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SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) IN EXPLORING STUDENTS' CRITICAL THINKING SKILLS

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Abstrak

Berpikir kritis merupakan salah satu profil pelajar Pancasila dan keterampilan penting dalam Abad 21 yang dapat dikembangkan melalui pembelajaran berbasis projek yaitu STEM. Dalam penelitian ini bertujuan untuk menggali keterampilan berpikir kritis siswa sekolah dasar melalui pembelajaran STEM yang berfokus pada konsep matematika (menyajikan data) dan konsep sains (sumber energi) yang melibatkan percobaan "kapal botol. Penelitian ini berbasis desain campuran dengan mengumpulkan data berbentuk kuantitatif dan kualitatif yang melibatkan 18 siswa kelas IV sekolah dasar. Instrumen penelitian yang digunakan adalah pedoman observasi, pedoman wawancara dan tes berpikir kritis. Observasi dan wawancara dilakukan selama pembelajaran STEM berlangsung di dalam kelas dan tes berpikir kritis diberikan setelah selesai pembelajaran. Hasil penelitian menunjukkan bahwa (1) Pembelajaran STEM berbasis projek mampu mendorong keterampilan berpikir kritis siswa; (2) Penemuan dan membangun argumen merupakan aspek keterampilan berpikir kritis dengan rata-rata paling rendah dibanding aspek lainnya yaitu 75 %; (c) mayoritas siswa memiliki keterampilan berpikir kritis yang baik. Oleh karena itu, pendekatan STEM berbasis projek dapat menjadi salah satu cara yang digunakan untuk mencapai profil pelajar Pancasila di sekolah dasar khususnya berpikir kritis.

Kata kunci: Berpikir kritis; pembelajaran; sekolah dasar; STEM.

Abstract

Critical thinking is one of the profiles of Pancasila students and an important skill in the 21st century that can be developed through project-based learning, with STEM. This study aims to explore the critical thinking skills of elementary school students through STEM learning that focuses on mathematical concepts (presenting data) and science concepts (energy sources) involving the "bottle boat" experiment. Mixed methods were used to collect quantitative and qualitative data involving 18 fourth-grade elementary school students. The research instruments used were observation guidelines, interview guidelines, and critical thinking tests. During STEM learning in the classroom, researchers used observations and interviews. A critical thinking test is given after learning is complete. The results show that (1) students' critical thinking skills can be supported through a project-based STEM approach (2) Invention and argument building are aspects of critical thinking skills with the lowest average compared to other aspects as much as 75%; (c) most students have good critical thinking skills. Therefore, the project-based STEM approach can be one of the ways used to achieve the profile of Pancasila students in elementary schools, especially critical thinking.

Keywords: *Critical thinking; elementary school; learning; STEM.*

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INTRODUCTION

Education development in the 21st Century requires various knowledge and skills related to technology. The learning characteristics directed students to have 4C skills (communication, collaboration, creativity, and critical thinking). According to Miller (2019), learning challenges in the 4.0 era can be achieved through cross-curriculum opportunities provided by education with STEM (Science, Technology, Engineering, and Mathematics). STEM learning is an approach in education where Science, Technology, Engineering, and Mathematics are integrated as a problem-solving approach in students' daily lives and professional lives.

Meng *et al.*, (2013) suggested that students with STEM knowledge can identify, apply and integrate concepts as the basis of thinking skills to solve complex problems and develop innovative solutions. Furthermore, according to Twiningsih & Sayekti (2020), the application of STEM-based learning could improve student skills, affecting learning outcomes. Suwardi (2021) also stated that with STEM learning, teachers could show students can integrate concepts, principles, science, technology, and mathematics to develop products, processes, or systems that are useful for real life. Therefore, implementing STEM in learning can be an effort to prepare students to compete with various skills.

Sirajudin et al. (2021) explain that STEM learning aims and is useful for developing critical and creative thinking skills, logical, innovative, and productive, instilling a spirit of cooperation in solving problems, introducing the perspective of the world of work, utilizing technology to create and communicate innovative solutions. In addition, STEM can also be a medium to develop the ability to find and solve problems as well as increase the capacity and skills of students.

Several research with different levels of education report how STEM has a positive impact on students' skills. Research So et al. (2017) reported that science projects significantly positively impacted students' mathematical and technological abilities. Hacioglu & Gulhan (2021) also found that STEM learning can develop students' thinking skills and build a positive perceptions.

