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The Effect of STEM Integration on Scientific Literacy and Scientific Attitudes: An Empirical Study in Primary Education

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Abstract: This study aims to examine the effect of implementing the Science, Technology, Engineering, and Mathematics (STEM) approach on elementary school students' scientific literacy and scientific attitudes. A quasi-experimental method with a one-group pretest–posttest design was employed. The participants consisted of 30 third-grade students from SD Negeri 100206 Pintu Padang, South Angkola District. Data were collected using a scientific literacy test in the form of essay questions, a scientific attitude questionnaire, and observation sheets to assess the implementation of the learning process. The data were analyzed quantitatively using the normalized gain (N-gain) to measure the level of improvement and a paired-sample t-test to determine the significance of differences between pretest and posttest scores. Prior to hypothesis testing, prerequisite tests, including tests of normality and homogeneity, were conducted. The findings indicate that the implementation of the STEM approach led to a substantial improvement in students' scientific literacy. The mean score increased from 48.33 in the pretest to 88.33 in the posttest, with an N-gain value of 0.77, categorized as high. Similarly, students' scientific attitudes improved significantly, with the mean score increasing from 49.50 to 89.17 and an N-gain value of 0.78, also classified as high. The paired-sample t-test yielded a significance value of 0.000 ($p < 0.05$), indicating statistically significant differences between pretest and posttest scores. These results suggest that the STEM approach is effective in enhancing both cognitive aspects (scientific literacy) and affective aspects (scientific attitudes). This effectiveness may be attributed to the characteristics of third-grade students, who are in the concrete operational stage of cognitive development. At this stage, students learn more effectively through direct experiences, hands-on activities, and real-life problem-solving. The STEM approach accommodates these needs by engaging students in practical investigations, collaborative tasks, and contextual learning, thereby making abstract concepts more tangible and meaningful. Therefore, the integration of STEM in science learning can be considered an effective instructional strategy to enhance students' engagement, critical thinking, and problem-solving skills in elementary education.

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Introduction

Education is a fundamental human endeavor aimed at developing individual potential both physically and spiritually in accordance with societal and cultural values. It plays a central role in shaping knowledgeable, skilled, and morally responsible individuals who can contribute to social development. In the Indonesian context, Law of the Republic of Indonesia No. 20 of 2003 on the National Education System defines education as a conscious and planned effort to create a learning environment that enables students to actively develop

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their potential, including spiritual strength, self-control, intelligence, noble character, and essential life skills. In line with global transformation, the rapid development of science and technology—particularly cyber technology—has significantly influenced various aspects of life, including education. This shift has marked the emergence of the Industrial Revolution 4.0, which emphasizes digitalization and automation, and has consequently given rise to the concept of Education 4.0, where learning integrates technology to foster more adaptive, innovative, and student-centered approaches (Lase, 2019).

In the context of 21st-century education, students are required to develop a set of essential competencies commonly referred to as the 4C skills, which include critical thinking, creativity, communication, and collaboration. Beyond these competencies, the ability to demonstrate scientific and digital literacy has become increasingly important, as these skills enable individuals to navigate complex and dynamic global challenges (Trilling & Fadel, 2009). Scientific literacy, in particular, is not limited to understanding scientific concepts, but also involves the ability to apply scientific knowledge in everyday situations and to make decisions grounded in empirical evidence (OECD, 2019). Consequently, science instruction at the elementary level should move beyond mere content delivery and instead foster inquiry-based learning, reasoning skills, and meaningful learning experiences that actively engage students (Bybee, 2013).

Despite these expectations, evidence suggests that the level of scientific literacy among Indonesian students remains a concern. Data from the Programme for International Student Assessment (PISA) 2022 indicate that Indonesia ranked 64th out of 78 countries, with an average score of 384, which is considerably lower than the OECD average of 500 (OECD, 2023). This result implies that many students experience difficulties in interpreting scientific information, connecting it to real-life contexts, and formulating logical conclusions based on available evidence. Consistent with this, Hidayah et al. (2020) reported that students' scientific literacy in Indonesia is still limited across several dimensions, including conceptual understanding, scientific processes, and contextual application.

