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Implementation of STEM Project-Based Learning (PjBL) student worksheet through the "otok-otok" boat game on engineering thinking skills

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Abstract: Physics learning is a science learning branch that explores and explains natural phenomena. Nevertheless, students still consider physics learning difficult because it has several abstract concepts and mathematics. Also, physics learning is rarely conducted in terms of higher-order thinking processes. This study aims to investigate students' engineering thinking skills using STEM PjBL on the "Otok-Otok" boat game. This type of research is qualitative research with a single case study method. Data were gathered through interviews, observation, and documentation. The data obtained were analyzed using a content analysis method. The results showed that the students' engineering thinking skills were excellent. STEM-PJBL directs students in structuring the engineering thinking skills. Students can solve problems in a structured way, from identifying issues to analyzing alternative solutions to problems. This study is expected as essential information to implement STEM-PJBL for teachers in their physics learning.
Keywords: Engineering thinking; Ethnoscience; Otok-otok boat game; STEM PjBL

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Introduction

Physics learning provides the theory of physics and its application in natural phenomena and human activities. The physics learning process should be carried out interactively, where students not only read, listen, and do the assignments given by the teacher but are also allowed to prove the theory they have learned (Kola, 2014). In reality, physics learning is a subject that some students consider difficult and avoid because it requires perseverance, thoroughness, and much practice (Sultan & Bancong, 2017; Hardiyanti et al., 2018). Students also consider that physics lessons contain much variety in discussing problems and descriptions to find the answer and too many formulas that must be memorized, which causes student saturation in learning (Lacambra, 2016). Another difficulty is that the material is abstract and unrelated to everyday life. Therefore, it is necessary to apply contextual learning so students can more easily understand the material and solve problems contextually.

STEM is a learning approach that is widespread and exciting issue learning in this era. STEM combines four disciplines, namely: science, technology, engineering, and mathematics. STEM is considered proficient in various binding fields of science in the actual world to train students to think from various contexts (Dou & Cian, 2022; Ortiz-Revilla et al., 2021; Razi & Zhou, 2022). Ivanitskaya et al. (2002) stated that multidisciplinary learning could build students' higher-order thinking skills and help them make sense of the relationships among fields of study. STEM implementation is a future revolutionary effort that can positively impact science learning (Kelley & Knowles, 2016). The innovative learning model widely used in the current era is STEM project-based learning (STEM-PjBL).

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The uniqueness of STEM PjBL is an engineering design that emphasizes multidisciplinary learning (Capraro et al., 2013). Lin et al. (2021) posit that STEM-PjBL would develop and explore engineering design thinking skills. Engineering is a complex series of design activities that involve multiple levels of component thinking systems (Berland et al., 2014). Design thinking trains students to solve problems by working in teams, and learning activities can be observed and completed collaboratively (Avcu & Er, 2020). Engineering design thinking also trained students to examine cognitive system issues and processes to solve existing problems (Winarno et al., 2020). Implementing STEM-PjBL can prepare students for higher-level thinking that does not emphasize tests but designing or solving (Capraro et al., 2013; Erdogan et al., 2016; Morgan & Golding, 2010). It also improves students' creativity (Erdogan et al., 2016) and sharpens their critical and creative thinking skills (Ariyatun, 2021).

Ethnoscience learning is an educational breakthrough focusing on collaboration between science and culture in society (Triyanto & Handayani, 2019). Ethnoscience is considered to meet the demands of the 2013 curriculum that contextual learning will make students easier to build knowledge associated with culture in everyday life for meaningful learning (Handayani, 2021; Sudarmin et al., 2019). Applying ethnoscience to science classroom learning will improve student learning activities (Cassin & Ochoa-Tocachi, 2021; Sumarni et al., 2021). One embodiment of the ethnoscience education system is traditional games. Traditional games are of ancestral heritage, and used as entertainment media, whether they use tools or not (Jamalludin et al., 2021; Suryawan, 2018). Traditional games are very diverse in type; one of the traditional games related to physics in principle is the Otok-Otok boat game. The Otok-Otok boat is a boat game with a length of about 20 cm, a width of 5 cm, and a height of 4 cm made of cans. This ship will emit a distinctive sound as a characteristic of the Otok-Otok boat game (Bangsawan, 2019: 64). The Otok-Otok boat game has many physics concepts in its working principle, one of them is thermodynamics (Fatmawati & Ishafit, 2021). The concept of thermodynamics is often encountered in human life (Meli et al., 2022) Ethnoscience can be integrated with STEM-PjBL, which is considered innovative learning that trains students to be skilled in designing projects and applying knowledge (Sumarni et al., 2021). Based on the elaboration, this study aims to investigate students' engineering design thinking by implementing STEM PjBL through the traditional game of the Otok-Otok boat.

