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A Comparative Study of Inquiry, STEAM, and STEAM-Based Guided Inquiry (GI-STEAM)

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ABSTRACT

This quasi-experimental study investigates the comparative effectiveness of inquiry-based learning, STEAM, and Guided Inquiry-STEAM (GI-STEAM) in fostering elementary students' creative thinking skills and scientific attitudes. A total of 115 students from public elementary schools in Semarang Regency, Central Java, Indonesia, were given a creative thinking test with five open-ended items and a questionnaire about their scientific attitudes, which comprises 15 statements. Data were analyzed using the Multivariate Analysis of Covariance (MANCOVA) to determine the impact of each instructional approach. The results revealed statistically significant differences across the three groups ($p < 0.05$), with students exposed to GI-STEAM demonstrating superior creative thinking and stronger scientific attitudes compared to those in the inquiry-only and STEAM groups. These findings suggest that integrating guided inquiry into the STEAM framework provides structured opportunities for exploration, problem-solving, and reflection that are not equally emphasized in conventional inquiry or STEAM models. Thus, GI-STEAM adoption in elementary classrooms has great potential to encourage creativity, foster scientific attitudes, and equip students with evidence-based reasoning and innovative thinking skills needed to tackle complex problems.

Keywords: creative thinking, GI-STEAM, inquiry, scientific attitudes, STEAM

INTRODUCTION

In addition to imparting conceptual knowledge, science education must foster students' scientific attitudes and creative thinking (Bybee, 2013a; Lederman, 2007). This is essential to address the global issues of 21st-century learning, which are becoming more complex (Saavedra et al., 2012). Students with creative thinking can investigate novel concepts, find creative answers, and relate what they have learned to actual circumstances (Runco & Acar, 2012). However, the process of learning science requires scientific attitudes, including curiosity, openness to evidence, healthy skepticism, and persistence in finding answers(Lederman, 2007; Osborne et al., 2003). When analyzing complicated problems, scientific attitudes prioritize evidence and logical reasoning, thus necessitating creative thinking abilities (Osborne et al., 2003; Runco & Acar, 2012).

Both scientific attitudes and creative thinking abilities encourage a more thorough investigation of natural events while helping students gain a deeper comprehension of scientific ideas. Strong scientific attitudes also enable students to approach learning obstacles with a positive and constructive perspective, critically assess material, and make fact-based decisions. Early development of creativity can broaden students' horizons and enrich their learning experiences. As their conceptual formation and abstract thinking skills continue to improve, elementary school children can come up with new ideas (Piaget, 1952). Similarly, Anderson et al. (2001) argued that creative thinking serves as a foundation for exploring new ideas innovatively and acquiring problem-solving skills to deal with complex issues. Thus, the development of these skills at a young age is essential to prepare learners to thrive as future innovators (Partnership for 21st Century Skills, 2015). For this purpose, elementary school students should be provided with ample opportunities to explore new ideas and design innovative solutions.

The capacity for creative thinking does not rely solely on intelligence; it is also strongly influenced by the scientific attitudes of each individual. Scientific attitudes help students produce innovative solutions and make discoveries by focusing on objective thinking, clear and effective communication, and well-structured collaboration. This underlines the contribution of scientific attitudes to creative thinking and the development of innovative and effective solutions (Conradty & Bogner, 2018). Students with positive scientific attitudes typically have better divergent thinking skills, which allow them to come up with multiple ideas or solutions for problem-solving purposes.

Scientific attitudes—which include skepticism, openness, objectivity, critical thinking, and systematic thinking—play a role in developing creative thinking abilities (Banton et al., 2024; Flake & Rubin, 2024; Grewe, 2025; Yildiz & Ecevit, 2025). A skeptical attitude encourages students to question existing ideas and seek new approaches to problem-solving. Openness and objectivity help students accept new ideas while considering various perspectives. Critical thinking enables students to evaluate ideas thoroughly and analyze the information they receive. Meanwhile, a systematic approach allows students to organize information logically and conduct methodical analyses. Strong scientific attitudes enhance students' creative thinking abilities (Conradty & Bogner, 2018), and these competencies should be developed starting in elementary school (Liu & Schunn, 2020; Seçgin & Sungur, 2020; Suryandai et al., 2022). This requires a learning model that accommodates both aspects effectively. An ideal learning approach, which is both structured and systematic, should encourage the exploration of innovative ideas while simultaneously deepening students' scientific understanding. The instructional model ought to facilitate students' development of creative thinking by engaging them in exploration, experimentation, and inquiry-driven problem-solving activities. Additionally, it should reinforce scientific attitudes by instilling values such as curiosity, precision, openness to evidence, and perseverance in finding solutions.

