STEM application in miniature bridge making can sharpen children's critical thinking patterns

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Abstract: To improve the skills required for students in the 21st century, such as basic skills, competencies, and character, mathematical literacy is one of the critical factors. With the application of STEM, students are expected to be able to think critically so that they can improve their mathematical literacy skills. This research used a descriptive qualitative method with subjects aged 3–9 years in Joho Village, D.I. Yogyakarta, Indonesia. In this study, data was collected using three methods: observation, interview, and documentation. The instruments used include a critical thinking scale, an observation guide, and an interview guide. The results obtained from this study indicate that applying STEM can hone students' critical thinking skills. Two classifications were obtained by applying STEM, namely groups with high and average levels of critical thinking. Students can identify given problems, formulate the core of the problem, provide solutions based on a problem, draw conclusions, and evaluate relevant arguments for solving a problem. Thus, research is expected to provide a strong foundation for applying STEM-based learning to enrich students’ mathematical learning experiences and prepare them for future challenges in the age of globalization towards Indonesia in 2045.

Keywords: Critical thinking skills, Mathematical literacy, STEM


INTRODUCTION

The rapid development of the world and the increasing changes in various aspects of life globally provide challenges for countries to prepare future generations (Rachmantika, 2019). In the era of globalization and relentless technological advances, the role of education is essential in maintaining harmony between technological advances and human potential (Faiz & Kurniawaty, 2022). The current generation will face more significant challenges than previous generations at the beginning of the 21st century. According to the National Education Association guidelines, students must not only be proficient in reading, writing, and arithmetic, but they must also be able to communicate effectively and creatively, think critically, and collaborate effectively and reliably (Habibi, 2021).

Nationally, the Ministry of Culture and Indonesia has determined that in the 21st century, students must develop essential skills, core competencies, and character; math literacy is one of the critical factors. Skills are needed to survive in a fast-changing world (Purwanto et al., 2023). Core competencies refer to the skills needed to develop oneself, cooperate with others, and develop oneself (Pidgeon, 2017). Character refers to the traits needed to achieve individual goals, such as caring, fairness, and communication skills (Lerner, 2018).

Mathematical literacy is critical in improving students' skills in the 21st century because mathematics is an essential discipline in the modern world (Salsabila, 2021). Mathematical
literacy is a person’s ability to form, formulate, and explain mathematical concepts in various situations. It includes thinking mathematically and using mathematical concepts, methods, facts, and tools to predict and explain events (Brief, 2017). It helps individuals understand how mathematics is vital daily and enables them to make accurate and socially relevant decisions. Mathematical literacy includes applying computational aspects to mathematics and understanding mathematics in general (Brief, 2017).

Several studies have shown that STEM learning can facilitate students’ mathematical problem-solving skills (Khoerunnisa et al., 2021). The STEM approach can help students change mathematical attitudes effectively and psychomotorly, and based on STEM, it can improve students’ mathematical problem-solving abilities (Khoerunnisa et al., 2021). Therefore, to improve students’ mathematical literacy, it is necessary to apply a learning model that integrates mathematical concepts into real-life contexts. One approach that can be used is implementing STEM (Science, Technology, Engineering, and Mathematics) activities (Sulistiawati et al., 2021). Integrating STEM into the mathematics learning process can help students overcome problems related to their daily lives and understand concepts more fully and meaningfully.

The STEM approach helps students identify questions and problems in everyday life, explain natural phenomena, design solutions, and draw conclusions based on scientific evidence relevant to STEM (Davidi et al., 2021). STEM learning methods have been proven effective in improving students’ critical thinking skills and increasing their scientific knowledge. It can also be used as an alternative to stimulate students’ interest in the learning process (Pradana, 2021). Through STEM learning, it is expected that every student will be able to solve real-world problems and significantly improve their academic performance.

In this study, the researcher aims to describe how STEM activities in the form of miniature bridge-making activities using straws can hone critical thinking patterns in students. In general, STEM activities aim to develop students’ critical thinking skills to understand STEM concepts holistically and apply them in the context of complex problem-solving (Khoerunnisa et al., 2021). Making miniature bridges is one example of a STEM activity that can hone students' critical thinking skills. In making miniature bridges, students can better identify their problems, gather relevant information, design solutions, and analyze data. Critical thinking in this context involves analytical, evaluative, and creative thinking so that students can develop their ability to understand STEM concepts holistically and apply them in the context of complex problem-solving (Pylypenko, 2020).