Method

This type of research is descriptive qualitative research. Qualitative research data can be pictures, sketches, words, or sentences used to systematically, facts, and accurately describe objects (Johnson & Christensen, 2013). One type of descriptive research is a case study. A case study is a method to investigate and study events or specific issues in more depth and detail (Yin, 2018). The research design used is a single case study because the researcher only focuses on one case: the students' design thinking skills with implementing the STEM PjBL student worksheet of the Otok-Otok boat game.

Qualitative research data were collected through observations, interviews, and documentation. Observations were carried out to observe the overall learning and discussion process. The researchers observed, recorded, and documented the objects observed in videos of activities and transcripts of verbal data on group discussions. Interviews were conducted after the learning activities to find more detailed information about students' activities and participation during the learning process. Furthermore, the data obtained were then analyzed with content analysis. Content analysis is a systematic and objective method that emphasizes written, verbal, or visual communication analysis (Elo & Kyngäs, 2008). A credibility test is used to check the data obtained with the data in the field. The credibility of the data was examined using the triangulation technique. Data triangulation is checking or comparing data for trustworthiness findings (Creswell, 2012). In this study, the triangulation used by the researcher is a triangulation of methods.

Results and Discussion

Engineering thinking is the ability to solve complex problems by making simple solutions by making prototypes or designs as core learning. Engineering thinking in this research includes thinking systematically, finding problems, visualizing, improving, solving problems creatively, and testing the final stage (adaptation) (Lucas & Hanson, 2016).

Systematic Thinking

The results of research on indicators of systematic thinking show that students can define problems well and systematically. In this indicator, there are three questions, namely: defining the problem, defining the cause, and defining the solution required by the client. The following are student opinions that lead to engineering thinking on indicators of systematic thinking of defining the problem.

> "… the case of the Yunicee motorboat accident and the sinking of the steamship Sultana." (Discussion, K1, G1).

> "…About the sinking of the ship." (Interview, K4, V4).

The second question is to define why the problem occurs. Opinions from participants with answers that lead to the category of engineering thinking are as follows.

> "... the passenger motor ship is because there was a big storm surge, in my opinion, the sultana is more accurate because there was a boiler explosion." (Discussion, K1, P1).

> "…the shipbuilding material is not good enough." (Discussion, K4, C4).

The third question is to define the solution to the problem. The results of the discussion with several students that lead to the resolution of the issue are as follows.

> "A client who asked an engineer to make a miniature ship so that the company knows how good quality the ship should be." (Discussion, K2, F2).

> "The client wants a miniature steamer to be made with a budget of less than IDR 100,000." (Interview, K4, V4).

Based on the description, the results show that students can think systematically in analyzing a problem. Students show a good pattern of systematic thinking because they can connect the three issues of defining the problem, the cause, and the solution. They understand the linkage of each. Systems thinking is a coherent pattern according to the steps and the relation. Even with a different delivery, all the answers are correct and follow the client's problems. In other words, students are flexible in understanding a problem if they can solve problems with diverse and logically precise answers.

Thinking systematically in problem-solving positively impacts engineering thinking and trains students to solve problems like engineers. An engineer will face a complex problem that must be solved by designing and then making a solution with structured steps. Jafer (2020) posits that complex and challenging tasks or problem-solving will involve students acting like engineers in investigating, making decisions, and designing a project. In short, complex problem-solving activities will provide opportunities for students to design and produce work.

Problem Finding

The second indicator of engineering thinking is finding problems. This indicator directs students to solve problems using physics concepts. The results of the group's discussion will be described as follows.

> "... the KMP. It is because there was a big storm surge. Thermodynamics is about heat, steamships are also affected by heat. So both theorize heat." (Interview, K1, G1).

> "... Judging from the formula $U = Q + W$, so there is the heat of combustion plus the work of the water that pushes out of the exhaust when it is out, it appears as kinetic energy." (Discussion, K3, T3).

In addition, students are also asked to describe the concepts of technology, engineering, and mathematics. The answers for each group are as follows.

"Technology is like equipment for making ships, such as pliers and scissors. The technique is how to make a ship. While mathematics calculates the budget to buy tools and materials." (Interview, K1, G1).

"I do not understand the technology, but it is related to the technical steps to make a ship. For mathematics, that is about the budget for tools and materials." (Interview, K4, V4).

The results showed that students understand and relate the concept to the studied physics of thermodynamics. The information obtained initially includes definitions, theories, and examples of its application in everyday life. The student develops the information obtained to associate with the problems and solutions that are planned or designed. In other words, conceptual understanding will be more meaningful if it is studied from general to specific, and students can relate to the concepts obtained. The concepts obtained are associated with the solution made in general or detail in part of the prototype. A good understanding of concepts will help students in engineering thinking. Students will consider each component in making a prototype of the Otok-Otok boat. The scientific information found will be more meaningful because it is applied directly to the solution. Concept understanding is the ability of students not only to understand the material but also to re-express and apply concepts according to their cognitive structure. Scientific investigation of information or concepts will provide information to students before the engineering design stage in solving problems (Chizek et al., 2018).

