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Exploring Students' Engineering Thinking Skills Through STEM Project-Based Learning in *Jukung* Boat Design Equilibrium Concept

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ABSTRACT

Engineering thinking is one of the 21st-century skills because it emphasizes problem-solving through prototyping as a solution to problems. However, facts in school learning show that students have difficulty in several aspects of engineering thinking, such as dealing with complex problems and generating innovative solution ideas. STEM-PjBL learning can be used to develop students' 21st-century skills, one of which is engineering thinking skills. STEM-PjBL can also be integrated with regional local wisdom to preserve the fading local wisdom of the region. This research aims to explore students' engineering thinking skills through STEM-PjBL on jukung boats. This type of research is a case study with a qualitative approach. The data sources in this study are observation sheets of engineering thinking skills, interviews, and documentation of students' worksheet. This research explores engineering thinking skills consisting of 6 indicators, namely system-thinking, problem-finding, visualizing, improving, creative problem-solving, and adapting. The results showed that the majority of students showed poor performance in the system-thinking and problem-finding indicators. While some students showed very good at visualizing and improving indicators. Furthermore, some students showed good at the creative problem-solving indicator. In the last indicator, the majority of students showed good adapting. Based on the study's results, the conclusion is that through PjBL integrated STEM learning, students' engineering thinking skills show good on visualizing, improving, creative problem-solving and adapting indicators. While the majority of students showed poor performance on system-thinking and problem-finding indicators.

INTRODUCTION

The era of revolution 4.0 brings new changes that 21st-century skills are needed to be possessed by students to face challenges and career success in the future (Baran et al., 2021; Capraro et al., 2013). 21st-century skills require students to master various skills such as critical thinking, problem solving, collaboration, building communication, as well as creativity and good use of technology (Baran et al., 2021). Engineering thinking is one of the 21st-century skills because this skill emphasizes analysis and problem-solving through prototyping as a problem solution (Angelina et al., 2023).

The STEM approach is an approach to learning that integrates science, technology, engineering, and mathematics and is globally recognized as one of the learning approaches that prepares students for the demands of 21st-century skills (Rusmana et al., 2021; Sartika et al., 2022). The integration of the project-based learning (PjBL) model with the STEM approach makes learning more effective because students can develop 21st-century skills such as technology, communication, and problem-solving skills (Capraro et al., 2013; Azis et al., 2023). Project-based learning through STEM directs students to think engineering, such as solving problems, connecting problems, causes, and solutions, analyzing scientific concepts, designing, prototyping, and testing alternative solutions, and completing tasks systematically (Angelina et al., 2023).

Engineering thinking skills linked through the STEM approach can train students in analyzing problems, evaluating, and making things based on creative ideas as problem-solving solutions and collaborating (Ulum et al., 2021; Rohma et al., 2024). However, facts in the field show that learning in schools has not emphasized the application of STEM, so that many students do not gain meaningful understanding in supporting students' engineering thinking skills (Fan & Yu, 2017).

Engineering thinking has several aspects, namely system-thinking, problem-finding, visualizing, improving, creative problem-solving, and adapting (Lucas & Hanson, 2016). But in fact, students have difficulty in connecting knowledge concepts with real-life applications, which are aspects of system-thinking (Aini et al., 2018). Research by Azizah et al (2015) and Himmah et al (2021) shows that in the problem-finding aspect, students have difficulty dealing with complex problems and have not maximized in producing various innovative solutions based on the problems given. In addition, in the creative problem-solving aspect, students have difficulty explaining the creative ideas obtained (Himmah et al., 2021). Based on these data, it can be concluded that students experience problems in several aspects of engineering thinking.

Local wisdom is an element of tradition that comes from the culture of local communities in a nation and becomes a regional characteristic that needs to be preserved (Sumarni & Kadarwati, 2020). According to Rumiati et al (2021), local wisdom at this time is slowly fading and has the potential to disappear along with the times and technology. The government's effort to preserve regional local wisdom is to implement it in learning through the curriculum (Sriyati et al., 2023). Local wisdom can be integrated with physics learning at school because local wisdom contains many local cultural heritages that contain physics concepts and can be analyzed (Rumiati et al., 2021). One of the local wisdoms that can be integrated into physics learning is the *jukung* boat. *Jukung* boats are boats that are widely used by the Puger community to catch fish at sea and have a simple size that is relatively small, only enough to accommodate 1 or 2 adults (Sa’diyah et al., 2023; Widodo et al., 2023). The characteristic of a *jukung* boat is that it is made of wood and has *cadik* consisting of two *katir* on the left and right sides of the boat and is connected by two bamboos (Putri, 2018).