The definition of critical thinking refers to a thought process that uses appropriate criteria to evaluate information and make decisions based on available evidence. Critical thinking is critical in learning and is in line with learning objectives, including mathematical problem-solving ability, development of critical thinking ability, and skills related to STEM. Conducting research related to the application of STEM can hone students’ critical thinking patterns. Hopefully, the information provided can help develop the field of education in the future.

The EDP (Engineering Design Process) process is used to apply STEM activities. EDP (Engineering Design Process) is a learning model that integrates the STEM (Science, Technology, Engineering, and Mathematics) approach to develop students’ critical and innovative thinking skills in the context of problem-solving. The STEM approach integrates concepts from several disciplines related to nature, technology, engineering, and mathematics, while the EDP model uses the STEM approach to develop and evaluate projects (Rahmawati, 2022).

EDP uses the STEM approach to develop creative thinking and discussions that are out of the box and promote integrated learning. This allows connecting with each STEM material to enhance student engagement and interest in mastering all STEM disciplines according to everyday problems (Rahmawati, 2022). EDP uses the STEM approach to develop and evaluate projects, which tends to take longer as students develop a project, evaluate it, and redesign it, so it is impossible to complete it face-to-face (Rahmawati, 2022). Improving the quality of
education in Indonesia requires an education reform to shifts from conventional methods to approaches that advance more critical thinking (Davidi et al., 2021). In line with this concept, research suggests that STEM can expand knowledge, support inquiry-based exploration, and encourage students to create new knowledge (Amir, 2021). Critical thinking is a form of reflective thinking that focuses on decision-making (Onsee & Nuangchalerm, 2019).

STEM learning, combined with its four components, can create student activities that support the development of critical thinking skills, including the ability to identify problems, formulate problems, provide solutions, draw conclusions, and evaluate (Benavides-Caruajulca, 2021). The four competencies are core, basic skills, character, and critical thinking ability. Core competencies refer to the skills necessary to develop yourself, work with others, and develop yourself. Basic skills refer to skills needed to survive in a rapidly changing world. Characters refer to qualities needed for individual goals, such as care, justice, and communication skills. Critical thinking is a process that uses the proper criteria to evaluate information and make evidence-based decisions. By bringing these four components into STEM learning, students can develop their ability to think critically and holistically and apply them in complex problem-solving contexts (Dewanti et al., 2021).

This research could fill the gaps that have been identified by focusing on the analysis of STEM-based learning implementations to facilitate mathematical problem-solving capabilities in the age of globalization. Through STEM integration, the research has significantly contributed to the development of STEM education and the improvement of critical thinking skills in children. STEM implementation in learning can help students change their mathematical attitudes effectively and psychomotorally, making them more active and engaged in the learning process (Khoerunnsa et al., 2021). Besides, the STEM approach can also improve students’ ability to solve mathematical problems (Jawad et al., 2021). Thus, this research provides a strong foundation for applying STEM-based learning to enrich students' mathematical learning experiences and prepare them to face future challenges in the era of globalization towards Indonesia in 2045.

METHOD

The research method used in this study is qualitative-descriptive. The research method was chosen for this study because it allows researchers to describe phenomena comprehensively, focusing on the quality, characteristics, and interrelationship of activities in the construction of mini bridges. This method helps in understanding children's critical thinking skills by interpreting and deducing the data that exists in parallel with the current situation, as well as expressing attitudes, contradictions, relationships, and views that occur within the scope of respondents (Rusli et al., 2014). With this approach, researchers can gain an in-depth understanding of how children use critical thinking skills in building mini bridges, providing valuable insights for developing STEM education and enhancing critical-thinking skills in children (Argianti & Andayani, 2021).

Purposive sampling is the method used to select a subject because it allows a researcher to take a sample with characteristics that match the purpose of the research (Campbell et al., 2020). In this study, children aged 3–7 years were selected as the subjects because they have expanding thinking abilities and have a broader experience than younger children. This sampling can also help understand children's critical thinking skills in constructing mini bridges, a relevant context for developing their critical thinking skills. The subjects in this study were children aged 3–7 years in Kampung Joho, Yogyakarta. It consists of one unschooled child, two kindergartens, two 1st-grade students, and one 2nd-grade student. There are three main stages in the research procedure, namely the pre-field stage, the fieldwork stage, and the population and sample data analysis stage (Newman & Gough, 2020). Here is a brief explanation of each stage illustrated in Figure 1.
In the pre-field phase, researchers conduct preliminary studies to understand the research context, while in the fieldwork phase, researchers collect data using observation, interview, and documentation methods. The data analysis phase involves processing the collected data and presenting the analysis results in narrative form. In this study, the researchers created a STEM education activity called "Miniature Bridge." The stage of EDP in this activity is shown in Figure 2.