At the primary school level, particularly in Integrated Science and Social Studies (IPAS), classroom practices are often still dominated by teacher-centered approaches. Instruction tends to emphasize lectures and rote memorization, providing minimal opportunities for students to engage in inquiry, experimentation, or problem-solving activities (Suryani et al., 2021). Such learning conditions contribute to passive student participation, where learners depend heavily on the teacher and have limited chances to construct knowledge independently. As a result, not only is the development of scientific literacy hindered, but essential scientific attitudes—such as curiosity, critical thinking, objectivity, honesty, and openness—are also insufficiently cultivated (Harlen, 2015).

These issues are also evident in preliminary findings from SD Negeri 100206 Pintu Padang. The data revealed that students' scientific literacy was relatively low, with an average score of 58.6%, categorized as poor. Furthermore, the assessment of scientific attitudes indicated that several key indicators, including collaboration, skepticism, and the use of evidence in reasoning, were still at a low level. Classroom observations showed that students tended to be passive, less engaged in learning activities, and not yet confident in expressing their ideas or conducting independent exploration. In addition, teacher interviews indicated that instructional practices were still largely teacher-centered, with limited implementation of innovative teaching strategies and learning media.To address these challenges, an innovative and integrative learning approach is needed to enhance both cognitive and affective learning outcomes. One such approach is the STEM (Science, Technology, Engineering, and Mathematics) approach, which integrates the engineering design process and the use of simple technologies to actively engage students in hands-on, inquiry-based learning, thereby addressing the issue of student passivity in the classroom.

. STEM education integrates multiple disciplines into a cohesive learning experience that emphasizes problem-solving, critical thinking, and real-world application (Bybee, 2013). According to Sanders (2009), STEM is not merely the teaching of four separate disciplines but an interdisciplinary approach that connects concepts and practices to solve authentic problems. Furthermore, Moore et al. (2014) argue that STEM-based learning can improve students’ engagement, conceptual understanding, and higher-order thinking skills through project-based and inquiry-driven activities.

A growing body of research has highlighted the potential of STEM-based learning in enhancing educational outcomes. For instance, Tsutaoka (2018) emphasized that STEM education plays a crucial role in improving the overall quality of education by strengthening students’ conceptual understanding and practical skills. Likewise, Afriana et al. (2016) demonstrated that STEM-oriented instruction can effectively enhance students’ scientific literacy through the integration of real-world problem-solving activities that are both meaningful and contextually relevant. Furthermore, Wahyuni et al. (2020) reported that student-centered approaches, including STEM, contribute positively to the development of scientific attitudes, particularly by promoting collaboration, curiosity, and persistence during the learning process.

Although these studies provide valuable insights, most of them tend to emphasize cognitive outcomes, such as academic achievement and conceptual mastery. Research that simultaneously examines both cognitive and affective dimensions—specifically scientific literacy and scientific attitudes—remains relatively limited, especially within the context of elementary education. In addition, the application of STEM in IPAS learning at the primary school level in Indonesia has not been widely investigated. This gap underscores the need for further empirical studies that explore the comprehensive impact of STEM-based learning. Accordingly, the present study offers a contribution by examining the integrated effects of the STEM approach on both students’ scientific literacy and their scientific attitudes within elementary school settings. Therefore, this study aims to analyze the effect of the STEM approach on the scientific literacy and scientific attitudes of third-grade students in IPAS learning at SD Negeri 100206 Pintu Padang.

Research Method

This study adopted a quasi-experimental approach employing a one-group pretest–posttest design to examine changes in students’ learning outcomes following the implementation of an instructional treatment. In this design, a single group of participants was assessed before and after the intervention without the inclusion of a control group. A pretest was administered at the beginning of the study to identify students’ initial levels of scientific literacy and scientific attitudes. Subsequently, the STEM (Science, Technology, Engineering, and Mathematics) approach was implemented during the learning process. At the end of the intervention, a posttest was conducted to evaluate the extent of improvement. Differences between pretest and posttest scores were analyzed using a paired sample t-test, as the measurements were obtained from the same group of participants. The population of this study included all third-grade students in South Angkola District, specifically from SD Negeri 100206 Pintu Padang and SD Negeri 100202 Napa. The sample was selected using purposive sampling, consisting of 30 third-grade students from SD Negeri 100206 Pintu

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Padang. This school was considered more representative than SD Negeri 100202 due to its relatively homogeneous student characteristics, particularly in terms of initial academic ability and learning background, which allowed for a more controlled examination of the intervention's effects. Additionally, the selected students demonstrated comparable levels of prior knowledge and classroom engagement, ensuring that the sample met the criteria necessary to support the validity of the study, as well as the practicality of conducting the research within the given context.