Inquiry-based learning has long been recognized as an effective strategy for enhancing students' conceptual understanding and critical thinking skills (Hmelo-Silve et al., 2007). This approach actively engages students in constructing knowledge through various processes, namely investigation, observation, question formulation, hypothesis development, data collection and analysis, and reflection on findings (Pedaste et al., 2015). Through inquiry-based learning, students not only have a deeper comprehension of the subject matter but also develop metacognitive skills and scientific attitudes essential for lifelong learning. However, the implementation of inquiry-based models in elementary schools continues to face numerous challenges. Limited instructional resources, inadequate laboratory facilities or supporting media, and insufficient time for exploration activities often hinder the effective application of this strategy (Khishfe & Abd-El-Khalick, 2002; Minner et al., 2009). Furthermore, many teachers struggle to design structured and effective inquiry activities, particularly in terms of facilitating students to ask relevant questions and carry out systematic experiments. Low student engagement also remains a persistent issue, commonly stemming from a lack of intrinsic motivation or the limited relevance of learning materials to their everyday lives. These challenges highlight the need for innovative approaches that integrate inquiry-based learning with contextual, collaborative, and interdisciplinary strategies, such as the Science, Technology, Engineering, Arts, and Mathematics (STEAM) approach. Such integration can potentially create more engaging, relevant, and holistic learning experiences that address both cognitive and affective dimensions of student development.

Previous studies have emphasized the importance of introducing STEM education from an early age, as the development of STEM-related skills can enhance students' interest, academic achievement, and future career choices (Kalogiannakis & Papadakis, 2020; Bicer et al. 2020). STEAM (Science, Technology, Engineering, Arts, and Mathematics) is an innovative framework for science education that developed from the STEM approach. This interdisciplinary strategy has attracted considerable interest in the educational field due to its ability to foster students' creativity through integrated problem-solving experiences (Land, 2013; Yakman & Lee, 2012). Studies have reported STEAM's effectiveness in promoting creativity and higher-order cognitive skills among learners (Henriksen, 2014; Quigley et al., 2017). However, students may encounter difficulties in linking scientific principles to technological and artistic components in the absence of explicit instructional support (Herro & Quigley, 2016; Jolly, 2017). In addition, it remains challenging to direct students toward in-depth investigations with the implementation of STEAM alone, thus necessitating its combination with a more systematic learning model (Quigley et al., 2017).

To address this challenge, Guided Inquiry-based STEAM (GI-STEAM) has emerged as a learning model that combines the strengths of guided inquiry with those of the STEAM approach. This model bridges the gap between theory and practice in scientific learning by providing a clearer and more systematic framework while simultaneously encouraging creative and investigative exploration in integrating concepts from science, technology, engineering, art, and mathematics (Meyer & Crawford, 2011). Furthermore, GI-STEAM also highlights teachers' function as facilitators who support students through organized stages of inquiry and encourage their active participation in collaborative, project-oriented learning experiences (Levy et al., 2009; Siew et al., 2015).

While the GI-STEAM model shows considerable potential, additional investigations are necessary to rigorously assess its effectiveness compared to other instructional approaches. Therefore, this study compares three pedagogical models—Inquiry, STEAM, and GI-STEAM—in their capacity to enhance elementary school students' creative thinking and scientific attitudes. By elucidating the relative advantages and limitations of each approach, this study aims to offer evidence-based recommendations concerning more effective teaching methodologies that support the development of 21st-century competencies in primary education.

METHOD

Research Design

This study employed a quasi-experimental design with a *non-equivalent control group* and three treatment groups exposed to different instructional approaches: Inquiry-Based Learning, STEAM, and Guided Inquiry-based STEAM (GI-STEAM). This allows for a direct comparison of the effectiveness of the three models in enhancing students' creative thinking skills and scientific attitudes, while considering the actual learning environments present in the school setting.

Data Sources

This study was conducted in three public elementary schools in Semarang Regency, Indonesia, involving 115 fourth-grade students as participants. The non-randomized purposive sampling technique was employed to select schools with similar minimum competency assessment scores and accreditation status classified as "A or excellent". Data were collected in compliance with ethical standards, supported by written approval obtained from the participating school (Approval No. 421.2/096) and informed consent forms signed by the students' parents or legal guardians. The research process began with students taking a pretest, comprising a creative thinking test with five open-ended questions and a scientific attitude questionnaire with 15 items. In the next phase, students were divided into three groups receiving different treatments (Inquiry, STEAM, and GI-STEAM). Each group participated in six sessions, totaling 15 instructional hours (15 × 35 minutes), focusing on the topic of plants as a source of life on Earth. After that, all students took a posttest with the same instruments as those of the pretest to assess changes in their creative thinking abilities and scientific attitudes.