The learning approach that integrates science in local wisdom, technology, engineering, and mathematics is Etno STEM (Sartika et al., 2022). The local wisdom of the Puger community in the form of *jukung* boats contains STEM content such as equilibrium content on *jukung* boats that can be connected to science and math concepts. Based on the description of the problems and urgency, this research examines the implementation of physics learning through project-based learning integrated with STEM based on local wisdom in an effort to prepare a generation that has 21st century skills, one of which is engineering thinking skills and preserve the local culture of the region.

RESEARCH METHOD

This research was conducted on 8 students who were divided into two groups. Determination of research subjects was carried out using a purposive sampling technique. The consideration of determining the subject of this research is that students in the class know about *jukung* boats, but do not understand the STEM concept of *jukung* boats. This research uses a qualitative approach with a case study research type. Case study according to Yin (2018) is a method used to investigate and understand a particular event or problem in detail and in depth. The case study design, according to Yin (2018) consists of six parts, namely plan, design, prepare, collect, analyze, and share. Illustration of case study research design according to Yin (2018) can be seen in Figure 1.

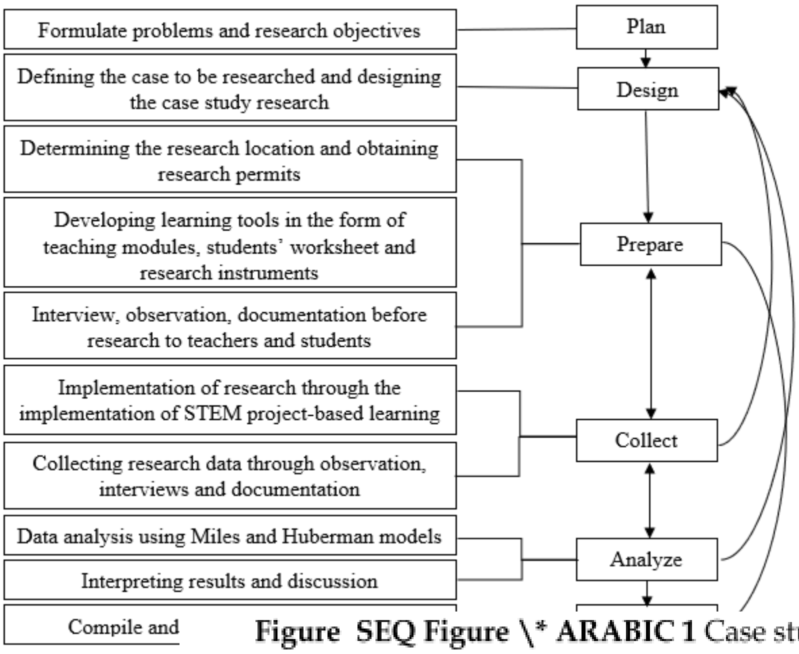

Figure SEQ Figure * ARABIC 1 Case study chart

Data collection techniques in this study included observation of engineering thinking skills, interviews, and student worksheet documentation. Data analysis in this study used the Miles and Huberman model, which consists of four stages, namely: data collection, data reduction, data presentation, and conclusion.

RESULTS AND DISCUSSION

Data on the results of engineering thinking skills research in the form of student worksheet results data through STEM-PjBL learning are shown in Table 1.

Table 1. Data from student worksheet assessment results per group.

Engineering Thinking Skills Indicator	Total Number of Groups (%)			
	Very Less	***Less***	***Good***	***Very Good***
System-thinking	-	75	-	25
Problem-finding	-	67	33	-
Visualizing	-	50	-	50
Improving	-	-	50	50
Creative problem-solving	50	-	50	-
Adapting	-	35	67	-

System-thinking

Based on the data in Table 1, it shows that in the system-thinking indicator, 75% of students are not good at understanding the whole context of the problem and connecting it, while 25% of students are very good at it. The following are quotes that show less understanding of the overall context of the problem:

"Unpredictable weather" (Discussion K1.AKP)

"Large waves that make the ship unbalanced" (Discussion K2.AA)

The quote shows a less systematic thinking process because students only analyze part of the problem content contained in the *jukung* boat, namely the big waves that make the ship unbalanced, and the uncertain weather changes. The problems analyzed by students are only some aspects of the problems on the *jukung* boat, but the complex problems on the *jukung* boat, such as the community aspect and boat construction, have not appeared in the students' way of thinking.