In addition, several studies have also reported the positive impact of STEM on student learning outcomes in elementary schools by utilizing innovative learning media (Nurlenasari *et al.*, 2019; Syadiah & Hamdu, 2020; Debora & Pramono, 2021; Handayani, 2021; Polydoros, 2021; Purwati et., 2022). The results of other studies also found that learning with the STEM approach in elementary schools proved to be effective in improving the critical thinking skills of elementary school students (Hefty, 2015; Davidi et al., 2021; Rahmawati et al., 2022). Widana, et al. (2019), stated that critical thinking is a directed process to solve various problems. Critical thinking is an ability individuals possess that can be seen through the nature of strong curiosity and daring to make decisions.

Therefore critical thinking is very meaningful and has the power of thinking that must be built on students in elementary school. However, research linking project- STEM learning with students' critical thinking skills in elementary schools still needs improvement. Even though the learning process in elementary schools is currently moving towards project-based learning aims to achieve a Pancasila Student profile.

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Project-based learning prioritizes understanding concepts through investigating various problems to be solved and trains students to become accustomed to thinking critically where this condition can be achieved through STEM learning. Ariyatun and Octavianelis (2020) stated that the project-based learning model integrated with STEM is more effective in elementary school students' critical thinking skills. Therefore, this study aims to explore the critical thinking skills of elementary school students through project-based STEM-based learning.

RESEARCH METHODS

The method used in this study is mixed-methods. According to Creswell (2014), the mixed-methods approach is suitable for research involving learning in the classroom because it can provide a complete picture of the phenomenon under study. Furthermore, qualitative and quantitative data can be collected and analyzed separately, and then the results can be combined (Creswell, 2014; Tippett & Milford, 2017).

The mixed research design is a concurrent triangulation design in which the researcher collects qualitative and quantitative data simultaneously and then combines quantitative and qualitative data analysis methods, then interprets the results together to provide a deeper picture and understanding regarding the implications of stem learning in students' critical thinking skills.

We carried out this research with 18 grade IV students at SDN 029 Tarakan, which was carried out in March for the 2021/2022 school year. The integrated material is mathematics and science contained in thematic learning on energy sources and data processing material (bar chart).

Researchers used several instruments to collect and analyze data during STEM-based learning in the classroom. The researcher designed an instrument consisting of a class observation sheet that integrates STEM learning into critical thinking aspects, a critical thinking test on math-science material, and interviews with students to obtain quantitative and qualitative data. Validation research instrument using expert validation by ID SINTA 6001332.

The class observation sheet consists of 6 aspects of critical thinking: interpretation, analysis, evaluation, information, discovery, and building arguments (Facione, 2020). Each aspect has 4 descriptions related to the skills shown by students during STEM learning in the “Bottle Boat” practicum. Furthermore, the tests contain knowledge and activities in STEM learning, especially mathematics and science. Interviews conducted by researchers with three students representing each group contained questions that aimed to determine students' critical thinking abilities during STEM learning. The students interviewed were projected group leaders appointed by the teacher as the person in charge of implementing their project. Table 1 shows the observation guidelines designed by researchers to collect data during STEM learning.

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Table 1. Aspects of critical thinking skills in the "bottle boat" practicum

Aspect	Score			
	1	**2**	**3**	**4**
Interpretation	Does not show an understanding of the bottle boat practicum.	Demonstrate an understanding of the bottle boat practicum and reveal 1 correct information.	Demonstrate an understanding of the bottle boat practicum and reveal 2 correct information.	Demonstrate an understanding of the bottle boat practicum and reveal more than 2 correct information.
Analysis	Unable to describe the stages of assembling a bottle boat.	Only able to reveal 2 steps of assembling a bottle boat.	Be able to reveal the 3 steps of assembling a bottle boat.	Able to reveal all the steps of assembling a bottle boat.
Evaluation	Unable to compare the distance of bottle boats when doing practicum.	Able to compare 2 bottle boat distances when doing practicum.	Able to compare 3 distances of bottle boats when doing practicum.	Able to compare more than 3 distances of bottle boats when doing practicum.
Information	Unable to provide steps taken to repair bottle boats that won't move.	Able to provide 1 step taken to repair a bottle boat that won't move.	Able to provide 2 steps that are carried out to repair bottle boats that don't want to move.	Able to provide more than 2 steps to fix a bottle boat that won't move.
Invention	Unable to explain the cause of the bottle boat that would not move.	Able to explain 1 cause of bottle boats that won't move.	Able to explain 2 causes of bottle boats that don't want to move.	Able to explain more than 2 causes of bottle boats that won't move.
Building Arguments	Unable to explain the conclusion of the bottle boat practicum.	Able to explain conclusions from the bottle boat practicum but not quite right.	Able to explain conclusions from bottle boat practicum but quite precise.	Able to explain the conclusions of the bottle boat practicum appropriately.