Statistical Analysis

Collected data were analyzed using Multivariate Analysis of Covariance (MANCOVA) to examine the effect of the treatments on multiple dependent variables simultaneously, while controlling for the influence of covariates that could potentially affect the research outcomes. This study uses the posttest scores as the dependent variable, the instructional group as the independent variable, and the pretest scores as a covariate to control for initial differences among participants (Tabachnick & Fidel, 2013). This study utilized MANCOVA for the following reasons: (1) there was more than one dependent variable (creative thinking and scientific attitudes); (2) this method controlled the covariate (pretest scores) to ensure that differences in posttest results were genuinely caused by the learning model and not by other factors; and (3) the analysis examined whether significant differences existed among the three treatment groups in terms of the dependent variables, while concurrently controlling for the covariate across multiple dimensions of students' abilities (Jr. Hair et al., 2019). Accordingly, the MANCOVA test provides a more comprehensive and accurate depiction of the effects of the three instructional models under investigation, particularly within an educational context where cognitive and affective skills are inherently interrelated.

Before performing the MANCOVA, several prerequisite assumption tests were performed to ensure valid and interpretable outcomes. Since non-linearity could distort the outcomes of the analysis, a linearity test was done to verify that the contribution of the covariate to the dependent variable was not non-linear. A normality test was also conducted to confirm that the dataset was free from extreme outliers that could potentially bias parameter estimates in MANCOVA. Furthermore, the homogeneity of variance-covariance matrices was examined to verify that the variances and covariances across treatment groups were equivalent. All prerequisite assumptions were thoroughly tested and confirmed to be satisfied before carrying out the MANCOVA analysis. This rigorous process guarantees that MANCOVA was applied in a technically sound and methodologically valid manner.

RESULT AND DISCUSSION

This study compares the effectiveness of inquiry, STEAM, and GI-STEAM instructional models in fostering students' creative thinking abilities and scientific attitudes, considering the influence of pretest scores as a covariate. The MANCOVA test used a single independent variable comprising multiple groups to simultaneously assess mean differences across dependent variables. Several assumption tests, i.e., the linearity test, normality test, and homogeneity of covariance matrices test, were done before the MANCOVA test. The results of the linearity tests can be seen in **Table 1** and **Table 2**.

Table 1. Results of the Linearity Test with the Covariate of Initial Creative Thinking

Learning	Dependent Variable	df	F	Sig.
Inquiry	Creative Thinking	13	.783	.668
	Scientific Attitudes	13	2.905	.053
STEAM	Creative Thinking	14	2.038	.098
	Scientific Attitudes	14	.846	.620
GI-STEAM	Creative Thinking	20	1.024	.464
	Scientific Attitudes	20	.801	.695

Table 2. Results of the Linearity Test with the Covariate of Initial Scientific Attitudes

Learning	Dependent Variable	df	F	Sig.
Inquiry	Creative Thinking	12	1.168	.375
	Scientific Attitudes	12	.823	.628
STEAM	Creative Thinking	13	.466	.913
	Scientific Attitudes	13	.471	.910
GI-STEAM	Creative Thinking	15	1.042	.438
	Scientific Attitudes	15	1.271	.268

The significance test of the linear relationship was used to analyze the linearity between initial abilities and creative thinking, as well as scientific attitudes, after receiving different types of instruction (Inquiry, STEAM, and GI-STEAM). The results indicated a consistent linear association between creative thinking abilities and scientific attitudes across all groups, as evidenced by significance values exceeding 0.05 ($p > 0.05$). This implies that students' improved creative thinking skills are generally accompanied by better scientific attitudes, thus supporting the findings of earlier studies (Strat et al., 2024; Zaqiah et al., 2024). Scientific attitudes are not solely dependent on initial academic ability; they are more influenced by a learning environment that fosters curiosity, active engagement, and reflective discussions (Osborne et al., 2003).

Following the establishment of the linear relationship between the covariate and the dependent variables, the homogeneity of variance-covariance matrices was the subsequent assumption to be evaluated. This assessment is critical to ensure the equality of covariance structures across groups—a prerequisite for conducting robust multivariate analyses (Tabachnick & Fidel, 2013). Box's M test was utilized to examine this assumption, with the results presented in **Table 3**.