Furthermore, 25% of students showed excellent system-thinking. Here is an example of a quote that shows excellent system-thinking:

> "On the *jukung* boat, there is a *katir*. The *katir* is to balance the boat so that it is not hit by the current. ... the technology is that the material from the *jukung* boat can use fiberglass. Engineering is just the steps of the miniature *jukung* boat, the steps of the miniature *jukung* boat design. The math is in the materials" (Discussion K1.NFR)

The quote shows excellent systematic thinking because students can see the overall STEM content in the learning and can connect it to the *jukung* boat systematically. Students can analyze the entire science, technology, engineering and mathematics content and connect it to the *jukung* boat.

System-thinking is a thought process in analyzing a content thoroughly, connecting related content to create a pattern (Angelina et al., 2023). In the implementation of project-based STEM learning, the majority of students are not good at thinking systematically in dealing with a problem. The implementation of STEM-PjBL in this study was carried out according to the stages of STEM-PjBL. However, based on the results of observations and video documentation, it shows that students lack discussion with their groups when facing problems. The observation showed that in one group consisting of 4-5 students, only 1-2 students actively discussed giving ideas to solve the problem so that the majority of students' system-thinking was not good. Discussion between students plays an important role in encouraging students to share ideas with each other, so that this makes the ideas obtained by students broader and more varied to solve problems (Purwanti & Kusumawati, 2021).

Problem-finding

The next indicator of engineering thinking skills is problem finding. This indicator emphasizes students' skills in analyzing problems and collecting problem-solving ideas, checking and verifying the solution ideas. The research results in Table 1 show that 67% of students are not good at analyzing problems and collecting problem-solving ideas, while 33% of students are good at it. The following is an example of a student quote that shows less performance in analyzing case study problems and collecting problem-solving ideas:

> "Sea accident when a *jukung* boat capsized after being hit by waves" (Discussion K1.AHS)
>
> "Provide an engineer who can help *jukung* fishermen design boats to minimize accidents." (Discussion K2.AA)

The quote shows a poor problem-finding indicator because the students answered that the problem with the *jukung* boat was a sea accident where the *jukung* boat capsized in the waves without analyzing the cause of the problem. The problem solution obtained by the majority of students to overcome the problem is to provide an engineer who can help fishermen in designing *jukung* boats to minimize accidents. This shows that students are not good at the aspect of collecting problem-solving ideas because students provide solutions without identifying the problems that must be overcome besides that, students also do not verify the solution ideas used to solve problems.

Furthermore, 33% of students are classified as good at analyzing problems and providing solution ideas to overcome problems. The following is an example of a student quote that shows good at analyzing problems and providing solution ideas to overcome problems:

> "There are many marine accidents. For example, a *jukung* boat capsized after being hit by a 2m wave, and a *jukung* boat accident due to a broken *katir* section after being hit by a large wave" (Discussion K2.AA)
>
> "The solution to marine accidents that befall Puger fishermen requires an engineer who can help *jukung* fishermen in making *jukung* boat designs to minimize accidents." (Discussion K1.AKP)

The quote shows that the students' problem-finding indicator is good because the students can analyze the problems and causes of the *jukung* boat. The problem of *jukung* boats in the case study that students analyzed was the number of sea accidents. The cause of the *jukung* boat accident problem is due to the broken part of the *katir* because which was hit by the waves. Students also identify problems that must be overcome by providing solution ideas and verifying these solution ideas. Students understand that the problem that must be overcome is the number of accidents, so the solution is to require an engineer to assist fishermen in making precise boat designs.

Problem-finding is an indicator of engineering thinking skills that emphasizes students in identifying the main problem and its causes and finding solutions to overcome these problems (Rohma et al., 2024). The results showed that through project-based STEM learning, the majority of students are not good at analyzing problems and their causes, and obtaining solutions to overcome these problems. One of the factors causing students to do poorly on the problem-finding indicator is the lack of discussion between groups, as mentioned in the system-thinking indicator. Another factor is that, based on the results of video documentation and observation, it shows that students do not verify ideas to get the best solution. The discussion process makes students exchange ideas so that many new ideas emerge from various points of view to assess the advantages and disadvantages of each idea in determining the best solution (Handayani et al., 2024)