The stage of EDP in this study was adjusted to reflect critical thinking indicators. Students will be divided into several groups to identify problems. Then, the researchers will present a problem in the form of a video showing news to students about the natural disaster that caused the bridge to collapse. This stimulates students to identify the problem from the video shooting. In this process, students are also expected to formulate a tree of the problem and provide a solution based on the given problem. Then, each group is directed to build a strong
bridge using the infusion as one of the solutions to the given problem. After that, each group will test the strength of their bridges, each with the help of a sword. The group that can withstand the most sword loads is the winner. The losing group must evaluate why the bridge they built is not as strong as the winning group's bridge.

This study's data is processed following observations, interviews, and documentation. Observations and interviews are used to gather information about students' critical thinking abilities while making miniature bridges. Observations use previously prepared observation sheets, while interviews are structured and targeted at students.

Data collection tools, such as observation sheets and interviews, are developed and adapted to meet the needs of this research. An observation sheet is used to collect data directly from children in making mini bridges, while interviews are used to gather data through previously prepared questions. This tool has been developed with a content analysis approach to facilitate understanding children's critical thinking skills in mini-bridge making. This tool may facilitate an understanding of the critical thought skills of children in mini-bridge making, which is a relevant context for developing critical thinking skills in children. Both are based on several skills used to assess critical thinking abilities. According to Angelo (Setiawan & Royani, 2013), critical thinking includes the following characteristics: 1) the ability to identify problems, 2) the ability to formulate the core of problems, 3) provide solutions, 4) the ability to conclude, and 5) ability to carry out evaluations.

This qualitative descriptive research uses data validation strategies with an ethnographic approach. The data analysis techniques applied in data reduction cover three aspects: the selection of basic information, the presentation of data in narrative form, and the drawing of conclusions or verification (Widiastuti et al., 2019). To ensure the reliability and validity of the data, the study also applied triangulation techniques. In this context, triangulation is used to increase the confidence level by verifying the data collection techniques and data sources used (Widiastuti et al., 2019).

RESULTS AND DISCUSSION

Results

Based on the results of interviews with students in Kampung Joho, D.I. Yogyakarta, Indonesia, students stated that school lessons are difficult to understand, especially on mathematics subjects, such as counting, reading, and writing numbers. In the interview, the students also stated that the teacher used a lecture approach in delivering material, which was eventually considered monotonous, rigid, and ineffective. The impact of this approach is that students will feel bored when listening, as well as boredom arising from repeated subject practice. Besides, students rate the materials taught by teachers less attractive; the teachers rarely use the learning media, and teachers often do not explain the relationship between the learning material and everyday life. The students realize that they understand the material when it is taught, but that understanding fades after learning. According to (Happy & Widjajanti, 2014), several factors can cause the student's ability to think critically mathematically to decline. One of them is the implementation of the learning process. The process of learning mathematics should support the active involvement of students and create favorable conditions for them to apply their critical thinking skills.

After conducting the interview, the researchers observed the application of STEM activity with the observation sheet research instrument for students. The analysis of student activity in the EDP phase of this application process is as follows:

Problem Identification

Students will be divided into two groups, and then the researcher will provide problems in the form of news video shows to students about natural disasters that cause bridges to
collapse. Students observe the video given, shown in Figure 3. Some students identify the problems given and then ask the researcher.

![Figure 3. Students observe the video given by the researcher](image)

**Formulate The Main Problem**

From the problem given, the researcher provoked the students to formulate the main problem, "Why can the bridge collapse?". Several students could provide explanations as to why the bridge collapsed. According to one student, "Bridges can collapse due to natural disasters such as floods; bridges become brittle and collapse easily." There are also those who say, "Bridges collapse because they are overloaded, so they cannot withstand the weight above them."

**Provide Solutions**

The researcher directed each group to make a strong bridge using straws, tape, a ruler, and scissors as tools. The researcher asked the students if they had any questions about the activity given. Before making the bridge, each group made a bridge design using color markers, which can be seen in Figure 4. After that, students began to make the bridge according to their design.