In this study, the STEM approach served as the independent variable, while scientific literacy and scientific attitudes functioned as the dependent variables. The STEM approach was conceptualized as an integrated learning framework that combines science, technology, engineering, and mathematics in a contextual and problem-oriented manner. Scientific literacy was defined as the ability to comprehend scientific phenomena, explain them using scientific reasoning, and apply evidence-based thinking to solve problems. Meanwhile, scientific attitudes referred to students' dispositions toward scientific thinking, including objectivity, critical thinking, honesty, openness, and responsibility.

Data were collected using multiple instruments, including a scientific literacy test, a scientific attitude questionnaire, observation sheets, and structured interviews. The scientific literacy test consisted of essay-type questions designed to assess students' understanding across content, process, and contextual dimensions. The scientific attitude instrument was developed to evaluate students' behavioral tendencies in responding to scientific situations. To facilitate interpretation, all scores were converted into percentage values.

Prior to data collection, all instruments were subjected to validity and reliability testing, as well as item analysis, including difficulty level and discrimination index. These procedures were conducted to ensure that the instruments were appropriate, consistent, and capable of distinguishing between varying levels of student ability.

The data analysis was carried out quantitatively. Students' learning improvements were measured using the normalized gain (N-Gain) formula, with its classification (high, medium, low) referring to Richard R. Hake (1998). Before conducting hypothesis testing, the data were examined for normality using the Shapiro–Wilk test, as the sample size was less than 50, and for homogeneity to ensure the equality of variance. The normality test was used to assess whether the data followed a normal distribution, while the homogeneity test examined the equality of variance. After fulfilling these assumptions, hypothesis testing was performed using a t-test at a significance level of 0.05 to determine the effect of the STEM approach on students' scientific literacy and scientific attitudes.

Students' scientific literacy and scientific attitudes were assessed using two instruments, namely a scientific literacy test consisting of 10 essay questions and a scientific attitude questionnaire comprising 20 items. The data collection process was carried out in two stages, starting with a pretest administered before the implementation of the STEM-based learning to identify students' initial abilities, followed by a posttest conducted after the learning process to measure the improvement in students' outcomes.

In addition to tests and questionnaires, the implementation of the learning process was also evaluated using an observation sheet. This instrument was used to examine how well the STEM approach was applied during the instructional activities. The sample of this study consisted of 30 third-grade students from SD Negeri 100206 Pintu Padang, who were selected as research participants. The learning material used in this study focused on the topic of energy transformation in IPAS. The results of the scientific literacy data are presented as follows:

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Students' Scientific Literacy Data in IPAS Learning Using the STEM Approach

Based on the research conducted in the third-grade class consisting of 30 students, the students' scientific literacy data were obtained from pretest and posttest results. The pretest was administered before the learning process to determine students' initial abilities, while the posttest was administered after the completion of the learning process. The pretest and posttest data on scientific literacy obtained from the study are presented in Table 1 below:

Table 1. Pretest and Posttest Data of Students' Scientific Literacy

Student Code	Pretest	Posttest	Gain	Ideal Score	N-Gain	Category
X1	40	100	60	60	1.00	High
X2	50	80	30	50	0.60	High
X3	55	85	30	45	0.67	High
X4	40	90	50	60	0.83	High
X5	55	95	40	45	0.89	High
X6	50	100	50	50	1.00	High
X7	55	85	30	45	0.67	High
X8	40	90	50	60	0.83	High
X9	45	70	25	55	0.45	Moderate
X10	50	90	40	50	0.80	High
X11	55	90	35	45	0.78	High
X12	40	70	30	60	0.50	Moderate
X13	60	95	35	40	0.88	High
X14	45	95	50	55	0.91	High
X15	50	90	40	50	0.80	High
X16	55	85	30	45	0.67	High
X17	55	80	25	45	0.56	High
X18	50	90	40	50	0.80	High
X19	40	95	55	60	0.92	High
X20	45	90	45	55	0.82	High
X21	50	75	25	50	0.50	Moderate
X22	55	85	30	45	0.67	High
X23	45	80	35	55	0.64	High
X24	40	95	55	60	0.92	High
X25	50	80	30	50	0.60	High
X26	55	85	30	45	0.67	High
X27	40	100	60	60	1.00	High
X28	45	100	55	55	1.00	High
X29	55	90	35	45	0.78	High
X30	40	95	55	60	0.92	High
Total	**1450**	**2650**	**1200**	**1550**	**23.0432**	
Average	**48.33**	**88.33**	**40.00**	**51.67**	**0.76811**	**High**

