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Exploration of Students' Engineering Thinking Skills Through STEM Integrated PjBL Model Design Water Rocket Momentum Material

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Abstract

The research aims to analyse the engineering thinking skills of students by integrating the PjBL model with STEM water rocket design on momentum materials. This research is an experimental study. The design of this study was qualitative research. There are three stages to the research stage: preparation, implementation, and the final stage. The researchers collected data through observation, interviews, posttests, and documentaries. The focus of this study is on students' engineering thinking skills. The researchers interactively analyse the collected data during the phases of data collection, reduction, presentation, and conclusion. Additionally, the researchers conducted data credibility tests using triangulation techniques to assess the appropriateness of the research data. The research results predominantly classify the six indicators of engineering thinking as very good. Based on the findings and deductions, it is concluded that most students' engineering thinking abilities, when combined with the PjBL model and STEM water rocket design material, score highly on the six indicators of creative problem-solving. Students in this study experienced new knowledge and learning experiences that enabled them to solve daily problems by applying engineering thinking skills and physics concepts.

Keywords: engineering thinking skills; momentum; PjBL integrated STEM; water rocket

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INTRODUCTION

According to Hiew & Cheah (2022) and Kolb (2014), learning that engages students with the world's data and tools keeps students actively involved in solving meaningful problems. The 21st-century learning does not rely on the ability of knowledge but also skills. The role of teachers is very decisive in developing the hard and soft skills of students in schools so that they have 4C skills (critical thinking, communication, creative thinking, and collaboration). Teachers can design learning to cultivate 4C skills using a STEM approach

(Ananda & Johari, 2024; Maulana, 2022; Yulianti et al., 2022). Through the STEM approach, students are facilitated and guided for self-development in creativity and product innovation. Merging STEM fields in the physics learning process is very possible (Hartini et al., 2020; Ridha et al., 2022; Saputri et al., 2023).

The STEM approach is beneficial to human life because it can show students how science, technology, engineering and math concepts, principles, and techniques are integrated to develop living products, processes and systems (Baharin et al., 2018; National, 2011;



Yusuf & Asrifan, 2020). Students with STEM will be facilitated and guided for self-development in creativity and product innovation. One of the project-related skills is Engineering Design Thinking (EDT) skills (Taleyarkhan et al., 2018; Waks et al., 2011). The relationship between EDT and STEM trains students in problem-solving, thought processes, creation, and collaboration. One of the activities to foster EDT's ability in physics is to design a water rocket, with students discussing the shape of the rocket and the things that affect the work of the rocket related to the application of momentum material. The application of momentum occurs in the event of the working principle of the water rocket. Physics learning activities that foster students' engineering thinking skills through an integrated PjBL model, STEM, water rocket design, momentum material, water rocket design, water rocket design, and water rocket design. Based on Azis et al., (2023) and Lin et al., (2021) research studies, STEM PjBL is able to hone students' 21st century abilities and skills. Students can explore themselves in the course. This study emphasises analysing students' engineering thinking skills through the PjBL model integrated

STEM design water rocket momentum material.

METHOD

The type of research used is qualitative research. The research was carried out with 33 students divided into six groups. Sampling using the *purposive sampling* method by considering physics teachers (Cresweel, 2015).

There are three stages of research procedures, namely preparation, implementation, and the final stage. The implementation stage is implementing the STEM-integrated PjBL model by designing water rockets on momentum materials. The final stage of this research is to analyse data based on *posttest* results to present results and discussion.

This research obtained data through observation, interviews, and documentation. In this study, the interactive method data analysis techniques proposed by Miles and Huberman consist of four stages: data collection, data reduction, data presentation, and conclusion. Interactive method analysis flow Rijali (2018) can be seen in Figure 1. A Likert scale was used to analyse the categorisation of students' engineering thinking skills.

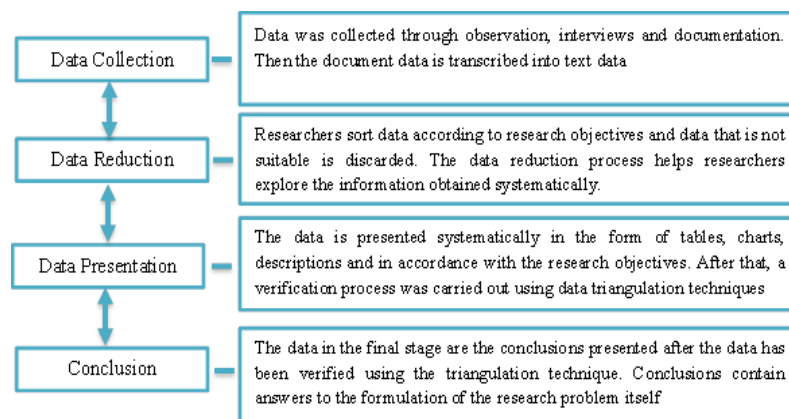


Figure 1 Interactive method analysis flow

RESULT AND DISCUSSION

The main data in this research results from engineering thinking skills with six

indicators: systematic thinking, finding problems, visualising, improving, solving problems creatively, and final

trials through the STEM-integrated PjBL model. The research data is presented in

Table 1.