Table 3. Assessment of Homogeneity of Covariance Matrices

Box's M Test	Box's M	F	df1	df2	Sig.
	9.159	1.484	6	113599.328	.179

The Box's M test obtained a value of 9.159, with a significance level of 0.179 ($p > 0.05$), indicating that the assumption of equal covariance matrices is met. Therefore, the analysis may appropriately proceed to the next assumption testing, namely the homogeneity of regression slopes. This assessment was carried out to confirm that the connection between the covariate and the dependent variables was consistent across all treatment groups. According to this assumption, the covariate's impact on the dependent variables must be constant across the independent variables' values (Jr. Hair et al., 2019; Tabachnick & Fidel, 2013). **Table 4** presents the results of this homogeneity test.

Table 4. Assessment of Homogeneity of Regression Slopes

Dependent Variable	df	Mean square	F	Sig.
Creative Thinking	3	2.343	.097	.961
Scientific Attitudes	3	36.224	1.212	.209

A homogeneity of regression slopes analysis was conducted to determine whether there was a statistically significant interaction between the independent variables (Inquiry, STEAM, and GI-STEAM) and the covariate (students' initial abilities) in their influence on the dependent variables (students' creative thinking and scientific attitudes). The results reveal significance values of greater than 0.05, namely $p = 0.961$ and $p = 0.209$ for creative thinking skills and scientific attitudes, respectively. This shows that the regression slopes are homogeneous, signifying that the interaction effect between students' initial abilities and the applied intervention does not significantly impact their creative thinking skills and scientific attitudes. Inquiry-based and STEAM learning approaches are generally effective in enhancing students' creativity and scientific attitudes, regardless of their initial ability levels (Runco & Acar, 2012). Similarly, creativity-based learning can be widely implemented without requiring differentiation based on students' initial abilities (Cropley, 2001).

Since the results of the homogeneity of the regression slopes test indicate that the assumption is satisfied, the next assumption test conducted was the normality test. The Kolmogorov-Smirnov test was employed to assess the normality of the data related to creative thinking abilities and scientific attitudes. As shown in **Table 5**, the results demonstrate that the distribution of creative thinking abilities [KS(115) = 0.046; sig. or p = 0.200] and scientific attitudes [KS(115) = 0.035; sig. or p = 0.200] conforms to normality. Consequently, the data satisfy the assumption of normality. **Table 6** and **Table 7** display the results of the subsequent analyses, namely the multivariate analysis and the examination of the between-subjects effects.

Table 5. Results of the Normality Test

Dependent Variable	Kolmogorov-Smirnov[a]		
	Statistic	df	Sig.
Creative Thinking	.046	115	.200*
Scientific Attitudes	.035	115	.200*

Table 6. Results of the Multivariate Analysis

Effect		Value	F	Hypothesis df	Error df	Sig.	Partial Eta Squared
Learning	Pillai's Trace	.414	14.374	4.000	220.000	.000	.207
	Wilks' Lambda	.586	16.714[b]	4.000	218.000	.000	.235
	Hotelling's Trace	.707	19.096	4.000	216.000	.000	.261
	Roy's Largest Root	.707	38.889[c]	2.000	110.000	.000	.414

Table 7. Examination of Effects Between Subjects

Source	Dependent Variable	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Learning	Creative Thinking	1002.936	2	501.468	21.373	.000	.280
	Scientific Attitudes	1104.250	2	552.125	18.366	.000	.250
Error	Creative Thinking	2580.918	110	23.463			
	Scientific Attitudes	3306.920	110	30.063			

As shown in **Table 6**, the multivariate analysis results reveal a statistically significant difference in students' creative thinking abilities and scientific attitudes across the GI-STEAM, Inquiry, and STEAM groups, after adjusting for their pretest scores ($F(4, 218) = 218.000$; $p = 0.000 < 0.001$; Wilk's $\lambda = 0.586$; $\eta p^2 = 0.2351$). The findings of the between-subjects effects analysis presented in **Table 7** further validate that all instructional models explored in this study significantly influence students' creative thinking abilities ($F(2, 110) = 21.373$; $p = 0.000$; $\eta p^2 = 0.280$) and scientific attitudes ($F(2, 110) = 18.366$; $p = 0.000$; $\eta p^2 = 0.250$). The magnitude of effect associated with the implementation of different instructional models is quantified by partial eta squared values of 0.280 and 0.250, both of which are interpreted as indicating a strong effect size.