![Figure 4. Students design the bridge that they will make](image)

The length of the bridge they make must be more than 25 cm because the length of the container used as a support is 25 cm. At this stage, students learn to measure using the ruler provided and think about how to make the straw longer than 25 cm because the straw given is only 20 cm long. In each group, there must be different opinions from each student who provides a solution to the problem.
Drawing Conclusions

After the bridge made by each group is finished, it is time to test how strong the bridge made by each group is. From testing the bridges made by the two groups, it turns out that both bridges are still equally fragile, not strong enough to withstand the load given to the bridge of group 1, which can only support 35 marbles, and the bridge of group 2 can only support 31 marbles, shown in Figure 5.

![Figure 5. Students test the bridge they made.](image)

At this stage, the researcher provoked students to reveal the problem of why the bridges they made were not strong enough to withstand the given load. Students can express problems, provide possible solutions, and observe their application at this stage. At this stage the researcher also gave worksheets to each group to fill in after making the bridge, Figure 6 is one of the worksheets that have been done by group 1.

![Figure 6. Student worksheet results](image)

Evaluated

At this stage, the researchers allowed each group to make a more vital bridge than the previous one. In the second experiment this time, it turned out that the bridges made by both groups became even more robust and could support 60-70 marbles, as can be seen in Figure 7. Based on the results of observations using observation sheets for students, the learning process with the application of STEM activities in making miniature bridges from straws goes as expected by researchers. Table 1 shows the EDP stages while making the miniature bridge and Table 2 is a recapitulation table of observations of critical thinking skills.
Figure 7. The second experiment of students.

Table 1. EDP table during the miniature bridge manufacturing process.

<table>
<thead>
<tr>
<th>Stages</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem</td>
<td>Students can identify problems given by researchers by identifying and formulating questions when viewing videos of natural disasters that cause bridges to collapse, then considering answers and asking researchers &quot;how to make a strong bridge.&quot;.</td>
</tr>
<tr>
<td>Identification</td>
<td></td>
</tr>
<tr>
<td>Formulate</td>
<td>Students can formulate the main points of the problem, namely that bridges can be damaged by nature (floods, rivers, landslides, and wind) and the bridge itself due to overload, maintenance, and age.</td>
</tr>
<tr>
<td>Main Problem</td>
<td></td>
</tr>
<tr>
<td>Provide</td>
<td>When making a miniature bridge using straws, each group worked together to provide solutions to make the bridge strong enough to withstand the weight of the marbles. One group was confused about making the bridge because the straw given was only 20 cm long, while the bridge that had to be made had to be more than 25 cm long. Based on this problem, one of the students provided a solution by combining two straws using solatip and then cutting them to 27 cm.</td>
</tr>
<tr>
<td>Solution</td>
<td></td>
</tr>
<tr>
<td>Drawing</td>
<td>During the first experiment, the bridges made by the two groups were still equally fragile and could not withstand the given load. Students can express the problem of why the bridges they make are not strong, provide possible solutions, and observe their application. Students can conclude the work of the worksheet given by the researcher. They can make and determine the results of considerations based on facts, consequences, and the application of existing facts.</td>
</tr>
<tr>
<td>Conclusion</td>
<td></td>
</tr>
<tr>
<td>Evaluate</td>
<td>In the second experiment, each group was able to correct the mistakes made while making the first bridge. The second bridge was more vital to support the weight of the marbles. Students could evaluate the results of the bridge they made and why it was not strong. According to one of the students, the bridge they built was not sturdy enough because there were many empty holes, and the tape was not tight enough, so the bridge collapsed quickly. In this case, students can express problems, choose possible solutions, and apply them.</td>
</tr>
</tbody>
</table>

Table 2. Recapitulation table of observations of critical thinking skills

<table>
<thead>
<tr>
<th>Name</th>
<th>Critical Thinking Indicator Scores</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>18</td>
</tr>
<tr>
<td>B</td>
<td>17</td>
</tr>
<tr>
<td>C</td>
<td>18</td>
</tr>
<tr>
<td>D</td>
<td>16</td>
</tr>
<tr>
<td>E</td>
<td>15</td>
</tr>
<tr>
<td>F</td>
<td>17</td>
</tr>
</tbody>
</table>
Discussion

The results of this research are expected to improve the quality of education in Indonesia in terms of developing critical thinking skills. As learning progresses, students show high enthusiasm for dealing with various phases, ranging from discussing problems, solving problems based on STEM activities, presenting the work results, and evaluating the work. Students also stated that the learning was fun; students learned while playing, like counting how many slugs could support the bridge they made. Students are invited to solve complex problems that require analytical, evaluative, and creative thinking. This process involves applying mathematical concepts to real-world problem-solving, thus helping students sharpen their ability to think critically and mathematically simultaneously. STEM activities strengthen students’ understanding of mathematics concepts and train them to think logically, analytically, and systematically (Wu & Rau, 2019).