1. Observation of STEM Learning

STEM learning was carried out in 4 meetings, where 1 meeting lasted 40 minutes. Researchers carried out STEM learning following the 'Bottle Boat' practicum design and were assisted by other researchers to observe during the learning process.

2. STEM Group

The researcher divided the students into 3 groups, namely groups A, B, and C, to carry out the "Bottle Boat" project. After the project was completed, the researcher asked some interview questions such as: what were the steps in making the "Bottle Boat," what energy was produced, the measurement they obtained during the project, what happened when the "Bottle Boat" was not moving, etc.

3. Critical Thinking Test

Students are asked to take tests related to the material they learned during STEM learning, specifically for mathematics and science, presenting the measurement data in diagramas and

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energy sources. The test results from the students were then analyzed and interpreted in the critical thinking categories, namely good, fair and low modified from (Basri et al., 2019), which is shown in Table 2.

Table 2. Categories thinking ability

Value Range	Category
$75 < CTS \leq 100$	Very High
$60 < CTS \leq 75$	High
$CTS \leq 60$	Medium

Quantitative data analysis was carried out using descriptive statistics, while qualitative data analysis (Huberman & Miles, 2012) was done using reduction, data display, and conclusion/verification.

RESULTS AND DISCUSSION

The researcher explained the study's results based on three stages of collecting data, namely observations (observation guidelines and field notes), student activities in STEM groups, interview results, and test results.

STEM Learning Observation

The observation process in STEM learning during the "Bottle Boat" project found two research results, namely conclusions from student project activities and quantitative data that contained critical thinking aspects of their STEM project.

Students showed enthusiasm during the "Bottle Boat" STEM project activity in the material presenting data and energy sources. The results of the researcher's documentation show that learning is active, fun, and cooperative. In addition, students' interpretation skills are shown by students being able to correctly name the tools and materials used in the bottle boat practicum. The ability to analyze information is shown by students when they can reveal the steps of assembling a bottle boat.

The evaluation ability is shown by group C, which can compare more than 3 distances of bottle boats when doing the practicum correctly. However, groups A and B have not been able to compare the exact distance of the bottle boats. The information ability shown by group C was able to provide more than 2 steps taken to repair a bottle boat that would not move. While groups A and B tend to only focus on the stages of assembling the bottle boat, they have not been able to explain the right way if the bottle boat does not want to move.

The discovery ability was shown by group C, which explained the cause of the bottle boat that would not move. Meanwhile, groups A and B have not been able to independently explain the cause of the bottle boat's inability to move. The ability to build arguments was also demonstrated by group C, which could explain the conclusions of the bottle boat practicum correctly. While groups A and B only provide conclusions based on the material described and have not concluded based on the STEM practicum they have done. Figure 1 shows the STEM project activities of students.

Building a Bottle Boat: A series of STEM lessons including science (transformation of energy), engineering (building boats), and math (data presentation and bar charts). For 3 days, students were involved in activities such as identifying tools and materials for making bottle boats. Students design bottle boats from used materials such as bottles, straws, ice cream sticks and cans. The peak activity is assembling bottle boats using the materials and tools that have been provided.

Figure 1. Activities of Students'.

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The results of student work showed that group A could collect data and make bar charts even though the results of student work were not accurate. The cause of the inaccurate results of student data collection is the lack of student cooperation in the bottle boat practicum. Students are also less careful in measuring the distance traveled by the bottle boat in the practicum, so the results of the data written are not accurate. As seen from the difference in the resulting distance is not stable. Figure 2 shows the students' STEM project activities in group C.

