The Effect of STEM Learning through the Project of Designing Boat Model toward Student STEM Literacy

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Abstract. STEM Learning focusses on development of STEM-literate society, the research about implementation of STEM learning to develope students’ STEM literacy is still limited. This study is aimed to examine the effect of implementation STEM learning through the project of designing boat model on students STEM literacy in energy topic. The method of this study was a quasi-experiment with non-randomized pretest-posttest control group design. There were two classes involved, the experiment class used Project Based Learning with STEM approach and control class used Project-Based Learning without STEM approach. A STEM Literacy test instrument was developed to measure students STEM literacy which consists of science literacy, mathematics literacy, and technology-engineering literacy. The analysis showed that there were significant differences on improvement science literacy, mathematics technology-engineering between experiment class and control class with effect size more than 0.8 (large effect). The difference of improvement of STEM literacy between experiment class and control class is caused by the existence of design engineering activity which required students to apply the knowledge from every field of STEM. The challenge that was faced in STEM learning through design engineering activity was how to give the students practice to integrate STEM field in solving the problems. In additional, most of the students gave positive response toward implementation of STEM learning through design boat model project.

1. Introduction
Science integration with other fields in learning has done by some of developed countries by developing STEM (Science, Technology, Engineering and Mathematics) education. The purpose of STEM education is to develop STEM-Literate society, the 21st century STEM education requires students as future citizens to apply knowledge from STEM discipline in real life [1]. STEM literacy as an ability to identify, to apply, and to integrate the concept of science, technology, engineering, and mathematics to innovate, and to solve the complex problems [2]. Those two definitions have the same idea that STEM Literacy is the ability of students in applying knowledge from STEM discipline to solve real-world problems. The integration of STEM in learning can be applied through design engineering activities. Engineering design can increase students’ abilities to solve complex problems [3].

Several studies show that STEM lesson can be reached through Project-Based Learning (PBL). PBL increased engagement, classroom culture and interest in STEM [4], PBL can develop students creativity [5][6][7]. Characteristics of PBL STEM are an ill-defined task and a well-defined outcome.
The students received contextual assignments to solve some problems by integrating the concepts of science, engineering, and mathematics. [10].

Studies on learning that can improve STEM literacy are still limited, some of which focus on improving one aspect of literacy. One study revealed that PBL learning can improve students science literacy on aspects of competence and attitudes, it also gives some recommendation to integrate Project-Based Learning with STEM approach in the lesson [11]. One of the STEM literacy development research proposed STEM literacy can be achieved through Scientific Imagineering through AR which consists of imagining, studying and researching, designing, developing, presenting and evaluating steps. Based on the evaluation of experts, experts strongly agree that Scientific Imagineering through AR can improve STEM literacy [12]. However, this research has not discussed the results of implementation Scientific Imagineering through AR in the learning process and how the achievement of student STEM literacy.

The study on learning to improve STEM Literacy of students needs to be implemented, one of which is by integrating STEM approach in the learning process. Thus, this study tried to investigate the achievement of student STEM literacy through STEM learning. In this study, ill-defined tasks are given to the students by providing the challenge of how to apply the principle energy transformation in the process to make a boat model which move in the fast and stable way by integrating the concept of science, technology, engineering, and mathematics.

Energy concept learning through engineering design activities expect students to apply the concept of energy conversions in designing steam-rubber band powered boat. Concepts of energy conversions and energy conservation laws are applied when students design boats to move faster. Energy can be changed from one form into other forms. Elastic potential energy is the energy stored in elastic materials as the result of their stretching or compressing. Elastic potential energy can be stored in rubber bands. The elastic potential energy (PE) stored in the rubber band is:

$$ PE = \frac{1}{2} k x^2 $$

Where, x is the distance of rubberband stretches from its equilibrium (m) and k is rubberband constant (N/m). In case rubber band powered boat, the value of x influence by the number of winds. The potential energy stored on the rubber band will turn into kinetic energy that can move the boat. The kinetic energy (KE) of rubber band powered boat is given by:

$$ KE = \frac{1}{2} m x v^2 $$

Where, m is mass of boat (kg) and v is velocity (m/s). Based on equations (1), (2) and the law of conservation of energy, it can be concluded that to increase the kinetic energy of the object can be done by increasing the potential energy. Through engineering design activities, students can propose several ways to obtain maximum kinetic energy of the boat. Students can propose many ideas and approaches to solve the problems with more than one possible solution to implement. [13].