Table 1 Data analysis of observation results of students' engineering thinking skills

No	Indicator of engineering thinking	Total number of students			
		Very Good	Good	Less	Very Less
1	Systematic thinking	40 %	40 %	7%	13%
2	Finding Problems	40%	24 %	20 %	16 %
3	Visualise	40 %	35 %	15 %	10 %
4	Repair	53 %	33 %	11 %	3%
5	Solve Problems Creatively	58 %	42 %	0%	0%
6	Final Trial	51 %	27 %	12 %	10 %

Systematic Thinking

Based on research on systematic thinking indicators, students are able to analyse the problem in general and state its core. Students collaborate to find solutions. The following are excerpts of student discussions and interviews about analysing the problem.

"... there was a failed Japanese H3 rocket worth 200 billion yen/ equivalent to 22 trillion" (Discussion, K₁,Cj₁).

"Japanese H3 rocket fails to launch" (Discussion, K₂,Yr₁).

of systematic thinking in the posttest, there are two questions related to the information obtained, and the subject matter in the readings that have been presented on the posttest sheet is stated. Thus, the students can explain the existence of a water rocket contest. However, there was a problem during assembly, namely that the water rocket glided unevenly during the test before participating in the contest. The following are examples of students' answers that lead to systematic thinking indicators in Figure 2.

Furthermore, for the results of engineering thinking skills and indicators

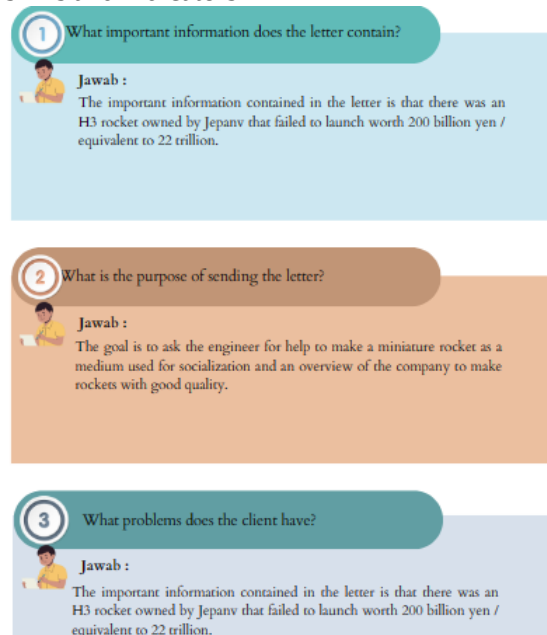


Figure 2 Example of group 1 answers on systematic thinking indicators

The following are examples of students' answers that lead to systematic thinking indicators in Figure 3.

1. What information is obtained in the reading above ?

Water rockets use water as air fuel, as many as 215 students from 54 junior and senior high schools in Yogyakarta and DKI Jakarta participated in the rocket contest at the SMA 3 field in Yogyakarta

Figure 3 Example of students' answers to the systematic thinking indicator on the posttest

Systematic thinking is the ability of students to think about doing a task in accordance with an appropriate, effective, and efficient sequence or planning (Siswono, 2016; Mardianto et al., 2022). Students show good systematic thinking because they can connect the three questions in the worksheets. All three questions by students are answered in detail as well as generally. Although the answers vary, they are correct and in accordance with the problems and objectives presented by the client. Systematic thinking done by students looks like that of an engineer who will be faced with real problems in a complex way that must be solved by designing solutions.

Finding Problems

The second engineering indicator is finding problems. This indicator leads students to describe the main problem and explain the reasons based on physics concepts. Students can search for physics concepts in books or on the internet. The excerpts from the results of discussions and interviews with each group lead to indicators of finding problems.

"Water rockets fail to launch if the load is too heavy. And if too little load exists, the water rocket will not have enough air to fly" (Discussion, K₆, Mf₁).

"Pressure, according to Newton's law, continues its momentum, and there will also be a reaction action in Newtonian III, for which the momentum of the impulse is when it bursts" (Interview, K₆, Ta₆).