Building a Bottle Boat: A series of STEM lessons including science (transformation of energy), engineering (building boats), and math (data presentation and bar charts). For 3 days, students were involved in activities such as identifying tools and materials for making bottle boats. Students design bottle boats from used materials such as bottles, straws, ice cream sticks and cans. The peak activity is assembling bottle boats using the materials and tools that have been provided.

Figure 2. Activities of Students'

The results of student work showed that group C could collect data and make bar charts accurately. Students can accurately write down the distance measurement results on the bottle boat practicum. As seen from the difference in the resulting distance is stable. Then it can be seen that students can also describe bar charts well. This shows that students have good cooperation in the bottle boat practicum.

The results of observations in the form of quantitative data by paying attention to critical thinking aspects during the "Bottle Boat" STEM project are presented in Table 3. Based on Table 3, the invention and argument building aspects are critical thinking aspects with an average of 75%. It can be seen that some students could only explain 2 causes of bottle boats that would not move, such as the incorrect combustion position on the bottle boat and the contents of the water in the bottle vessel reservoir which had run out. Some students couldn't come up with other reasons why the bottle boat could not move.

Table 3 Assessment of observation results

CT	A	B	C	$\dot{x}$
Interpretation	75	100	100	91,7
Analysis	75	75	100	83,3
Evaluation	75	75	100	83,3
Information	75	75	100	83,3
Invention	50	75	100	75,0
Building Arguments	50	75	100	75,0

The aspect of building arguments also reaches 75%. It can be seen that some students are only able to explain the conclusions from the bottle boat practicum, but it is not quite right. Like they only mentioned that the shorter the drain pipe, the faster the speed of the bottle boat; they did not mention why the bottle boat could move and what energy changes occurred in the bottle boat experiment.

STEM Group Activities

Data from 18 grade IV elementary school students who were the subject of this study and divided into 3 groups obtained from classroom learning and interviews during and after the "Boat Botol" STEM project are presented in below .

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Group A

Researcher	:	What makes bottle boats move?
Student	:	Because there is water in the reservoir which is heated, so the water evaporates and comes out of the drain pipe. This is what makes the bottle boat move.
Researcher	:	What causes bottle boats to not move?
Student	:	The fire is too small

Group B

Researcher	:	What makes bottle boats move?
Student	:	The reason the bottle boat can move is that the heating in the water reservoir causes water to enter and exit through the drain pipe as a driving force for the bottle boat.
Researcher	:	What causes bottle boats to not move?
Student	:	The shelter is too heavy

Group C

Researcher	:	What makes bottle boats move?
Student	:	The reason the bottle boat can move is the pressure of water vapor which is heated on low heat in the bottle boat, so that the difference in temperature due to heating in the water reservoir causes water to enter and exit through the exhaust pipe as a driving force for the bottle boat.
Researcher	:	What causes bottle boats to not move?
Student	:	The water reservoir is empty, the combustion position is not right, there is a leak between the straw connection and the water reservoir

The results of the interview transcripts above show that students are able to tell about the results of their measurements based on the results of the STEM practicum. However, the results of the data obtained by students are different, some are accurate, and some are inaccurate. Accurate practicum result data is seen in group C with the difference in distance traveled by bottle boats looking stable. Inaccurate data from practicum results is seen in group A with the difference in distance traveled by bottle boats looking unstable.

This condition demonstrates that there are still unable to measure accurately in the nearest unit and cannot find that the difference in the size of the same pipe cut will likewise be proportional to the resulting distance. The results of the interviews also revealed that students understood and could explain the reasons why bottle boats move. Meanwhile, the groups, specifically groups A and B, haven't been able to determine why the cause bottle boat not moving, therefore they can't come up with a reason for what they should do in that situation.

According to the findings of the interviews, it was also observed that all groups showed critical thinking skills in the aspects of interpretation, analysis, evaluation and information. While the other groups still need help from the teacher to understand and find the cause of the bottle boat not moving.

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Critical Thinking Test

Following the bottle boat practicum, the researchers also administered a critical thinking test in which students were required to answer questions about the STEM-related math and science concepts they had acquired, such as representing measurement data as diagrams and energy sources. The analysis and interpretation of the student test results in the critical thinking area is shown in Table 4.