Visualizing

The next indicator is visualizing. This indicator emphasizes students' skills in visualizing abstract things into reality and can manipulate materials and try to make designs more practical. The research results in Table 1 show that some students (50%) are outstanding in the aspect of manipulating materials and some other students (50%) are less at visualizing abstract things into reality through design. The following are the results of student quotes that show excellence in the aspect of manipulating materials:

> "The thin ice cream sticks cost Rp.7000. Burning glue costs Rp.2000, three makes Rp.6000. Scissors 0 Rupiah" (Discussion K1.AHS)
>
> "Ruler" (Discussion K1.NFR)
>
> "Cutter, glue" (Discussion K2.ZM)
>
> "The G glue is Rp.5000, the ice cream sticks are Rp.7000" (Discussion K2.YF)

The quote shows that students are very good at manipulating the materials used in making products because students can mention simple tools and materials used for making miniature *jukung* boat products. In addition, students also consider the cost of making products by choosing tools and materials that are cheap, simple and easy to obtain. The biggest cost for students in the project manufacturing process is Rp27,000. Cost consideration in product manufacturing is an important aspect because it trains students to apply mathematical concepts to calculate the budget and efficiency of product manufacturing costs (Hardani & Thoyibah, 2021)

Furthermore, some students (50%) showed less visualizing indicators in the aspect of visualizing abstract things into reality through design. The following are examples of quotations and the results of student product designs:

> "Google it. Look for the one with the satin. ...but there's no satin." (Discussion K1.AKP)
>
> "Search the internet. Look for the one with the *katir*. ...but there's no *katir*" (Discussion K1.AKP)

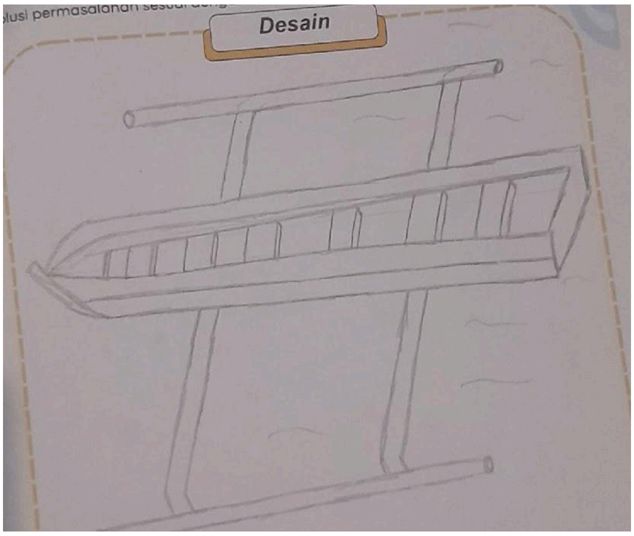

Figure SEQ Figure * ARABIC 2 Group 1 Miniature *Jukung* Boat Design Example

The quotation and Figure 2 show that students are not good at visualizing solution ideas into designs because the solution ideas given are not in accordance with the boat design. In addition, the *jukung* boat design drawn by students is not clear because there are no precise measurements of boat parts and descriptions of boat parts as a design for making miniature *jukung* boats. So this increases the risk of product failure due to design drawings that lack precision and size. This contradicts the research of Angelina et al (2023) which states that students are said to be good at visualizing if students can design problem solution designs in detail and precision.

Improving

The next indicator of engineering thinking skills is improving. This indicator emphasizes students' skills in improving projects through designing, sketching and prototyping. In the improving indicator, students applied the design by making a miniature *jukung* boat product. The miniature *jukung* boat that has been made is then tested to identify the obstacles contained in the miniature *jukung* boat. The following is an example of a quote that leads to the aspect of analyzing the constraints of a miniature *jukung* boat product:

"One-sided, leaky" (Discussion K1.AHS)

"The first test run was balanced but there were holes in the miniature boat" (Interview K1.AA_{18})

Figure SEQ Figure * ARABIC 3 (a) Example of a prototype *jukung* boat (b) First trial of a *jukung* boat

The quote and Figure 3 show that students applied the *jukung* boat design into a prototype *jukung* boat and analyzed the constraints found in the prototype *jukung* boat. The majority of students identified the obstacles experienced during the first trial as leaking *jukung* boats and unbalanced *jukung* boats.

