allows students to do science rather than memorizing facts [40]. Ding research confirms these results that the content knowledge and reasoning closely related to each other and constitute mutual evidence of the learning of science [8]. Therefore, this kind of learning develops students’ scientific reasoning and problem-solving skills [41].

The results also showed that students who carried out scientific reasoning had an excellent conceptual understanding of fluids. Conceptual knowledge is an understanding of the essential parts and causal relationships that exist in a system. Being able to reason causally is an essential cognitive skill for physics understanding [42]. Causal reasoning allows students to predict, infer, and explain the encountered phenomena [43]. The results of this study are not excessive because it is in line with Ding's research that content knowledge is closely related to reasoning.

STEM integrated PjBL has succeeded in both developing proportional reasoning aspect and has not yet succeeded in developing aspects of probabilistic reasoning and controlling variables. Related to probabilistic reasoning aspects, students do not consider all the possibilities to resolve a given problem. Whereas related to controlling variables, students have difficulty in choosing the right variable to be tested and solving problems based on the identification of variables [44]. These results consistent with previous studies that science instruction in middle and high school contributes to
improving aspects of proportional reasoning, but less in the development of probabilistic reasoning and control variables.

4. Conclusion
STEM integrated PjBL has succeeded in improving scientific reasoning. This learning trains students to consider various possible solutions for designing projects. In designing the project, students also train to reason scientifically by considering the size of the products that are made to produce a product that can work well. However, the STEM integrated PjBL is still not optimal in improving aspects of probabilistic reasoning and controlling variables. The suggestion is to include an "if-and-then-but-therefore" thinking model to improve probabilistic reasoning and record all the variables involved in the problem to improve the aspect of controlling variables in STEM integrated PjBL.

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