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PROJECT-BASED LEARNING INTEGRATED WITH SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) TO THE CRITICAL THINKING SKILLS OF STUDENTS IN ELEMENTARY SCHOOL

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ABSTRACT

This research aims to explore the influence of Project-Based Learning (PBL) integrated with Science, Technology, Engineering, and Mathematics (STEM) on the critical thinking skills of elementary school students in thematic learning. A quantitative design with a pre-experimental one-group pretest-posttest design was used in this study. The collected data was collected using observation and tests. The data is collected and analyzed descriptively and inferentially using the SPSS Version 26 application. Data analysis begins with descriptive statistics, normality, and hypothesis tests. The results showed an influence of Project Based Learning integrated with Science, Technology, Engineering, and Math on the critical thinking skills of elementary school students. Through that learning, students' necessary thinking skills are provoked and trained so that students can define, formulate, argue, and also conclude in solving a problem.

KEYWORDS: Critical Thinking Skills, Project-based Learning, STEM.

ABSTRAK

Penelitian ini bertujuan untuk mengetahui pengaruh Pembelajaran Berbasis Proyek (PBL) yang diintegrasikan dengan Sains, Teknologi, Rekayasa, dan Matematika (STEM) terhadap kemampuan berpikir kritis siswa sekolah dasar dalam pembelajaran tematik. Penelitian ini menggunakan desain kuantitatif dengan rancangan *pre-eksperimental one-group pretest-posttest design*. Data dikumpulkan menggunakan observasi, wawancara, dan tes. Data yang terkumpul dianalisis secara deskriptif dan inferensial dengan menggunakan aplikasi SPSS Versi 26. Proses analisis data diawali dengan statistik deskriptif, uji normalitas, dan uji hipotesis. Hasil penelitian menunjukkan adanya pengaruh pembelajaran berbasis projek yang terintegrasi dengan Sains, Teknologi, Rekayasa, dan Matematika terhadap kemampuan berpikir kritis siswa sekolah dasar. Melalui pembelajaran tersebut, kemampuan berpikir kritis siswa dipancing dan dilatih agar siswa dapat mendefinisikan, merumuskan, berargumentasi, dan juga menyimpulkan dalam menyelesaikan suatu permasalahan.

KATA KUNCI: Keterampilan Berpikir Kritis, Pembelajaran Berbasis Proyek, STEM.

INTRODUCTION

The 21st century requires students to master various skills, such as critical thinking, creative thinking, collaboration, problem-solving, and communication, to become successful individuals (Kivunja, 2014; Septikasari, 2018). In addition, Apollo Education Group identifies students' skills to work in the 21st century: leadership, communication, adaptability, collaboration, innovation, productivity and accountability, global citizenship, Entrepreneurship, critical thinking, analysis, and synthesizing information (Zubaidah, 2016). The 2013 curriculum has facilitated capabilities in the 21st century on content, process, and assessment standards (Fernandes, 2019). Implementing the 2013 Curriculum in Indonesia includes developing higher-order thinking skills. One of the higher-order thinking skills is critical thinking skills.

In the 2013 curriculum, learning materials must be arranged sequentially to the metacognitive stage so students can predict and design their problem-solving. (Mailani, 2018; Rindarti, 2018) In the 21st century, the demands on students have changed significantly. In addition to traditional academic knowledge, students are expected to master critical skills to help them become successful individuals in an ever-changing world. Some fundamental skills include critical thinking, creative thinking, collaborating, problem-solving, and communicating effectively. Developing higher-order thinking skills, especially critical thinking skills, is considered one of the key strategies to prepare students for success in the complex and dynamic 21st century.

Critical thinking is one of the 21st-century skills students need. Critical thinking is important to adapt to changes in the existing environment and to be more careful in receiving information by examining the information first. Critical thinking skills can help students solve a problem well, be cautious in making decisions, and not assume that something can be done instantly (Lismaya, 2019; Romadhoni Hidayatullah et al., 2022). Critical thinking skills are analyzing problems, classifying them carefully, and identifying information to establish problem-solving strategies (Seman et al., 2017; Zabit, 2010).