2. Methods

2.1. Research Design and Participant

This study is a quasi-experiment study with nonrandomized pretest-posttest control group design [14]. In this study, experiment group was given Project Based Learning treatment with STEM approach and control group was given Project Based Learning treatment without STEM approach. The participants of this study were 8th-grade students in a junior high school in Kuningan- West Java. Fifty-six students were divided into two classes, 28 students in experiment class and 28 students in control class.
2.2. Data Sources and Analysis

The measurement of students STEM literacy used multiple choice problem solving, which consist of science literacy, mathematics literacy, and technology and engineering literacy. The instrument of science and mathematics literacy test was developed based on indicators of science and mathematics literacy assessment which is developed by Programme for International Student Assesment (PISA), whereas instrument of technology and engineering literacy test was developed based on indicators of technology and engineering literacy which is developed by National Assessment Educational Progress (NAEP). The instrument of STEM literacy test was validated by five expert judgements, the data of validation result were analyzed with CVR (Content Validity Ratio) method [15]. The result used CVR method, STEM literacy test shows Instrument Content Validity Ratio was 0.97. The result of instrument reliability which analyzed by SPSS 22 shows that coefficient alpha Cronbach’s was 0.71.

The enhancement of students’ STEM literacy is known by analyzing normalized gain (\(<g>\)) on experimental group and control group [16]. Furthermore, to examine the significant differences of STEM literacy improvement, the data were processed with IBM Statistics SPSS 22 software. In comparing the two groups, effect size Cohens (d) can be computed by subtracting the mean of the second group from the mean of the first group and dividing by pooled standard deviation of both groups[17]. In addition, to get information about students’ respond toward implementation of STEM Project-Based Learning, the researcher gave a questionnaire to the students and analyzed percentage and its interpretation from every statement that was given.

2.3. Experimental and Control Group Treatments

Learning stage of the experimental class used STEM- Project based learning model consisting of reflection, research, discovery, application and communication [18]. These learning steps correspond to engineering design process that include identify the problems, research, ideate, analyse ideas, build, test and refine, and communicate [19]. Both the experimental and control classes are assigned to make steam-rubber band powered boat. The main difference is in the experimental class is redesign activity to get best boat performance. Engineering design activity required students to apply their understanding of science, mathematics and technology in making projects.

| Table 1. Experimental and control group treatments |
|--------------------------------------------------|
| **Experimental Class**                          | **Control Class**                     |
| **Stage 1: Reflection**                         | Students observed toys and tools to understand the concept of energy transformation |
| Students are given the problem: “Can you help Mr. Udin create a boat that can move without rowing and how to design the boat to move quickly?” | Students are given the problem: “Can you help Mr. Udin create a boat that can move without rowing?” |
| **Stage 2: Research**                           | Student searched information from various sources about concepts related to the project |
| Students observed toys and equipments to understand the concept of energy transformation. The students searched information from various sources about concepts related to the project | |
| **Stage 3: Discovery**                          | Students made timeline for the project components |
| Students created sketches of boat designs and analyzed its weaknesses and advantages The students discussed to decide the best boat design | Students created sketch of boat designs |
Stage 4: Application
Students built the boat, tested the boat, troubleshoot malfunction, redesigned boat components to improve boat performance

Stage 5: Communication
Students presented and discussed their experience in making boats in front of the class, teachers provided reinforcement of energy concepts according to the student’s experience

3. Result and Discussion
The data analysis of STEM literacy improvement among the students is classified based on the STEM literacy components, namely: science, technology engineering, and mathematics. The difference of the STEM literacy improvement between the class applying the STEM Project-based learning and the class applying Project-based learning without the STEM approach can be seen in Table 2.

Table 2. STEM literacy improvement in control class and experimental class

| STEM Literacy Components | Experiment Group | Control Group | p-value* | Effect Size |
|-------------------------|------------------|---------------|----------|-------------|
|                         | <g> | Std.Dev | <g> | Std. Dev |             | Cohens (d) |
| Science                 | 0.55 | 0.16 | 0.42 | 0.16 | 0.005 | 0.80 |
| Technology-Engineering  | 0.62 | 0.23 | 0.42 | 0.22 | 0.001 | 0.88 |
| Mathematics             | 0.50 | 0.17 | 0.35 | 0.19 | 0.004 | 0.83 |

*α = 0.05
**p-value<0.05

Table 1 shows that, in general, the STEM literacy improvement among the students in the experimental class is higher than the control class. The mean difference test results indicate that there is a significant difference in STEM literacy improvement between the control class and the experimental class. The highest improvement was achieved in the literacy components of technology-engineering, while the lowest increase was achieved in the literacy component of mathematics. From all components of STEM literacy, PBL-STEM Learning had a large effect (effect size ≥ 0.8).

The improvement in the literacy component of science consisted of students’ ability to explain scientific phenomena as well as interpreted data and evidence scientifically. The class which taught by PBL-STEM was trained to be able to predict scientific phenomena by designing boat activities undertaken at the discovery stage. The challenge the teachers faced in boat designing activities was the lack of students’ knowledge and experience related to project tasks. The activity of design drawing trained students’ scientific imagineering since they had to be able to predict what would happen if they made the design [20]. The process of scientific imagineering was based on prerequisite knowledge (the concept of force, pressure, density), and energy concepts that they obtained at the research stage. The application of the scientific concept in boat design was closely related to the indicator of technology-engineering literacy that i.e. to understand the principles of technology and develop solutions to achieve goals. Figure 1 shows an example of a boat design sketch that students have made.
These findings suggest that engineering design activities that integrate the four STEM components can help students contextualize the principles of science to improve student learning achievement [21][3]. Students need to apply the concept of science, technology-engineering, and mathematics in designing and making products. At each stage of product manufacturing, students conceptualize related science. This experience enables students to build understanding of the relationships between concepts [22]. Engineering design activities in PjBL-STEM learning can help students understand the content of science over a long period of time [23].