The quote above shows that each group finds various information that can be used as a reference to find a solution to the problem. However, there is a diversity to describe the main problem and explain the reason based on physical concepts. Some of these answers relate physics concepts to rocket work. Two groups, however, provided answers by explaining the cause in a technical manner that focused on the work of the original water rocket without relating physical concepts. The following is an example of an answer in the worksheets with a very good category, as shown in Figure 4.

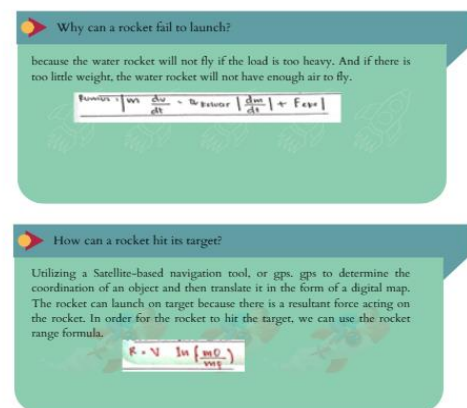


Figure 4 Example of group 6 answer on problem finding indicator

Engineering thinking skills for indicators of finding problems on the posttest, students are asked to explain physics concepts related to water rockets. One of the physics concepts is to explain the application of momentum to water rockets. The students can only understand physics concepts, as the research results show. Students did not explain momentum material in more depth in water rocket work. But in general, the answers given by students are correct.

Collecting information begins with reading some references through books or the internet. Information collection will make it easier to solve problems (Cross, 2023; Mardianto et al., 2022;

Ningkaula et al., 2021; Thunberg & Arnell, 2022). Students' answers were general and included some examples of life applications. Conceptual understanding will help students think technically. A student will better consider each specific to create a project that is in line with the analysed physics concepts. Based on research by Nuryani (2021) and Thunberg & Arnell (2022), students will obtain scientific concepts more meaningfully by involving engineering in learning.

Visualise

The third indicator is visualising. After students learn to know the problem and its cause and effect, they determine solutions to problems, argue about the tools and materials used, and are able to design water rockets collaboratively. A total of 37 students were able to visualise very well; 32 students were categorised as good, 19 as lacking, and 14 as very lacking. Here's an excerpt of the discussion that leads to the visualising indicator.

"... make sure the amount of water used is not too much and make two wings of the same size" (Discussion, K₆, Sa₁).

"... By needing a bottle to fly the rocket, in order for the rocket to fly it needs a balancer, namely made from infraboard. Rockets can launch by giving water filled in bottles so that they can launch from there after being given a wind pump" (Discussion, K₁, Nm₄).

"... manila paper, plastic bottles, infraboard, duct tape, bottle caps" (Discussion, K₄, Md₄).

"Rocket tools and materials: infrabot, 1 plastic bottle, acrylic paint, tape: 3000, scissors: 3000, cutter, shooting glue: 1000. Rocket launcher tools and materials: water: free, pump: free bicycle, pump, paralon, bicycle valve, noscone" (Discussion, K₆, Sf₁).

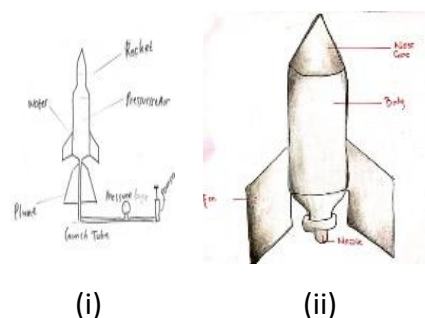


Figure 5 Examples of student answers on visualising indicators (i) Group 1 rocket design, and (ii) Group 6 rocket design

In this indicator, students generate ideas for making water rockets, such as wing shapes, nosecones, sizes, colours, and tool materials to be used. The basic difference can be seen in the shape of the wings and nosecone. After doing project activities, do a posttest to find out the engineering thinking skills of each student.

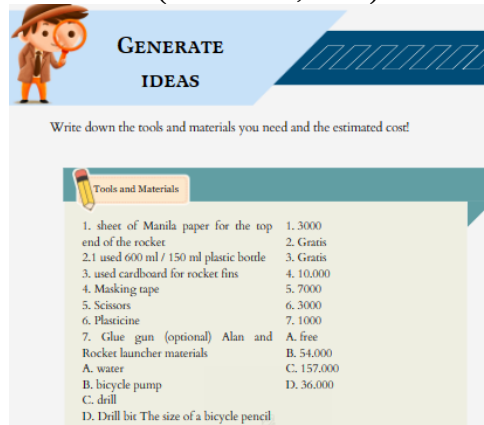
Engineering thinking skills for visualising indicators on the post-test students were asked to explain the design of a water rocket wing. Students explain the design suitable for the rocket to launch in a balanced manner. Research shows that students are able to explain and provide an overview of water rocket wing design.