This opinion was reinforced by Aizikovitsh-Udi & Cheng, who explain that critical thinking can be done with reflective thinking in determining a decision and problem-solving strategy by analyzing the situation, evaluating arguments, and drawing the correct conclusions (Aizikovitsh-Udi & Cheng, 2015). People who think critically can conclude what they know, know how to use the information to solve problems, and find relevant sources to support problem-solving (Ayub et al., 2021).

Critical thinking is seeing information and solving a problem by asking oneself to extract data for the problem (Christina & Kristin, 2016). Based on the explanation above, critical thinking skills are basic problem-solving abilities. There are two phases in applying critical thinking skills, namely, the first phase of internalization. Students build their minds through basic ideas, principles, and theories embedded in the content. The second phase is the externalization phase. Students effectively use these ideas, principles, or theories in life as a form of application.

Students' competence in Indonesia is still low based on the 2021 Program for International Student Assessment (PISA) results. Indonesian students' PISA scores related to literacy, numeracy, and science in 2021 were below average, even decreasing compared to the assessments three years earlier (Susilowati et al., 2022). That is supported by the results of observations of researchers in one of the elementary schools in the city of Makassar. As a result, researchers found that applied learning still uses conventional models instead of scientific approaches, so students' skills are not trained. The teacher gives explanations only accompanied by media in the form of pictures, so they cannot maximize students' critical thinking skills. In addition, the teacher evaluates students' abilities through quizzes with low-order thinking skill questions, so students' critical thinking skills are not optimal. Applying critical thinking skills in the learning process is crucial for students to build their knowledge.

Project-based learning (PBL) is one learning model that can stimulate students' critical thinking skills (Barrows & Tamblyn, 1980). This model is a project where students are given freedom in their activities because it is student-centered. The project's output was carried out collaboratively, resulting in a memorable product and experience for students (Kokotsaki et al., 2016). PBL can train independent students to solve and overcome a problem that exists in a project (Hmelo-Silver, 2004). Several previous studies in the context of PBL integrated with the Science, Technology, Engineering, and Mathematics (STEM) approach show significant opportunities to improve the critical thinking skills of elementary school students, such as research (Asyari et al., 2016; Febrianto et al., 2021; D. K. Putri et al., 2023; Saputra et al., 2019).

These studies noted that students naturally engage in critical thinking processes when they engage in challenging STEM-based projects. They must analyze information, solve complex problems, and decide based on available evidence. In addition, STEM-PBL often involves solving real-world problems requiring students to think critically in a context relevant to the world around them. These contextualized learning experiences allow students to connect STEM concepts with practical applications, strengthening their understanding and encouraging critical thinking. In addition, collaboration in teams and effective communication in PBL projects also play an important role in developing critical thinking skills.

Previous studies have confirmed that STEM-integrated PBL can improve elementary school students' analysis, evaluation, and problem-solving skills. Thus, this approach can strengthen students' critical thinking skills while providing relevant and immersive learning experiences. In addition, STEM is also suitable to help students practice their critical thinking skills through science. STEM focuses on solving real real-life problems(Mu'minah & Suryaningsih, 2020). The four fields of knowledge or disciplines in STEM will help and train students' critical thinking skills.

The first field is science. This field can help students gain understanding through experimental tests and observations that refer to the principles of something being researched and studied. The second field of science is technology. This field supports other fields of knowledge and assists and facilitates student work. The third field is engineering. This field helps students to do something they want to do. The fourth field is mathematics. This field allows students to explain the interrelationships between concepts and apply concepts in accurate, efficient, and flexible ways to solve problems (Laboy-Rush, 2010; Mu'minah & Suryaningsih, 2020). STEM learning aims to develop students' abilities in these four fields of knowledge.

PBL integrated with STEM is appropriate for developing creativity, problem-solving, training critical thinking, and student collaboration. That is supported by previous research, which revealed that the integration of STEM with PBL could help students explore ideas, develop a product, and develop their design skills (Annisa et al., 2021; Lutfi et al., 2018; Maulana, 2020; C. Putri et al., 2020). In PBL, students understand concepts by making products. In contrast, a design and redesign process in STEM learning makes students produce their best products. Integrating STEM impacts students positively, especially in improving learning outcomes and critical thinking skills in technology and science (Becker & Park, 2011). Based on this background, the authors are interested in exploring the influence of PBL integrated with STEM on the critical thinking skills of elementary school students in thematic learning. The proposed hypothesis is that H_0 has no effect, and H_1 has an impact.