In the improving indicator, after students analyze the obstacles found in the *jukung* boat product, they then repair these obstacles. Table 1 shows that some students (50%) are very good at improving the project after identifying the constraints found in the product through trials. The following are examples of quotes and interviews that show students are very good at improving the constraints found in miniature *jukung* boat products:

"… this must be glued" (Discussion K2.AA)

"By patching between the holes so that water cannot enter the ship so that the ship can balance well in the water" (Interview K2.AA_{16})

The quotes and interviews show that students are very good at fixing the problems found in the *jukung* boat product because students are able to fix all aspects that experience problems in the product. The obstacle experienced by students is that there is a leak in the *jukung* boat product. The solution chosen by students to fix the problem is to patch between the holes using glue. This shows very well on the improving indicator because students can improve all aspects that experience problems in their products.

Creative problem-solving

The next indicator is creative problem-solving. This indicator emphasizes students' skills in applying knowledge, generating ideas and solutions through collaboration and providing constructive criticism. Table 1 shows that some students (50%) are good at applying knowledge as one aspect of the creative problem-solving indicator. The following are examples of quotes and interviews that show students are good at applying knowledge:

> "The first equilibrium condition is that the amount of gravity and normal force is zero. Second, the torque of the right and left outriggers is the same, the total torque is zero. The *jukung* boat that has been made meets the requirements of the concept of equilibrium" (Discussion K1.AKP)
>
> "The equilibrium conditions of gravity and normal force are equal to zero, downward is equal to upward. The right and left outrigger torques total zero" (Interview K1.AHS17).

The results of the quotations and interviews show that students are good at applying knowledge to the miniature *jukung* boat products that have been made because students can analyze the physics concepts contained in the *jukung* boat, namely the concept of *jukung* boat equilibrium. Students can analyze the forces acting on the *jukung* boat, namely gravity and normal force, torque on the right and left outriggers of the *jukung* boat and the position of the *jukung* boat to achieve equilibrium conditions based on equilibrium conditions. The application of science and mathematics concepts through engineering design learning in STEM can help train students' thinking processes in solving problems, besides that, students are also able to analyze the torque and forces found on the *jukung* boat (Rusmana et al., 2021).

Adapting

The last engineering thinking skills indicator is adapting. This indicator emphasizes students' skills in testing products, analyzing, reflecting, and re-designing. The results of Table 1 show that 67% of students are good at testing, analyzing, and reflecting on the *jukung* boat products that have been made. The *jukung* boat product trial was conducted twice. The first trial was conducted on the improving indicator. The last trial was conducted when students had analyzed the results of the first trial and corrected the obstacles found in the miniature *jukung* boat during the first trial. The following are examples of quotes and interviews on the first trial results that show students are good at testing and analyzing products during the final trial:

> "It's float and very sturdy. But the *katir* is tilted" (Discussion K2.HP)
>
> "The results of the final trial are pretty good because it doesn't leak anymore but it's not balanced" (Interview K1.AHS$_{18}$)

(a) (b)

Figure SEQ Figure * ARABIC 4 (a) The first trial result of the *jukung* boat
(b) The final trial result of the *jukung* boat

The quotes, interviews and Figure 4 show that students are good at testing, analyzing and improving products because students can analyze the constraints during the first trial and try to improve so that the product becomes better. The obstacles experienced by the majority of students during the first trial were leaking and unbalanced *jukung* boats. The solution that students chose to overcome these obstacles was to glue the leaking parts of the boat. Final product trial was conducted to determine the effectiveness of the product and the success of the solution used by students to overcome obstacles. used by students to overcome obstacles (Febriansari et al., 2022). The final product trial was conducted to determine the effectiveness of the product and the success of the solutions used by students to overcome obstacles. The results of the final trial showed that the repaired *jukung* boat did not leak and could firmly float in the water. This shows that students are able to fix the obstacles found in the first trial, namely the leaky boat so that water enters the *jukung* boat through gluing on the leaking part.

CONCLUSION

Based on the results and discussion that have been described, the conclusion obtained is that students' engineering thinking skills through PjBL-integrated STEM learning on system-thinking and problem-finding indicators are mostly poor. Some students show very good on visualizing and improving indicators. In the creative problem-solving indicator, most students showed good and in the adapting indicator, the majority of students showed good. The results of data analysis show that the majority of students are still not good at thinking systematically in dealing with a problem, analyzing problems and their causes, providing problem solutions. However, some students are very good at visualizing solutions in real forms such as product designs and analyzing the constraints on *jukung* boats and obtaining solutions to improve these constraints. Some students also did well in analyzing physics concepts, namely the concept of equilibrium. In addition, the majority of students were also very good in the final trial of the product and reflecting on it.

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