Visualizing

After defining the problem, causes, and solutions and knowing the relevant physics concepts, the following indicator of engineering thinking is visualizing. The meaning of visualizing is to create or describe the design of the chosen solution. The results of the group's discussion will be described as follows.

"… the forepart must be sharp to light the criteria for a fast-moving ship." (Discussion, K1, N1).

"Um.. if it is connected to the concept of first thermodynamics Law, the movement of the ship is influenced by the work. The exhaust can be made a little longer so that the pressure is maximum later." (Discussion, K2, H2).

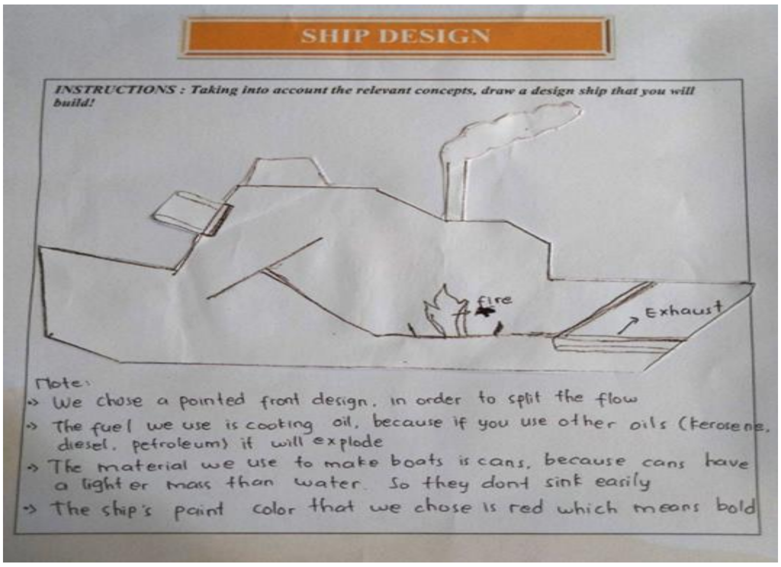
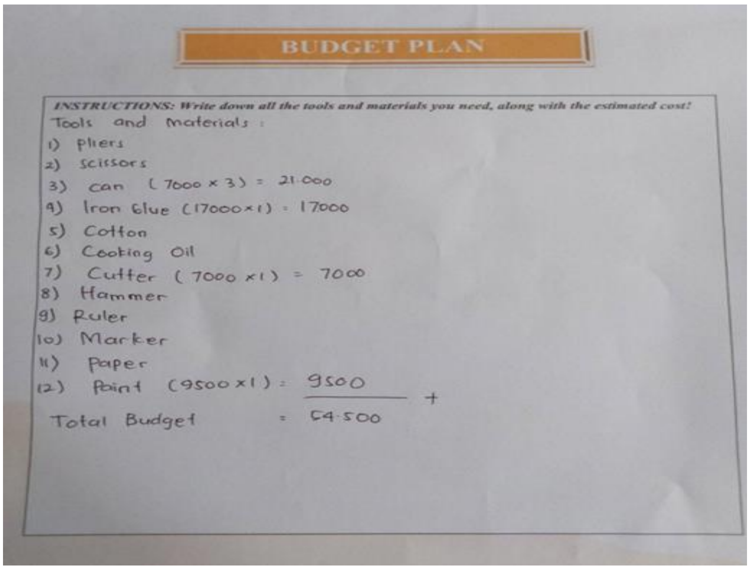


Figure 1. Example of Student Answer Design

In visualization, each group of student design the solution. Figure 1 is an example of the students' design of the Otok-Otok boat. The design of the Otok-Otok was carefully thought out, starting from the selection of materials accompanied by an explanation of physics concepts. For example, the boat's shape had to be sharp because it could split the waves quickly. In addition, students recognized the manufacture of exhaust and boilers as the main components in steamships related to the laws of thermodynamics. This indicates that the design process is not just about design but also scientific inquiry and theories. The existence of a design process to produce work will make students more creative and enthusiastic (Williams et al., 2004). The design results will be more diverse, seen in each group's different forms of design and thinking.



BUDGET PLAN

INSTRUCTIONS: Write down all the tools and materials you need, along with the estimated cost!