METHODS

Quantitative design with a pre-experimental one-group pretest-posttest design is the type of research used in this study. This design allows for measuring changes in students' critical thinking skills before and after the intervention, is simple to control, produces quantitative data that can be statistically analyzed, and has significant relevance in the context of education policy. It helps measure the impact of STEM-integrated PBL on students' critical thinking skills. This study only used 1 group as the research subject. Research subjects will be given a test before treatment to determine their initial abilities. After the treatment, the research subjects were given a post-test to assess the effect of Integrated STEM-PBL on the critical thinking skills of elementary school students in thematic learning. The research design can be seen in Figure 1.

O_1	X	O_2
Pretest	Treatment	Post-test

Table 1. The research design

The research population was fifth-grade students at Komplek IKIP Public Elementary School. At the same time, the sample is fifth-grade student A, totaling 25 students selected using the purposive sampling technique. This study used observations and tests to collect data. This observation was carried out in the pre-research to determine the initial conditions of the subjects and research objects. Tests were conducted in pre-research to assess teachers' learning conditions or situations. The test sheet consists of five essay questions with tangible material to measure the critical thinking skills of elementary school students.

Making the test sheet refers to the indicators of critical thinking skills developed by Robert Ennis, which include clarification first, essential support, inference, advanced clarification, and creating a strategy or technique. Before being used, test instruments were validated. The data is collected and then analyzed descriptively and inferentially using the SPSS Version 25. Data analysis begins with descriptive statistical analysis, normality, and paired sample tests. The hypothesis of this study is H_0: There is no difference in Critical Thinking Ability before and after being given PBL Integrated STEM, and H_1: There is a difference in Critical Thinking Ability before and after being given PBL Integrated STEM.

RESULT AND DISCUSSION

Result

Project-based learning integrated with STEM has stages: reflection, research, discovery, application, and communication. The five steps of learning were carried out in three meetings. The first meeting includes the reflection and research stages, the second comprises the discovery stage, and the third consists of the application and communication stages. Before learning, students are asked to do a pretest to determine their initial Skills. After learning with treatment, students do a post-test. The results of the pretest and post-test of students are shown in Table 2.

Table 2. Pretest and post-test results of students' critical thinking skills

	N	Range	Min	Max	Mean	Std. Deviation
Pretest	25	35	40	75	54.60	7.762
Posttest	25	40	55	95	76.40	11.772
Valid N (listwise)	25					

Based on Table 1, the average student scores are 54.60, with a standard deviation of 7.762 and a maximum score of 75 in the pretest. In the post-test, students obtained an average score of 76.40 with a standard deviation of 11.772 and a maximum score of 95.

The pretest and post-test data results were tested for normality to determine whether the data were normally distributed as a condition for testing the hypothesis. The normality test results can be seen in Figure 1.

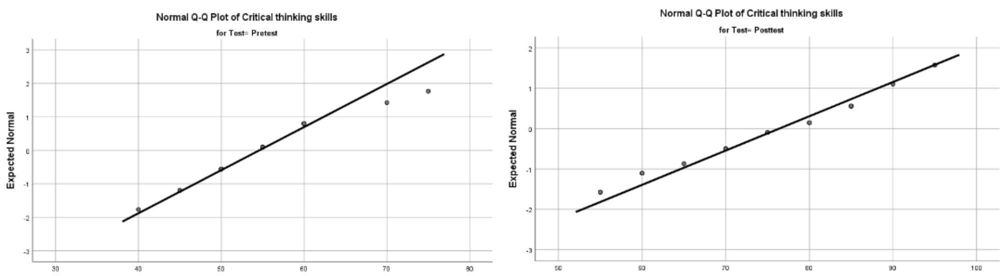

Figure 1. The normality test results for students' critical thinking skills

Figure 1 shows the spread of points following a diagonal line so that the data has an assumption of normality. The Kolmogorov-Smirnov test to test the normality of the residual data states that if the Kolmogorov-Smirnov test obtains a significant value above 0.05, the residuals are normally distributed. Conversely, the residuals are not normally distributed if a significant value is below 0.05. The results of the data normality test in Table 3 support Figure 1.