Based on Table 1, it can be seen that the average pretest score obtained by the students was 48.33%, which is significantly lower compared to the posttest average score of 88.33%. The average N-Gain score achieved by the students was 0.76811, which falls into the high category. A total of 27 students achieved a high category, while 3 students were categorized in the moderate level.

Students' Scientific Attitude Data in IPAS Learning Using the STEM Approach

Based on the research conducted in the third-grade class consisting of 30 students, the data on students' scientific attitudes were obtained from pretest and posttest results. The pretest was

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administered before the learning process to determine students' initial attitudes, while the posttest was administered after the completion of the learning process. The pretest and posttest data on scientific attitudes obtained from the study are presented in Table 2 below:

Table 2. Pretest and Posttest Data of Students' Scientific Attitudes

Student Code	Pretest	Posttest	Gain	Ideal Score	N-Gain	Category
X1	50	90	40	50	0.80	High
X2	55	95	40	45	0.89	High
X3	40	100	60	60	1.00	High
X4	45	85	40	55	0.73	High
X5	50	95	45	50	0.90	High
X6	55	95	40	45	0.89	High
X7	55	90	35	45	0.78	High
X8	40	75	35	60	0.58	Moderate
X9	45	85	40	55	0.73	High
X10	50	80	30	50	0.60	Moderate
X11	55	95	40	45	0.89	High
X12	40	100	60	60	1.00	High
X13	60	85	25	40	0.63	Moderate
X14	45	90	45	55	0.82	High
X15	50	70	20	50	0.40	Moderate
X16	55	90	35	45	0.78	High
X17	55	80	25	45	0.56	Moderate
X18	50	90	40	50	0.80	High
X19	40	95	55	60	0.92	High
X20	45	90	45	55	0.82	High
X21	60	80	20	40	0.50	Moderate
X22	50	85	35	50	0.70	High
X23	55	90	35	45	0.78	High
X24	55	95	40	45	0.89	High
X25	50	80	30	50	0.60	Moderate
X26	40	85	45	60	0.75	High
X27	45	100	55	55	1.00	High
X28	50	90	40	50	0.80	High
X29	60	100	40	40	1.00	High
X30	40	95	55	60	0.92	High
Total	**1485**	**2675**	**1190**	**1515**	**23.427**	
Average	**49.50**	**89.17**	**39.67**	**50.50**	**0.7809**	**High**

Based on Table 2, it can be seen that the average pretest score obtained by the students was 49.50%, which is considerably lower than the posttest average score of 89.17%. The average N-Gain score achieved by the students was 0.7809, which falls into the high category. A total of 23 students achieved a high category, while 7 students were categorized as moderate. The average scores of the pretest, posttest, and N-Gain are illustrated in the following figure.

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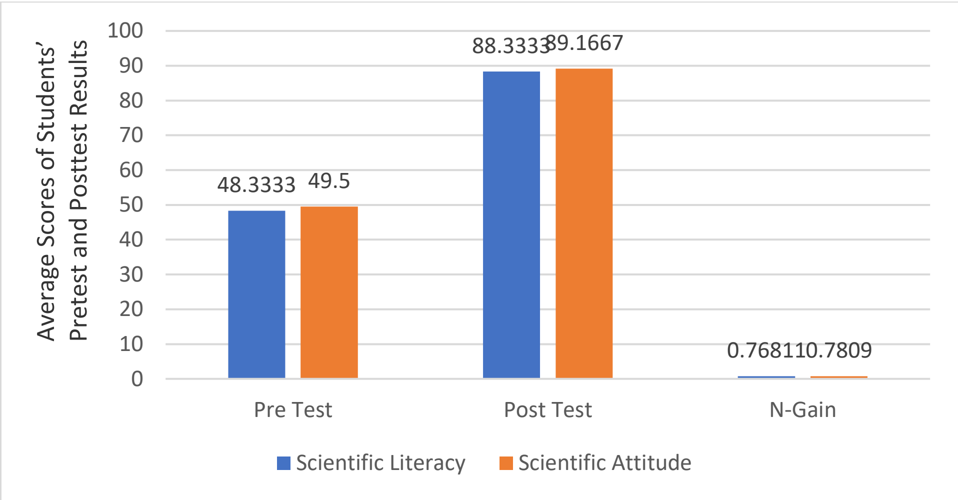