After adjusting for baseline pretest results, the implementation of the GI-STEAM learning model demonstrates a statistically significant improvement in both creative thinking abilities and scientific attitude scores. This finding confirms that the GI-STEAM model has a strong effect on enhancing students' creative thinking abilities and scientific attitudes. Then, the next output analysis in MANCOVA is the estimates, which provide information on the marginal mean estimates for each group based on the dependent variables controlled by the covariate. These estimates reveal the average differences between groups after considering the effects of the covariate (pretest scores). The estimated values can be seen in **Table 8**.

Table 8. Estimation Summary

Dependent Variable	Learning	Mean	Std. Error	95% Confidence Interval	
				Lower Bound	Upper Bound
Creative Thinking	Inquiry	74.815[a]	.988	72.856	76.774
	STEAM	78.448[a]	.886	76.692	80.205
	GI-STEAM	83.098[a]	.708	81.695	84.501
Scientific Attitudes	Inquiry	73.659[a]	1.119	71.442	75.876
	STEAM	77.198[a]	1.003	75.210	79.186
	GI-STEAM	82.271[a]	.801	80.683	83.859

As seen in **Table 8**, the GI-STEAM learning model has the highest marginal mean in creative thinking abilities and scientific attitudes, followed by the STEAM model and the inquiry-based model. This indicates that the GI-STEAM model is more effective in enhancing students' creative thinking abilities and scientific attitudes, compared to the other learning models. Considering the standard error, the mean differences among the learning groups also show significant differences. The small standard error suggests that the estimated means obtained are stable and reliable in representing the study population. Further interpretation can be made from the pairwise comparison results in **Table 9**.

Table 9. Pairwise Comparison

Dependent Variable	(I) Learning	(J) Learning	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
Creative Thinking	GI-STEAM	Inquiry	8.283*	1.311	.000	5.685	10.881
		STEAM	4.650*	1.130	.000	2.410	6.890
	Inquiry	GI-STEAM	-8.283*	1.311	.000	-10.881	-5.685
		STEAM	-3.633*	1.336	.008	-6.280	-.986
	STEAM	GI-STEAM	-4.650*	1.130	.000	-6.890	-2.410
		Inquiry	3.633*	1.336	.008	.986	6.280
Scientific Attitudes	GI-STEAM	Inquiry	8.611*	1.484	.000	5.671	11.552
		STEAM	5.073*	1.279	.000	2.537	7.609
	Inquiry	GI-STEAM	-8.611*	1.484	.000	-11.552	-5.671
		STEAM	-3.538*	1.512	.021	-6.535	-.542
	STEAM	GI-STEAM	-5.073*	1.279	.000	-7.609	-2.537
		Inquiry	3.538*	1.512	.021	.542	6.535

Pairwise comparison results indicate that the differences between groups have a significance value of less than 0.05. The comparison of creative thinking abilities between the GI-STEAM and inquiry-based learning approaches has a mean difference of 8.283, with a significance level of 0.000 ($p < 0.05$), signifying a statistically significant disparity in creative thinking outcomes. Similarly, the analysis between GI-STEAM and STEAM instruction models shows a mean difference of 4.650 and a significance level of 0.000 ($p < 0.05$), confirming a meaningful difference in creative thinking abilities. In terms of scientific attitudes, the mean difference between GI-STEAM and inquiry-based learning is 8.611, with a significance value of 0.000 ($p < 0.05$), revealing a substantial variation in the development of scientific attitudes. Additionally, the comparison between GI-STEAM and STEAM learning has a mean difference of 5.073 and a significance value of 0.000 ($p < 0.05$), demonstrating a statistically significant distinction in scientific attitudes. After controlling for pretest effects, the significant differences between each group confirm the results of the previous multivariate analysis (Wilks' Lambda).

Overall, these estimation results support the finding of a study by (Quigley et al., 2017) that the GI-STEAM learning model has a greater impact on improving students' creative thinking abilities and scientific attitudes, compared to inquiry-based and STEAM learning models. While inquiry-based learning focuses on independent exploration, students often struggle to connect theoretical concepts with practical applications (Hmelo-Silver, C. E., Duncan, R. G., & Chinn, 2007). Likewise, STEAM learning is effective in fostering creativity, but lacks structure in scientific thinking (Yakman & Lee, 2012). GI-STEAM learning combines the strengths of both approaches, where creative exploration remains guided within the framework of a systematic scientific investigation (Land, 2013). This suggests that a more structured and project-based approach can optimize students' scientific attitudes and capacity for creative thought. By engaging in challenge-based activities that resemble games, children can enjoyably acquire a wide range of knowledge and skills (Suryani et al., 2021). The playful elements embedded in these challenges not only foster a sense of joy but also help maintain learners' focus for longer periods, thereby enhancing their memory retention. Such a learning environment aligns closely with the syntactic framework of the GI-STEAM model, which highlights direct exploration in concept discovery and problem-solving through reflective investigative activities. Ultimately, this approach contributes to the development of students' scientific attitudes and creative thinking skills by encouraging them to effectively communicate the outcomes of their projects.