Table 4. Student critical thinking test results

Value Range	Category	x	%
75 < CTS ≤ 100	Good	14	77,7%
60 < CTS ≤ 75	Fair	4	22,3%
CTS ≤ 60	Low	0	0%

Subjects with good critical thinking skills can bring up all aspects of critical thinking in their worksheets. Figure 5 shows an example of a student worksheet with good categories where the subject can interpret the measurement data in tabular form into a bar chart correctly. In addition, the aspect of building an argument is also seen where he can reveal the steps he finds if the boat can't move.

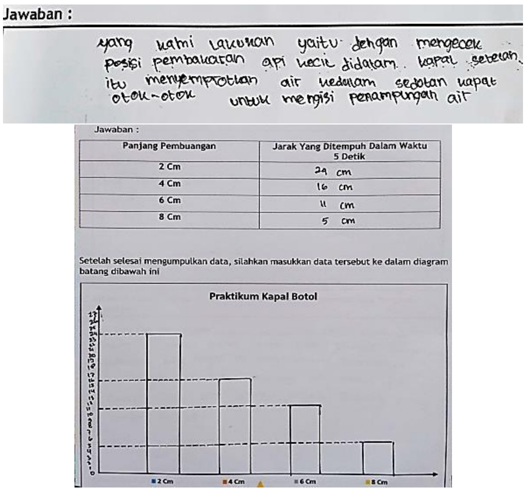

Figure 3. Example of worksheet a good critical thinking

Figure 4 shows a worksheet for students with fair categories which seem to have been able to interpretation and present measurement data in tabular form to diagram form correctly. However, it has not been able to fulfill the discovery aspect and build an argument. The subject has not been able to develop appropriate arguments regarding the steps that the subject must take if the boat does not move so that they have not found the right steps.

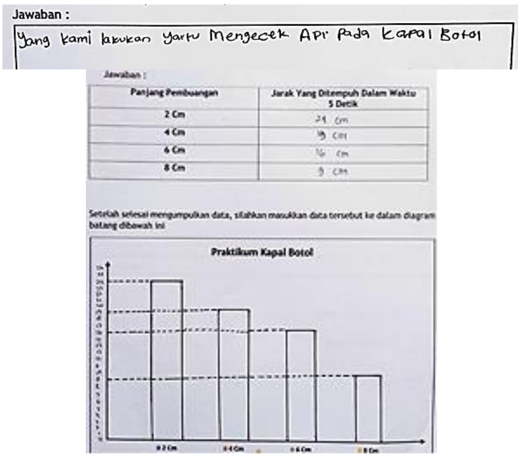

Figure 4. Example of worksheet a fair critical thinking

Based on the results of the critical thinking test, it can be seen that through STEM-based learning with the "Bottle Boat" project 77.7% of subjects have good skills, and 22.3% are in the fair category, and there are no subjects with low critical thinking categories. This shows that learning using STEM can support students' critical thinking skills in elementary schools.

Discussions

Based on observations, interviews, and tests, it was found that STEM learning can support students' critical thinking ability in elementary schools. STEM learning can support students' critical thinking skills in elementary schools because students'

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enthusiasm for learning increases due to STEM learning. Students are more active in collaborating in acquiring new knowledge in learning to increase their critical thinking skills.

The observation results show that the first four aspects of critical thinking are well seen. Meanwhile, their critical thinking skills in finding and building arguments still need to be improved, so it still needs to be developed in these aspects. The factor that causes this to happen is that students need to be more careful in collaborating, so the data obtained by students from the results of some of the findings need to be corrected. The ability to build arguments still needs to be improved because some students need better communication skills, so they cannot explain bottle boat practicum.

STEM learning can make students active in learning, create good cooperation for students and improve their critical thinking skills. In line with Suardi (2020) states that the implement-tation of STEM learning can improve conceptual understanding, critical and creative thinking skills, and the ability to work together among students. Through project-based STEM, it turns out that students can familiarize students with finding an understanding of the material that has been taught by carrying out an activity so that students are actively involved in the learning process.

STEM-integrated PBL models are more effective in critical thinking skills and provide new learning experiences for elementary school students. This is in line with several studies that the STEM-integrated PBL model is more effective in the critical thinking skills of elementary school students (Satriani, 2017; Ariyatun and Octavianelis, 2020; Riyanto et al., 2021).