Table 3. Results of normality test of students' critical thinking skills data

	Test	Kolmogorov-Smirnov[a] Statistic	df	Sig.
Critical thinking skills	Pretest	.163	25	.084
	Posttest	.167	25	.069

Based on Table 3, the data is stated to be normally distributed. That is evidenced by the significant value of students' critical thinking skills in the pretest and post-test greater than 0.05. In the Kolmogorov-Smirnov test, the pretest obtained a significance value of 0.084 > 0.05, while the post-test obtained a significance value of 0.069 > 0.05. After the data is normally distributed, the data will be tested using a paired sample test. In addition, the homogeneity test results showed sig = 0.546 > 0.05. Hence, the data on students' critical thinking skills on the pretest came from populations that met the homogeneity requirements. The results of hypothesis testing can be seen in Table 4.

Table 4. Hypothesis Test Results

	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	95% Confidence Interval of the Difference Upper	t	df	Sig. (2-tailed)
Pretest - Posttest	-21.800	10.296	2.059	-26.050	-17.550	-10.587	24	.000

Based on Table 4, the t-count for critical thinking skills is -10.587, with a significance of 0.000. That shows that H_0 is rejected and H_1 is accepted, so project-based learning integrated with STEM significantly influences students' critical thinking skills because of the probability Sig <0.05. In addition, the post-test score is greater than the pretest, with details of the post-test score of 76.40 and the pretest score of 54.60.

Discussion

Integrated Project Based Learning with STEM consists of reflection, research, discovery, application, and communication stages (Laboy-Rush, 2010). Through the reflection stage, students are invited to see changes in the shape of objects found in everyday life. So, at this stage, students combine learning through real-world experiences (Agustina et al., 2018; Dewi et al., 2016; Usmaedi, 2017; Wiratman et al., 2019).

At the research stage, students receive information from the teacher and can ask questions and give opinions. The teacher acts as a facilitator to actively involve students in learning activities. At this, students understand the material using rational reasoning (Armadi, 2017). Students will make decisions after obtaining the information needed(McGregor, 2007).

At the Discovery stage, students carry out experimental designs. Students understand the experimental steps in the student activity sheet at this stage. In their understanding, students also prepare the tools and materials needed in the experimental material to change objects' shapes. Students also provide opinions on the available experimental designs. In this discovery stage, students will prioritize the ability to define, formulate, argue, and conclude in solving a problem (Zohar & Nemet, 2002).

In the Application stage, students experiment with material changes in the shape of objects. The purpose of the experiments carried out by students was to solve problems in changing objects' shapes. Students will prove something, interpret what something means, and solve problems (Facione, 2020; Suryaningsih, 2017). In this experiment, students try to prove the experiment to get answers or solve problems. After students carry out experiments, they will make decisions using a conclusion. That follows the indicators of critical thinking in the inference section (Ennis, 1981).

In the communication stage, students present the results of the experiments that have been carried out. It differentiates the project-based learning and project-based learning flow integrated with STEM. The steps of Project Based Learning reach the evaluation stage, where at the end of the learning process, educators and students only reflect on the activities and results of projects that have been carried out without presenting the results of their experiments. Through the communication stage, the learning process becomes an activity that can provide students with an exciting experience(Arumsari et al., 2017; Utami, 2018). Each step of Project-Based learning integrated with STEM aims to provoke students' critical thinking skills, as evidenced by the difference in scores before and after treatment (Afriana et al., 2016; Khoiriyah et al., 2018). In addition to giving test sheets to students, researchers also conducted observations with students to obtain additional data.