Descriptive statistics results presented in **Table 10** provide preliminary data before further analysis was carried out on creative thinking abilities and scientific attitudes in each learning group (Inquiry, STEAM, and GI-STEAM). Variations are observed in the average scores of creative thinking abilities and scientific attitudes across different learning groups, with the GI-STEAM group showing higher average scores compared to the other groups.

Table 10. Summary of Descriptive Data

Dependent Variable	Learning	Mean	Std. Deviation	N
Creative Thinking	GI-STEAM	82.98	4.187	54
	Inquiry	75.06	5.709	31
	STEAM	78.40	4.882	30
	Total	79.65	5.846	115
Scientific Attitudes	GI-STEAM	82.20	5.695	54
	Inquiry	73.71	4.584	31
	STEAM	77.27	5.872	30
	Total	78.63	6.519	115

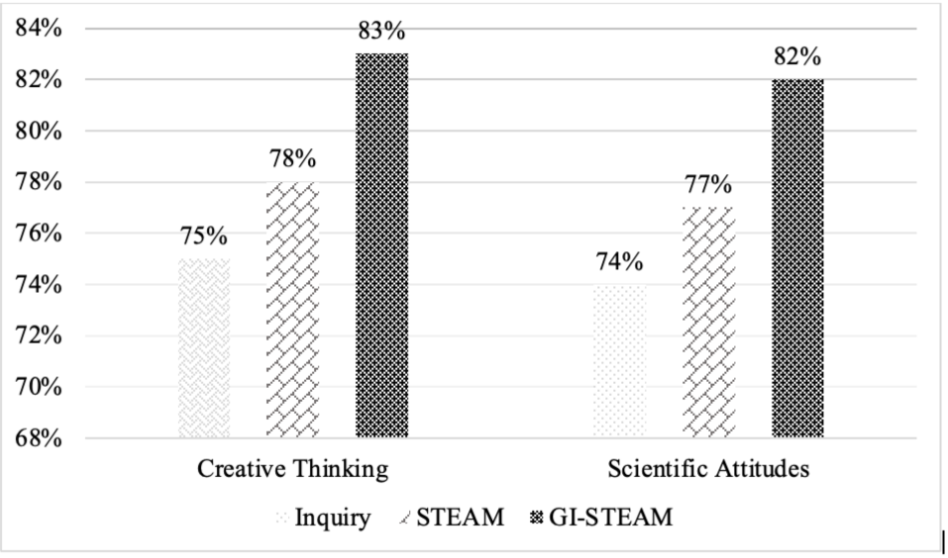

Figure 1. Graph of Creative Thinking and Scientific Attitudes of Students Experiencing Inquiry, STEAM, and GI-STEAM Learning

The results of the post-hoc Bonferroni test reveal that the GI-STEAM group has the highest mean score in both variables, compared to the Inquiry and STEAM groups.

As illustrated in **Figure 1**, the group that implemented the GI-STEAM instructional model has higher mean scores in both variables than those employing either inquiry-based or STEAM models. Students in the GI-STEAM group demonstrate better creative thinking abilities, with an average score of 82.98, compared to the inquiry group and the STEAM group, which have average scores of 75.06 and 78.40, respectively. Similarly, students receiving GI-STEAM learning have an average score of 82.20 in terms of their scientific attitudes, while those in the inquiry and STEAM groups obtain average scores of 73.71 and 77.27, respectively. These findings indicate that the GI-STEAM learning model is more effective in enhancing creative thinking abilities and scientific attitudes than the other learning models.

An important indicator of GI-STEAM's effectiveness is the observed improvement in students' creative thinking abilities and scientific attitudes, which surpasses those in both the inquiry and STEAM groups. While the performance levels of students in the inquiry and STEAM groups are classified as "good" for both dimensions, students in the GI-STEAM group exhibit "very good" performance. Integrating the STEAM approach into inquiry-based learning can facilitate the acquisition of deeper conceptual understanding and promote the application of knowledge across various real-world contexts (Johnson & Johnson, 2009). This model enables students to explore multiple disciplines in an integrated manner (Bybee, 2013b). The implementation of STEAM-based learning through various inquiry strategies has been shown to improve students' conceptual comprehension and critical thinking skills. Additionally, the interdisciplinary nature of this approach fosters greater student engagement (Khine, 2019). Within the GI-STEAM model, students are not passive recipients of information; they participate actively throughout the learning process, where they discover concepts, tackle problem-solving challenges, and communicate the outcomes of their STEAM-based projects.