Tools and materials :
1) Pliers
2) Scissors
3) can (7000 × 3) = 21.000
4) Iron Glue (17000×1) = 17000
5) Cotton
6) Cooking Oil
7) Cutter (7000 ×1) = 7000
8) Hammer
9) Ruler
10) Marker
11) Paper
12) Paint (9500×1) = 9500 +

Total Budget = 54.500

Figure 2. Example of Student Answer Budget Plan

Furthermore, students try the estimated costs required and do not exceed the budget limit. However, one group provides the most significant budget due to the purchase of glue to deal with leaks (Figure 2). The cost consideration process is necessary because it constructs students' abilities with mathematics to calculate the expenses needed to achieve solution effectiveness.

Improving

Furthermore, the following indicators are improving. Improving is about applying the design in a final prototype. Each group made an Otok-Otok boat project according to the design. The results showed that students could make prototypes well. The manufacture of the Otok-Otok boat consists of three essential parts of the boat's hull, the boat's exhaust which is integrated with the boiler, and the top cover of the Otok-Otok boat. Figure 3 is an example of students' prototypes of the Otok-otok boat.

Figure 3. Example of Initial Trial of the Prototype of the Otok-otok Boat

However, after being tested, all groups failed to make the Otok-Otok prototype move well and produce sound. The average problem for each group was that the boat had a leak at the exhaust and boiler, which caused the ship not to run well. For this reason, all groups decided to re-discuss the problems and find solutions to overcome and find the cause of the problem. The trial was conducted to evaluate whether the prototype could solve problems according to the client's wishes. Designing and manufacturing of engineering design activities integrated with repairs (Nuraeni & Zahra, 2021).

"Of course, it has not been effective because it has not appropriate the client's criteria. Needs to be fixed to make it run and sound." (Discussion, K3, E3).

"What is certain is that it is not effective because it has not been able to operate properly. It needs repairs on the leaking part." (Discussion, K4, M4).

Creative Problem Solving

In this study, there were failures at the initial trial stage, so students needed to think creatively and critically about the best solutions to these problems. Each group decided to dismantle the original exhaust from the Otok-Otok boat, which would then install on the boat body that had been created (Figure 4). In the original Otok-Otok boat building video, it appears that the exhaust and boiler are made separately from the hull, so students know how to remove the exhaust and boiler and attach it to the hull. Students seemed to choose an alternative solution when observed from the process. This certainly makes students think about solutions or improvements that must cause. The results on students' thinking in solving problems are as follows.

"By replacing artificial boilers with original boilers, because the manufacture of the boiler itself is prone to leaks." (Discussion, K2, H2).

"Redesigned then replaced the original exhaust." (Interview, K3, T3).

Figure 4. Otok-Otok Boat Original Exhaust and Boiler

Students get the stimulus and analysis process on the original Otok-Otok boat-making video. It stimulates students' ideas and creative thinking by duplicating and replacing the original exhaust of the Otok-Otok boat. Creative ideas can appear accidentally, but the idea has undergone a different process. Saeed and Ramdane (2022) posit that creativity can be shown by making something new and unique or combining old and new components. Creative problem-solving is needed in engineering thinking because it trains students to solve problems with diverse alternative solutions.

Adapting

After students improve the prototype, the final stage is to retest whether the chosen solution is in the early-stage trial (figure 5). The differences between the problematic and the chosen solution were analyzed in this process.

Figure 5. Example of final Trial the Prototype

Students' answers varied greatly from the manufacturing process, tools and materials used. They investigated the complex parts of the boat (position of the exhaust and boiler), analyzed the problem, and looked for alternative solutions. The higher-order thinking skills include investigating, analyzing, and adapting the solution. The ability to analyze and adapt is the skill that an engineer must have to assess the effectiveness of the chosen solution. In other words, engineers should investigate and find alternative solutions when facing problems and challenges. Engineers must solve problems with various techniques using either a direct solution or many other alternative solutions (Nusyirwan et al., 2020). The following is an example of students' responses to adapting indicators.

> "… the boiler has a tiny vacuum. While ours, the Otok-Otok prototype, is big. Maybe that is why the boat does not produce a sound because the pressure is so high that the boiler cannot move when it's pressed" (Discussion, K2, S2).
>
> "The exhaust winding is not neat if the original one is in the form of an exhaust tube. The glue is also not much. Then the room in the boiler is too small, and the exhaust we put it not curved, so the water is easily wasted and does not heat." (Interview, K_3, SR).

Conclusion

Based on the results and discussion above, it can be concluded that STEM project-based learning positively impacts students' engineering thinking. Engineering thinking skills directed students to solve complex problems by identifying and analyzing, linking existing issues to the causes and solutions, analyzing appropriate scientific concepts, designing, making prototypes, and testing and analyzing selected alternative solutions. It also conducted students completing tasks in a structured manner. Engineering thinking is a higher-order thinking skill that should train in physics learning. This study is expected as basic information for physics teachers that traditional games can be used as an exciting topic when implementing STEM project-based learning.

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