The research showed that integrated project-based learning with STEM could stimulate students' critical thinking skills. That can be seen in the answers from students. In the first student's response, namely reading the reading, understanding it, and then making questions according to the reading. That represents the ability to think critically through elementary clarification's first indicator (Ennis, 1981). The indicator is broken down into asking questions and responding to explanations or challenges (Vidal-Abarca et al., 2010). Then, the answer to the second test is to find the cause of the problem first and then solve the problem. This answer follows the second indicator of critical thinking, namely Basic

Support (Ennis, 1981)—the student answers by understanding the reading first and then concluding the reading.

The third student's response follows the indicator of critical thinking, namely inference (Ennis, 1981). The answer to the fourth question is that students understand existing reading sources, then if asked to explain, it will be appropriately presented following the reading that has been read. From these results, students can think critically according to the fourth indicator of critical thinking, namely advanced clarification (Ennis, 1981). Finally, students are asked to develop strategies or steps for making ice cream. As a result, students can provide strategies or actions for making ice cream. According to the fifth indicator, this question provoked students' critical thinking skills, namely developing a method or technique (Ennis, 1981).

The critical thinking skills of elementary school students can be strengthened by applying a Project Based Learning approach integrated with STEM concepts, supported by several relevant educational theories. First, constructivism theory asserts that students construct knowledge through direct interaction with the environment (Sugrah, 2020). In the context of PBL, students are exposed to real-world tasks that demand creative problem-solving, encourage active participation in understanding STEM concepts, and hone critical thinking skills. Second, Bruner's cognitive principles highlight the effectiveness of relevant and meaningful learning (Hatip & Setiawan, 2021). In STEM-integrated PBL, students engage in practical projects pertinent to everyday life, facilitating the integration of abstract STEM concepts with the natural world and stimulating improved critical thinking skills. Third, Bandura's social learning theory shows the importance of learning through social interaction (Reflina, 2018).

Through PBL, students collaborate in groups to solve problems, observe each other, and share ideas, stimulating the development of critical thinking skills through social exchange. Fourth, Vygotsky's collaborative learning theory emphasizes the crucial role of social interaction in learning (Erbil, 2020). STEM-integrated PBL encourages cooperation and knowledge exchange between students, deepens understanding of STEM concepts, and promotes critical thinking. Finally, Lave and Wenger's context- and activity-based learning principles emphasize the relevance of real contexts in learning (Dar, 2021; Niesz & Ryan, 2018).

STEM-integrated PBL allows students to engage in real projects that require the application of STEM concepts in real-world situations, promoting deep understanding and critical thinking skills. The comprehensive integration of these theories in STEM-integrated PBL allows students to hone necessary thinking skills through learning experiences focusing on problem-solving, social interaction, and practical application of STEM concepts in real-world contexts.

The effect of PBL integrated with STEM on students' critical thinking skills is also supported by previous research (Rahardhian Guru et al., 2022; Sumardiana et al., 2019), which revealed that PBL-integrated STEM has a significant influence on students' critical thinking skills. That is evidenced by the increased scores on the post-test of students' critical thinking skills.

CONCLUSION

The scientific conclusion of this study is that implementing Project-Based Learning integrated with STEM impacts students' critical thinking skills. The research shows that the five learning stages combined in this approach, reflection, research, discovery, application, and communication, can encourage the development of students' critical thinking skills. The results of the data analysis showed a significant increase in critical thinking scores on the post-test compared to the pretest. Thus, this approach improved students' critical thinking skills through the implemented learning stages. In addition, this research also supports relevant educational theories, such as constructivism, Bruner's cognitive principles, Bandura's social learning theory, Vygotsky's collaborative learning theory, and Lave and Wenger's context- and activity-based learning principles.

The comprehensive integration of these theories in the STEM-integrated PBL approach enables students to develop critical thinking skills through learning experiences focusing on problem-solving, social interaction, and practical application of STEM concepts in real-world contexts. The findings of this study are also consistent with previous studies showing that the STEM-integrated Project Based Learning approach positively influences students' critical thinking skills. Therefore, this approach can be considered as an effective method to improve student's critical thinking skills in the context of STEM learning. This study contributes to the discourse surrounding innovative educational practices that prioritize the development of essential cognitive skills in students, thus bridging the gap between theoretical understanding and practical problem-solving capabilities in elementary education.

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