Figure 1. Graph of the Average Pretest, Posttest, and N-Gain Scores of Students

Based on Figure 1, the average pretest and posttest scores of all students indicate that each student's learning outcomes improved, both for male and female students. There are differences in the improvement of students' scientific literacy and scientific attitudes observed during the learning process using the STEM approach.

Hypothesis Testing

Hypothesis testing in this study was conducted using a paired sample t-test, in accordance with the one-group pretest–posttest design. This statistical technique was employed to determine whether there were significant differences between pretest and posttest scores obtained from the same group of participants. Specifically, the analysis aimed to examine the effect of the STEM approach (independent variable) on students' scientific literacy and scientific attitudes (dependent variables).

The decision criteria were based on the significance value (2-tailed). A significance level of less than 0.05 indicates a statistically significant difference between pretest and posttest scores, suggesting that the treatment had a meaningful effect. Conversely, a significance value greater than 0.05 indicates that no significant difference exists, implying that the treatment did not produce a meaningful effect. The data were analyzed using SPSS version 24.0, and the results of the paired sample t-test are presented in the following table.

Table 3. Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Pretest -Postes	-40,00000	11,29541	2,06225	-44,21777	-35,78223	-19,396	29	,000

The results of the paired sample t-test analysis indicate that the significance value is 0.000 ($p < 0.05$). This finding demonstrates a statistically significant difference between students' pretest and posttest scores in scientific literacy. Accordingly, it can be inferred that the implementation of the STEM approach had a significant positive effect on students' scientific literacy. In addition, to further examine changes in students' scientific attitudes, the comparison between pretest and posttest scores is presented in the following table.

Table 4. Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference Lower	Upper			
Pair 1	Pretest - Posttest	-39,66667	10,41661	1,90180	-43,55629	-35,77704	-20,857	29	,000

Based on the table above, the results of the paired sample t-test using SPSS 22 show a The paired sample t-test results show a significance value of 0.000 ($p < 0.05$), indicating a statistically significant difference between pretest and posttest scores in students' scientific attitudes. This finding suggests that the implementation of the STEM approach had a significant positive effect on students' scientific attitudes. Based on these results, the alternative hypothesis (Ha) is accepted, while the null hypothesis (H_0) is rejected. This confirms that the STEM (Science, Technology, Engineering, and Mathematics) learning approach significantly influences both students' scientific literacy and scientific attitudes. This study was conducted through face-to-face instruction in a third-grade classroom at SD Negeri 100206 Pintu Padang, involving 30 students as the research sample. The primary objective was to examine the effect of the STEM approach on students' scientific literacy and scientific attitudes. These variables were measured using a scientific literacy test consisting of 10 essay items and a scientific attitude questionnaire comprising 20 items. Data collection was carried out through pretests administered prior to the intervention and posttests conducted after the completion of the learning process. Additionally, the implementation of the instructional activities was evaluated using an observation sheet to assess the application of the STEM approach.

The results of the pretest–posttest data on scientific literacy, analyzed using the paired sample t-test, indicated that the STEM approach had a significant effect on scientific literacy, with a significance value of 0.000 (sig < 0.05, H_1 accepted). This result suggests that the STEM approach is effective in improving students' scientific literacy. The posttest results showed an average scientific literacy score of 88.33, indicating that students who participated in STEM-based learning achieved higher levels of scientific literacy.

This effectiveness can be understood by considering the cognitive characteristics of third-grade elementary students, who are in the concrete operational stage according to Jean Piaget (1952). At this stage, students learn best through direct, hands-on experiences and real-life contexts. The STEM approach accommodates these needs by engaging students in inquiry-based, contextual, and collaborative learning activities, making abstract scientific concepts more concrete and meaningful.

From a theoretical perspective, this finding is supported by constructivist learning theory and further strengthened by the socio-constructivist theory proposed by Lev Vygotsky (1978), which emphasizes the importance of social interaction and collaboration in learning. Through group discussions, investigations, and presentations, students learn within their zone of proximal development (ZPD), enhancing both cognitive and affective development.