The GI-STEAM learning model has been proven effective in enhancing students' creative thinking abilities and stimulating positive scientific attitudes. The effectiveness of a learning model is a crucial aspect in education, as it provides empirical evidence on how well a newly developed model can improve learning outcomes compared to existing models (Fraenkel et al., 2011). Thus, it can be assessed through improved learning outcomes (Taber, 2018). This study examines students' creative thinking abilities and scientific attitudes, as well as the impacts of the implemented learning models (Inquiry, STEAM, and GI-STEAM) on their active engagement. The results show that the GI-STEAM learning model demonstrates a significantly greater effectiveness than the inquiry and STEAM models.

Students in the GI-STEAM group exhibit higher average levels of creative thinking abilities and scientific attitudes than those in the other groups. This is because GI-STEAM learning incorporates both investigative group discussions and democratic principles in the process. These two aspects contribute to creating an environment that encourages exploration, collaboration, and creative problem-solving (Haryati, 2018; Ozkan & Topsakal, 2019; Timotheou & Loannou, 2021; Vygotsky, 1978). Within the GI-STEAM framework, students work in small groups to identify, envision, plan, construct, test, and evaluate solutions to assigned challenges through collaborative discussions. Such activities enable students to exchange ideas, acquire new understanding, and upgrade their creative thinking skills through systematic scientific procedures (Hmelo-Silver, 2004). Investigative group discussions also facilitate the resolution of challenges assigned by the teacher, as students are required to critically and deeply evaluate information during the *concept invention* stage. Moreover, before attempting to solve the given problems, students collaborate to gather data from diverse sources to validate the concepts. Collaborative learning in small groups has been shown to improve conceptual understanding and higher-order thinking skills, including creative thinking (Alali et al., 2024; Johnson & Johnson, 2009). In addressing challenges through group discussions, students are given the autonomy to design, build prototypes, and reflect on their work outcomes throughout the GI-STEAM learning process. This approach allows students to develop innovative solutions and gain a deeper understanding of the underlying concepts (Sawyer, 2022).

Figure 2. Syntax of GI-STEAM Learning (Suryani et al., 2025)

The enhancement of creative thinking skills and scientific attitudes is strongly influenced by the instructional syntax embedded in GI-STEAM, which consists of three key stages: *concept invention, challenge,* and *communication* (see **Figure 2**). In the initial stage, namely the *concept invention,* students construct concepts based on their prior knowledge and experiences, drawing from various sources of information. Then, the *challenge* stage provides opportunities for students to work collaboratively in completing projects that leverage technology, thereby fostering creative thinking and enabling students to develop innovative solutions to real-world problems. Technology-based learning has been shown to significantly enhance self-efficacy in applying computational thinking and science teaching (Kalogiannakis & Papadakis, 2019). These findings highlight the potential of integrating technology into the GI-STEAM framework as an interactive medium that promotes exploration, cross-disciplinary problem-solving, and creative collaboration, ultimately supporting the achievement of scientific learning's adaptive and innovative objectives. Consequently, combining inquiry-based learning with the STEAM framework can cultivate curiosity, perseverance, and scientific attitudes needed to tackle complex issues (Quigley et al., 2017). In GI-STEAM learning, students are guided to explore scientific concepts, identify problems, ideate, plan, create projects, test, and evaluate their STEAM outputs, culminating in the *communication* stage where they present their results. This final stage not only reinforces mastery of content but also trains students to think scientifically and systematically in addressing challenges presented by their teacher.

Several factors contribute to the effectiveness of GI-STEAM in enhancing students' creative thinking abilities and scientific attitudes, including: (1) the integration of challenging tasks and STEAM-investigation activities; (2) integration across multiple disciplines; (3) collaboration and communication within inquiry-based groups; and (4) contextualization in real-life applications. Integration of various disciplines allows students to understand how scientific concepts are applied in real life (Quigley et al., 2017). Through a teacher-guided exploration, students are stimulated with various prompts to deepen their understanding throughout the GI-STEAM learning process (Aguilera & Ortiz-Revilla, 2021; Bertrand & Namukasa, 2023). This aligns with the constructivist theory, which underlines the importance of students' active involvement in developing their understanding (Bruner, 1977). As a project-based learning model, GI-STEAM emphasizes the provision of challenges that require students to engage in collaborative work and scientific discussions within investigative groups, ultimately improving students' higher-order thinking and communication skills (Branden et al., 2011). By participating in STEAM-based investigative activities, students learn to share ideas, work collaboratively, and present their findings effectively. This involves the application of previously acquired concepts in real-life contexts to create tangible products. The STEAM products developed by students during investigative learning activities represent a contextualization of knowledge in real-life situations, offering practical benefits to the community (Tegegn, 2024). This is in line with the statement of (Kaufman & Reisman, 2016) that learning experiences that are linked to authentic, real-world contexts are more effective in stimulating students' creativity.