The enthusiasm of students can be seen when they tell the practicum they are doing. These results align with the opinion (Artobatama, 2018) that by producing work in learning, students will be enthusiastic about the learning involved in doing work. This can encourage students to be critical and creative. The teacher must actively assist students during the STEM learning practicum in project learning. Because the success of student projects depends on students' accuracy when carrying out practicum. Although students already understand the steps in STEM projects, they are sometimes less careful in carrying out practicals, so the results are inappropriate. These condintions in Group A and Group B, who made a mistake in measuring the distance of the bottle boat.

According to Hefty (2015), STEM learning outcomes can help teachers to assess each student's understanding; for example, through STEM, teachers can find many students who have difficulty measuring length to the nearest centimeter unit so that teachers can collaborate with other teachers to prevent student understanding gaps.

Group C has been able to fulfill all aspects of critical thinking. Groups A and B have not fulfilled all aspects of critical thinking, both groups experienced problems at the evaluation stage where they showed errors when comparing the distance of bottle boats when doing practicum so the data they recorded in the table was not accurate. Then at the invention, groups A and B also showed a mistake about what to do if the bottle boat did not want to move. Because these conditions affect the ability to build arguments groups A and B still need guidance from the teacher.

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STEM learning can improve students' teamwork skills in learning. That stem learning can lead to student teamwork. This is in line with the opinion that the general goals and benefits expected from the STEM learning model include: developing critical and creative thinking skills, logical, innovative, and productive, and instilling a spirit of cooperation in solving problems (Sirajudin et al., 2021).

STEM learning can improve discovery skills and make students enjoy learning. This follows the opinion (Widyastuti et al., 2021) that STEM learning activities involving invention, experimentation, and conclusion are learning ideas that children like because children will learn without realizing that children are learning.

STEM can train students to think critically. This is in line with (Hadi, 2021) research which states that the integration of STEM-based learning is more effective in the critical thinking skills of elementary school students. This is shown when they work together in groups; the ability to analyze the condition of students becomes more trained when they discuss and conclude the results of the discussions. This is in line with the opinion Suwardi (2021) that STEM learning can improve students' critical thinking skills and foster creativity.

Both male and female students showed that all students expressed pleasure in STEM learning and gained experience following the learning stages; it generated motivation and interest in learning. These results indicate that implementing STEM learning can improve student learning abilities. With STEM learning, students can improve multi-presentation and critical thinking skills and are not affected by gender, both male and female. This is also in line with research Davidi, et al. (2021) which states that the STEM approach can improve the critical thinking skills of elementary school students.

Critical thinking skills are also influenced by students' communication skills, as seen from the results of observations made showing various results (Oktavia & Ridlo, 2020). Groups with a high level of critical thinking have good communication as well as in discussing and responding to teachers during STEM learning. Likewise, the group with a level of critical thinking skills who are having poor communication.

STEM learning can also improve students' critical thinking skills in solving problems (Debora & Pramono, 2021). It can be seen during the STEM practicum that some students look critical in solving problems when the bottle boat doesn't want to move. Students practice their way of getting the bottle boat to move. STEM learning that is carried out contributes to training students' critical thinking skills and can train students to be able to solve problems and improve students conceptual understanding (Fathoni et al., 2020).

The advantage of STEM learning is increasing students' critical thinking skills and encouraging students to be more active in learning. Sharpen students' communication and collaboration skills and improve students' ability to solve problems and find things.

The weakness of STEM learning is that the time used to complete the project is quite long; The project practiced in this study can only be associated with energy source materials; Teachers can only be integrated STEM

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learning in elementary schools into some materials. This study results that using STEM learning could have implications for students' critical thinking skills. So it is expected that elementary school teachers to achieve a Pancasila student profile, one of which is critical thinking, can choose to use project-based STEM learning in learning.

CONCLUSION AND RECOMMENDATION

Based on analysis of the results and discussion, that STEM instruction using the "Bottle Boat" project can help students develop their critical thinking abilities. Additionally, it was discovered that students still need to develop their critical thinking abilities in the aspect of invention and building argument. Students with good critical thinking skills were able to complete all aspects of critical thinking, while students with sufficient categories have not been able to fulfill the aspects of invention and building arguments. In addition, there are no students who have low critical thinking skills, and 77.7% of students are already in the category of good critical thinking skills, while 22.3% are in the fair category.

Further STEM research is to optimize the technology more because many skills can be produced in STEM learning so that future research can emphasize the relationship between stem learning and other skills such as creative thinking, communication, and collaboration.

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