The visualisation activities carried out by students are determining the agreement on the solution to be chosen, determining tools and materials, and designing the design depicted through the worksheets. Drawing sketches manually is highly recommended because students can directly illustrate ideas through brainstorming, and it also makes it easier for students to delete if there are additions or changes in ideas (Ibrahim et al., 2020; Nusyirwan & Prayetno, 2020).

The materials were designed for the design of the water rocket, along with the presentation of the concept related to momentum. The shape of the water

rocket must be light and balanced so that it can glide well. In addition, paying attention to the material used to design water rockets to be strong when given gas pressure is important because the launch process can analyse the occurrence of momentum. This shows that the design process is not just designing but also relates to the laws of scientific theory (Lor, 2017; Nuraeni & Zahra, 2021).

However, based on communicating the results, the presentation of the tools and materials used by each group is not 100% appropriate as in the worksheets. The results showed that the estimated cost needed by students was not to exceed the budget limit; the highest cost was Rp 271,000 due to the purchase of glue of more than 1 pcs to minimise leakage, so the results obtained were expected to be better. Other costs range from Rp 10,000 to Rp 200,000, with the number of purchases of tools and materials being in the standard category. The cost consideration process is also important because it includes mathematical activities that require calculations (Izzati et al., 2019).



Tools and Materials	
1. sheet of Manila paper for the top end of the rocket	1. 3,000
2.1 used 600 ml / 150 ml plastic bottle	2. Gratis
3. used cardboard for rocket fins	3. Gratis
4. Masking tape	4. 10,000
5. Scissors	5. 7,000
6. Plasticine	6. 3,000
7. Glue gum (optional)	7. 1,000
Rocket launcher materials	A. free
A. water	B. 54,000
B. bicycle pump	C. 157,000
C. drill	D. 36,000
D. Drill bit The size of a bicycle pencil	

Figure 6 Example of cost estimation answer on visualising indicator

Repair

The fourth indicator of engineering thinking is improving. After students discuss designing solution designs, they apply them in real form until initial trials are conducted. In this study, each group

collaboratively made a prototype of a water rocket according to the design agreed upon by the group. Water rockets are then tested, and improvements are made to new solutions in the event of failure in the initial trials based on teacher feedback and opinions from group members. A total of 53 students were able to improve very well; 33 students were categorised as good, ten students were categorised as lacking, and two students were categorised as very lacking. Here are excerpts from discussions and interviews that lead to indicators of improvement.

"... Make wings by forming a right triangle wing – elbow, 4. Make sure all is covered, there is no air chamber, 5. Make it so that the volume of water is not too much. 6. Launch at an approximate angle" (Discussion, K₄, Wa₄)

"... water volume 250 cc" (Interview, K₃, Ab₄)



Figure 7 Examples of answers and student work on problem-finding indicators

Based on this, students were able to explain how water rockets can glide and name things that affect them. The students explain briefly without any obvious details. However, in general, the answers given by each student are correct. Improving the prototype aims to perfect the prototype to suit its needs. After the prototyping is complete, the students test the water rocket that has been made. The pilot test was conducted to evaluate whether the prototype can be

used to determine the extent to which the prototype overcomes problems in accordance with the wishes of the client (Cross, 2023; Febriansari et al., 2022).

The creative solution chosen by the students in this study was to change the angle of rotation, the *nozzle*, the volume of water and the rocket's placement in the launcher. The idea of changing the volume of water, the launch angle, and the rocket laying were launched by students who observed successful groups and their spontaneous opinions while on the ground. When observing the process, students seem to choose alternative solutions suddenly, but in fact, the students have gone through the stimulus process (Nuraeni & Zahra, 2021).

Solve Problems Creatively

The fifth indicator of technical thinking is solving problems creatively. In this research, 3 groups failed the initial experiment, so they needed to think of a creative solution to the problem. Nineteen students were able to solve problems creatively very well; 14 were retrieved as good, 0 as lacking, and 0 as very lacking. Here's an example of a discussion excerpt on solving creatively. "... sufficient water and weight are balanced, and the wings are also right so that the rocket can launch successfully and that can be balanced because it can pump well and fit" (Discussion, K₁, Ad₄).