CONCUSION

The findings of this study indicate that the GI-STEAM model surpasses traditional inquiry-based instruction and isolated STEAM approaches in promoting creative thinking and scientific attitudes among elementary students. The synergy between a structured inquiry framework and integrated STEAM elements, supported by active teacher engagement, is crucial for improving students' overall learning outcomes. Consequently, elementary school science education should more extensively incorporate GI-STEAM as a more innovative and effective alternative to other methodologies. The MANCOVA analysis provides significant evidence regarding the pedagogical advantages of the GI-STEAM approach. The observed effect sizes for creative thinking abilities ($\eta p^2 = 0.280$) and scientific attitudes ($\eta p^2 = 0.250$) highlight the importance of applying this integrated model in elementary education settings. The findings correspond with current educational research highlighting the significance of scaffolded learning experiences that integrate disciplinary knowledge with opportunities for creative problem-solving.

The enhanced performance of GI-STEAM students, indicated by the highest marginal means for both dependent variables, implies that the structured guidance within this model fosters optimal conditions for cognitive development. The combination of guided inquiry principles and STEAM elements fosters a learning environment that harmonizes exploration with structured guidance, enabling students to cultivate innovative thinking and evidence-based reasoning skills. This pedagogical balance addresses a significant deficiency in conventional educational methods that frequently prioritize either structured content delivery or unstructured discovery learning. The consistent linear relationship between creative thinking abilities and scientific attitudes across all instructional groups, as shown by the linearity tests, suggests that these constructs are fundamentally interconnected. This relationship indicates that educational interventions focused on one domain are likely to affect the other, thereby reinforcing the holistic nature of the GI-STEAM approach. The model demonstrates effectiveness beyond initial student ability levels, as evidenced by the homogeneity of regression slopes analysis, suggesting its potential for broad application across varied student populations.

These results theoretically contribute to the literature supporting constructivist learning theories and the effectiveness of interdisciplinary education. The GI-STEAM model effectively implements the principles of active learning, collaborative problem-solving, and authentic assessment while ensuring pedagogical coherence. This synthesis examines persistent issues related to the fragmentation of knowledge frequently observed in conventional subject-specific teaching methods. The implications for educational practice are extensive. Teacher preparation programs should integrate GI-STEAM methodologies into their curricula to equip educators with the essential skills for effective implementation of these approaches. Curriculum designers must acknowledge the capacity of integrated models to improve both student engagement and learning outcomes concurrently. The organized approach of guided inquiry in the STEAM framework offers educators a definitive instructional guide, while allowing for adaptability in student-focused exploration.

Limitations and Further Research

In this study, several limitations need to be acknowledged to clarify the scope of the findings. First, this study applied a non-random sampling technique, which could potentially introduce bias and limit the participants' representativeness. Second, the intervention period was relatively short, making it challenging to capture the long-term effects of the inquiry, STEAM, and GI-STEAM learning models on students' scientific attitudes and creative thinking abilities. Third, this study focused solely on elementary school students in Indonesia, so its findings could not be broadly interpreted at other educational levels or international contexts. When implementing similar instructional models, differences in curriculum characteristics, learning cultures, and institutional readiness across educational settings may lead to varying outcomes.

These limitations have the practical implication of requiring teachers and policymakers to carefully consider local conditions in terms of infrastructure preparedness, teacher training, and student needs when planning the adoption of the GI-STEAM learning model. Moreover, continuous adaptation and adequate institutional support are crucial to successfully implement this model and ensure that its impacts are both immediate and sustainable. Therefore, future studies are recommended to employ longitudinal designs, involve larger and more diverse samples, and examine the replication and adaptation of inquiry, STEAM, and GI-STEAM learning models across secondary, upper-secondary, and cross-cultural contexts. Such efforts are expected to not only strengthen the external validity of the current findings but also provide valuable contributions to the development of transformative, contextually grounded, and globally relevant learning models that foster both creative thinking skills and scientific attitudes among students.

Conflict of Interest

We declare there are no conflicts of interest.

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