Furthermore, the concept of scientific literacy as defined by the Organisation for Economic Co-operation and Development (2019; updated in PISA 2022 framework) highlights the ability to apply scientific knowledge in real-life contexts, explain phenomena scientifically, and use evidence-based reasoning. The STEM approach aligns with this

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framework by integrating science, technology, engineering, and mathematics into meaningful problem-solving activities.

In terms of previous empirical studies, the findings of this research are consistent with those reported by Winarni (2019), which found that STEM-based learning significantly improves students' scientific literacy and 21st-century skills. Similarly, research by Margaret Honey et al. (2014) emphasizes that integrated STEM instruction enhances students' ability to connect concepts across disciplines and apply them in solving authentic problems. These studies support the effectiveness of STEM learning in improving both academic outcomes and higher-order thinking skills.

The implementation of STEM in this study consisted of five stages: reflection, research, discovery, application, and communication. In the reflection stage, students were introduced to contextual problems to stimulate prior knowledge. In the research stage, they explored concepts related to energy through inquiry activities. In the discovery stage, students conducted investigations and applied the engineering design process, which encouraged critical and systematic thinking. In the application stage, they solved real-life problems by integrating STEM knowledge, and in the communication stage, they presented their findings, enhancing collaboration and communication skills.

The results of this study demonstrate that students developed the ability to recognize various forms and sources of energy, conduct investigations related to energy use in daily life, and identify strategies for energy conservation. These outcomes indicate that science learning plays a crucial role not only in developing scientific literacy but also in fostering scientific attitudes, which are essential for developing independence, collaboration, and problem-solving skills. Overall, the significant improvement in students' posttest scores compared to pretest results can be attributed to the integrated, contextual, and student-centered nature of STEM learning. Therefore, supported by both theoretical perspectives and previous empirical findings, the STEM approach can be considered an effective strategy to enhance students' scientific literacy and scientific attitudes, particularly at the elementary school level.

Conclusion

Based on the findings, it can be concluded that the implementation of the STEM (Science, Technology, Engineering, and Mathematics) approach has a significant positive effect on students' scientific literacy and scientific attitudes in IPAS learning. This is supported by the paired sample t-test results, which revealed a significance value of 0.000 ($p < 0.05$), indicating a statistically significant difference between pretest and posttest scores. The improvement is reflected in the increase in the average scientific literacy score from 48.33 to 88.33, with an N-Gain value of 0.768 (high category). Similarly, students' scientific attitudes showed a substantial increase from 49.50 to 89.17, with an N-Gain value of 0.781, also classified as high. These results demonstrate that the STEM approach effectively enhances both cognitive and affective learning outcomes. Furthermore, the integration of science, technology, engineering, and mathematics through contextual problem-solving activities provides meaningful learning experiences that promote critical thinking, collaboration, and active student engagement. Therefore, the STEM approach can be considered a viable and effective instructional strategy for improving scientific literacy and fostering positive scientific attitudes among elementary school students.

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Recommendation

Based on the findings of this study, several recommendations can be proposed:

1) For Teachers
   Teachers are encouraged to adopt the STEM (Science, Technology, Engineering, and Mathematics) approach as an alternative instructional strategy in IPAS learning to enhance students' scientific literacy and scientific attitudes. Learning activities should be designed to be interactive, contextual, and problem-oriented in order to promote active student engagement.
2) For Schools
   Schools should support the implementation of STEM-based learning by providing adequate facilities, instructional resources, and professional development opportunities for teachers. Such support is essential to ensure the effective and sustainable integration of STEM in classroom practices.
3) For Students
   Students are expected to actively participate in learning activities by demonstrating collaboration, curiosity, and engagement. Through STEM-based learning, students can enhance their critical thinking, problem-solving abilities, and develop positive scientific attitudes.
4) For Future Researchers
   Future researchers are recommended to conduct further studies with larger samples and different research designs, such as experimental studies with control groups, to obtain more comprehensive results. Additionally, future studies may explore the implementation of STEM in different subjects or educational levels.
5) For Policy Makers
   Education policymakers are advised to promote the integration of STEM approaches into the curriculum, especially at the elementary level, to better prepare students with 21st-century skills, including scientific literacy and scientific attitudes.

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