Based on interviews and observations, students can identify problems that need to be solved when making miniatures of bridges, collecting relevant information, and designing practical solutions. Students also can analyze the data obtained and make informed decisions. Thus, applying STEM activities specifically affects students’ critical thinking skills, enabling them to develop analytical, evaluative, and problem-solving skills that are important in the context of STEM education (Hayes & Kraemer, 2017). These findings are consistent with previous research that has been quoted about the implementation of STEM in improving students’ ability to think critically. Previous research also highlighted the importance of applying STEM in mathematics learning to facilitate students' mathematical problem-solving skills in the New Normal era (Khoerunnisa et al., 2021). This aligns with the finding that STEM learning can enhance students' ability to think critically, especially in mathematical problem resolution.

This research contributes to understanding how STEM applications can improve students' critical thinking skills by focusing on specific activities. Students can develop their ability to think critically and holistically by integrating concepts from various STEM disciplines. Concrete examples of observations and interviews show that students engaged in STEM activities can better identify problems, gather information, design solutions, and analyze data, all essential critical thinking skills (Fathoni et al., 2020). Thus, the research provides a deeper understanding of how STEM applications can affect and enhance students’ critical-thinking skills, which aligns with previous research findings that emphasize the importance of STEM approaches in the context of mathematical education and student problem-solving skills development.

Moreover, based on research by Setio and Utama (2022), it was concluded that ‘the use of science, technology, engineering, and mathematics (STEM) can significantly improve students’ ability to think critically. STEM-based education has grown to integrate a wide range of science subjects, thus providing a holistic and relevant understanding of students' daily lives to prepare them to face careers in various innovative fields (Ongc Bey et al., 2023). According to (Febril et al., 2022), using STEM in learning encourages students to participate actively and responsibly in understanding the subject matter.

The active involvement of students in the STEM learning process contributes to developing their critical thinking skills. Students actively engaged in STEM learning can take the initiative in problem-solving and evaluating their work outcomes (Rahman, 2023). For example, students can identify problems, gather relevant information, design solutions, and analyze data better. For instance, students actively engaged in STEM learning can take the initiative to identify the problems they encounter in the construction process of their mini bridge. Students can collect relevant information, design solutions, and analyze data better to make bridges more efficient. Students can also take the initiative to evaluate their performance, such as analyzing their bridge performance and identifying areas of improvement that need to be made. Thus, the active involvement of students in the STEM learning process helps develop their critical thinking skills so that they can understand STEM concepts holistically and apply them in complex problem-solving contexts (Prajahan & Worapun, 2023).
CONCLUSION

The key findings of this study proved that integrating STEM with learning can sharpen students' critical thinking patterns. The study was conducted in Kampung Joho, D.I. Yogyakarta, Indonesia, for 3–9-year-old students. The interviews and observations show that students can identify problems that need to be solved when making miniatures of bridges, gathering relevant information, and designing practical solutions. Students also can analyze the data obtained and make informed decisions. The findings of this research are essential because the STEM approach can help sharpen students' critical thinking patterns, which are needed to improve the quality of education in Indonesia. STEM approaches can combine various methods for collecting and analyzing data, such as triangulation methods that combine different data sources and analysis methods. This integration can help students develop more holistic and relevant critical thinking skills needed to improve the quality of education in Indonesia.

It is hoped that STEM applications will continue to be developed for learning in schools, not only for elementary school students but also for high school students' learning. High school students also need to be implemented because applying STEM in sharpening learning not only sharpens critical thinking patterns. However, it can make students seem very enthusiastic about dealing with the various processes, ranging from discussing problems, solving problems based on STEM activities, and presenting the results of the work to evaluating the work. Research areas that can be explored based on the results of this research are integrating the STEM approach with learning more and more deeply, developing students' ability to think critically, holistically, and relevantly, combining various methods for collecting and analyzing data, such as triangulation methods that combine various data sources and analysis methods, using theory to validate research results, and integrating STEM methods with student skills and character education.

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