"... The shape of the wing also affects making the rocket's movement more stable. Wingspan also affects the speed of water rockets" (Discussion, K₆, Ti₄)



Figure 9 Group 4 water rocket trial

The results show that each group has the same way of choosing rocket wings and nozzles. But for nosecones, some groups have different opinions, namely that some use the loncong shape of a plastic bottle as well as the rocket body. But some use mica and infraboard material. In addition, the treatment of the launch angle and water volume is also different. Shiva made improvements during rocket construction when they found references from the internet that successfully launched and the group that failed to solve the problem creatively by paying attention to the angle of launch and the volume of water during the test. The launch angle used is 60° in groups 1, 50° in groups 3 and 6, 45° in groups 4, 40°

In groups 2 and 5. The volume of water used was 200 ml in groups 1 and 2 and 250 ml in groups 3, 4, 5, and 6.

In the posttest, the students were asked to explain how a water rocket can glide balanced to the maximum distance. So, the students are expected to be able to explain their understanding after doing project assignments. The outcome of the study shows that the students are able to explain that water rockets can glide balanced to maximum distances.

Final Trial

The last indicator of *engineering* thinking skills is the final trial. After students improve and solve problems creatively, they are able to collaborate to test the repaired water rocket again, and they discuss completing evaluation activities at worksheets. A total of 34 students were able to test the final trial very well. Eighteen students were categorised as good, eight students were categorised as lacking, and three students were categorised as very lacking.

"...the principle of rocket thrust satisfies the law of conservation of momentum. At first, the system (rocket and fuel) is stationary so that its momentum equals zero" (Discussion, K₆, Sa₄).

"... make angles when making wings"
(Interview, K₄, Wa₈)

The results showed that the solution that made the water rocket successfully glide. There are two groups that, at the stage of finding problems, do not explain physical concepts in detail or just mention them, but at this stage, they raise the relationship between water rockets and the concept of momentum in accordance with the material studied in this study. The difficulties faced by each group were the manufacture of wings and the imbalance of the rocket during the launch process. Furthermore, regarding the results of *engineering* thinking skills through the *posttest* of each student after carrying out project activities.

7. How to design a good water rocket to launch on target?
By paying attention to the design of water rockets that must be made with the right precision, the appropriate launch angle. The greater the air pressure the greater the maximum height of the rocket, the lighter the rocket makes the rocket launch on target.

Figure 10 Examples of student answers for final trial indicators on the posttest

The results showed that students were able to analyse and evaluate both solutions very well when there were mistakes in making water rockets. This is shown by the answers to worksheets of the students, who are very diverse in analysing the manufacturing process, tools and materials used, and the more detailed parts of the water rocket. Analysing and evaluating are abilities that an engineer must possess. This is due to the engineering process, the effectiveness of the chosen solution being assessed, and the engineer's ability to analyse and evaluate the solution.

The survey results show that students could analyse and evaluate both solutions very well. Student answers vary greatly in analysing, starting from the preparation process, the devices and materials used, and the more detailed parts of the water rocket. The ability to

analyse and evaluate is an ability that an engineer must possess because the engineering process not only assesses the effectiveness of the chosen solution but also the engineer's ability to describe alternative solutions (Angelina et al., 2023; Ortiz-Marcos et al., 2020). An engineer should solve problems with various technicalities using one simple decision or with many other alternative solutions (Nima et al., 2022; Nusyirwan & Prayetno, 2020). Based on this solution, you will be able to evaluate activities as reflection material to find out how well students understand after being given a treatment that starts with not knowing the working principle of water rockets is related to momentum material and then becomes understanding for the application of momentum material in life.

CONCLUSION

Based on the results and discussion, it can be concluded that most students' engineering thinking skills through the PjBL model integrated with STEM water rocket design momentum material are categorised as good indicators of engineering thinking skills. The Water Rocket Momentum Material Design recommends using a material from a small soda bottle with a rocket bell made from a water rocket.

The data analysis has shown that students have been able to solve problems by solving steps and thinking patterns like engineers, able to understand complex problems with systematic thinking patterns, then relate to science concepts, design solutions, make prototypes and repair failures in the initial test stage, find alternative solutions creatively by selecting the number of rocket wings, rocket shape, nozzle and nosecone shape and analyse the effectiveness of alternative solutions used. Based on the data processing results, it can be concluded that 40% are in the excellent category of indicators of

systematic thinking, problem-solving, and visualisation. The repair indicator is categorised as very good at 53%, and the solve problems creatively indicator is categorised as very good at 58%. Meanwhile, the final trial indicator is 51%.

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