The STEM literacy in the literacy components of technology-engineering consists of indicators of understanding the principles of technology and developing solutions to achieve goals. The technology-engineering literacy assessment examines students to be able to propose solutions and alternatives, selecting the right materials and troubleshoot malfunctions. Activities that train students’ technology-engineering literacy are carried out at the application stage. The activity of boat modeling that apply the principle of energy change requires students to be able to think critically and creatively in overcoming any obstacles found in the boat making process. Students should think how to overcome the leakage of steam systems, create larger steam pressures, make steering propellers, and modify other components to improve boat performance. Therefore, students need creativity and critical thinking to develop solutions to achieve goals. This is consistent with previous research stating that PjBL-STEM learning can enhance student creativity, students’ thinking skills, and problem-solving skills [23]. STEM-based learning can encourage students to improve the quality of planned products [24]. Figure 2 shows an example of boat products that students have made.

Figure 1. The example of boat sketch that students have made

Figure 2. Example of boat products: steam-rubber band powered boat

Figure 2 shows an example of student boat products. Students used two energy sources, namely steam power and rubber band power. While testing the boat, the teacher gave some questions to train students in developing solutions.

Teacher : “How do you enlarge the boat energy?”
Student 1: “Rotating the propeller more, and changing the stick propeller with the spoon blade propeller”
Student 2: “I add the amount of rubber, so it has two rubbers for each propeller”
Teacher : “How can you make a boat produce steam quickly and has a high pressure?”
Student 3: “By reducing the amount of water in can and increasing the number of burned candles”
Student 4: “By Minimizing the area steam output”

The answers of student 1 and 2 show that students have applied the concept of energy conservation law. In this case, to obtain maximum kinetic energy, students had to provide maximum potential energy by increasing the number of propeller rotations and increasing the amount of rubber used. Increasing the number of rotation of the blades means increasing the amount of rubber length (x); meanwhile, adding the amount of rubber used means adding the value of the rubber constant (k). it was similar with the student 3 who proposed solutions by increasing the number of candles burned; it meant increasing the amount of heat provided to accelerate the production of steam. Student 4 proposed solutions by minimizing the steam channel. It meant that students have been able to apply concepts related to style and pressure. To produce a large thrust power, great pressure is required. Efforts to increase the pressure is conducted by minimizing the area of the steam channel. Engineering design activities show that in STEM learning, students can propose more than one solutions to make the boat move faster [13]. One of the differences in treatment between the experimental class and the control class was the existence of a boat racing competition conducted at the end of the lesson. This boat racing competition required students to redesign the boat in order to have the best performance. Previous researches have shown that engineering design competitions can improve students’ enthusiasm in learning. The winners of the competition could apply the concept well and design the boat based on their own knowledge and used the strategy to achieve their goals [25].

The research results in the mathematical literacy indicate that there is a significant difference of mathematical literacy between the experimental class and the control class. Some activities of integrating mathematics in boat making are deciding boat shape design, using mathematical equations in managing boat making cost, measuring distance and time, calculating boat speed, and making charts. This result is in accordance with the theory that one of the advantages of PjBL-STEM learning is to improve the learning outcomes of mathematics. [18]. Mathematical literacy is one of the foundations in STEM education; mathematics gives a role to train students in analyzing data and providing explanations based on the available data [21].

Based on the research results described previously, it can be concluded that STEM learning through designing boat project gives a large effect in improving the science literacy, technology-engineering literacy, and mathematical literacy. The obstacle experienced by teachers in applying STEM learning was the lack of readiness of students in boat design activities due to weak knowledge and experience of students related to the project tasks. This led the time required for boat designing activities was longer than the planned time.

Based on the analysis results of students’ responses of STEM PBL, it can be concluded that students were more motivated and interested in learning science after experiencing a boat design learning. Most of the students were enthusiastic in designing activities and making boat model and participating in boat racing competitions. The experience in engineering design activities was new for students; therefore, they need to be trained on how to integrate science, technology, engineering and mathematics in solving problems.

4. Conclusion
Based on the results of the analysis and discussion, STEM learning through the boat designing project that has been implemented has a significant effect on the improvement of students’ STEM literacies in the literacy component of science, mathematics, and technology-engineering. The highest improvement in STEM literacy was obtained in the literacy component of engineering-technology since the students experienced in the engineering design process. Students’ knowledge understanding related to the project task influences the engineering design activities. Therefore, it is important to identify the students’ initial understanding before assigning the project tasks so that teachers can re-emphasize the concepts required for project works. Mostly students show a positive response to the STEM learning that has been implemented; in addition, students were more motivated in learning science.
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