Nidhomul Haq: Jurnal Manajemen Pendidikan Islam **E-ISSN: 2503-1481**
Accredited Number: 79/E/KPT/2023 pp: 222-236
DOI: https://doi.org/10.31538/ndhq.v11i1.363
Journal Homepage: https://nidhomulhaq.uacmjk.ac.id/index.php/ndh/index
Vol 11 Issue (1) 2026

The Effect of STEAM-Based Learning on Critical Thinking, Creativity, and Collaboration Skills of Senior High School Students

Dadan F Ramdan[1], Muhamad Rizza[2], Hilyatun Najuba[3], Muhammad Yusuf Muharam[4]

[1] Universitas Islam Negeri Sunan Gunung Djati Bandung, Indonesia
[2] Universiti Utara Malaysia, Malaysia
[3] Universitas Islam Negeri Sunan Gunung Djati Bandung, Indonesia
[4] Universitas Islam Negeri Sunan Gunung Djati Bandung, Indonesia

e-mail Correspondent: dadanramdhan74@uinsgd.ac.id

Received: 11-07-2022 Revised: 30-10-2023 Accepted: 07-11-2023

Info Artikel

Keywords:
Creativity; Collaboration; Critical thinking; STEAM-based learning

Abstract

This study aims to examine the effect of STEAM-based learning (*Science, Technology, Engineering, Arts, and Mathematics*) on students' critical thinking, creativity, and collaboration skills in secondary education. Utilizing a quantitative survey design, the study involved 108 twelfth-grade students at SMA Telkom Bandung, Indonesia, selected through purposive sampling from classes that actively implement the STEAM approach. Data were collected using validated and reliable Likert-scale questionnaires and subsequently analyzed using descriptive statistics and simple linear regression at a 0.05 significance level. The findings indicate that STEAM-based learning has a significant positive effect on all three core competencies: critical thinking (t=13.120; R^2=0.619), creativity (t=14.200; R^2=0.655), and collaboration (t=12.106; R^2=0.580). These results confirm that the integration of the arts into STEM education effectively strengthens students' cognitive, creative, and social dimensions simultaneously, establishing it as a highly relevant pedagogical model for 21st-century demands. The novelty of this research lies in its integrative analysis, which simultaneously examines three fundamental 21st-century competencies within a single research model in the context of Indonesian secondary education. This area remains underexplored compared to Western literature. This study provides a significant contribution by offering empirical evidence that the "Arts" element is not merely an aesthetic addition but a primary catalyst in enhancing divergent thinking and social engagement. However, the study is limited by its localized sample within a single institution and its cross-sectional survey design. As a recommendation, educational policymakers should prioritize teacher professional development in interdisciplinary curriculum design.
.

Kata Kunci:
Berpikir Kritis; Kreativitas; Kolaborasi; Pembelajaran berbasis STEAM

Abstrak

Penelitian ini bertujuan untuk mengkaji pengaruh pembelajaran berbasis STEAM (Science, Technology, Engineering, Arts, and Mathematics) terhadap kemampuan berpikir kritis, kreativitas, dan kolaborasi siswa pada tingkat pendidikan menengah. Menggunakan desain survei kuantitatif, penelitian ini melibatkan 108 siswa kelas XII di SMA Telkom Bandung, Indonesia, yang dipilih melalui teknik purposive sampling dari kelas yang secara konsisten menerapkan pendekatan STEAM. Data dikumpulkan melalui kuesioner skala Likert yang telah teruji validitas dan reliabilitasnya, kemudian dianalisis menggunakan statistik deskriptif dan regresi linier sederhana pada tingkat signifikansi 0,05. Hasil penelitian menunjukkan bahwa pembelajaran berbasis STEAM memiliki pengaruh positif dan signifikan terhadap ketiga kompetensi utama: berpikir kritis (t=13.120; R^2=0.619)*, kreativitas* (t=14.200; R^2=0.655)*, dan kolaborasi* (t=12.106; R^2=0.580)*. Temuan ini mengonfirmasi bahwa integrasi seni dalam pendidikan STEM secara efektif memperkuat dimensi kognitif, kreatif, dan sosial siswa secara simultan, menjadikannya model pedagogi yang relevan bagi tuntutan abad ke-21. Novelty atau kebaruan penelitian ini terletak pada* *analisis integratif yang menguji tiga kompetensi abad ke-21 secara serempak dalam satu model penelitian di konteks sekolah menengah Indonesia, sebuah area yang masih jarang dieksplorasi dibandingkan dengan literatur di konteks Barat. Penelitian ini memberikan kontribusi penting dengan menyediakan bukti empiris bahwa elemen seni (Arts) bukan sekadar tambahan estetika, melainkan katalisator utama dalam meningkatkan kemampuan berpikir divergen dan keterlibatan sosial siswa. Meskipun demikian, penelitian ini memiliki batasan pada lingkup sampel yang terbatas pada satu institusi dan desain survei yang bersifat cross-sectional. Sebagai rekomendasi, pembuat kebijakan disarankan untuk memprioritaskan pelatihan guru dalam desain kurikulum interdisipliner.*

INTRODUCTION

Students in the 21st century are increasingly confronted with complex, real-life problems that demand higher-order thinking skills. These real-life problems cannot be effectively addressed through traditional education, which emphasizes only the transmission of knowledge. Traditional teaching approaches tend to focus on developing students' cognitive knowledge rather than practical and adaptive skills (Ping, Saibon, & Hamzah, 2025; Pranata & Syamsijulianto, 2025). However, contemporary learners require skills-based education to analyze problems, generate solutions, and respond to real-world challenges. Therefore, identifying effective teaching approaches that support the development of essential 21st-century skills is a critical educational concern. In particular, modern educational systems are expected to cultivate students' abilities to think critically, generate innovative ideas, and collaborate effectively in solving interdisciplinary problems (Bagheri Noaparast, 2022; Ogbonnaya, Loubser, & Lessing, 2025; Tan, Koh, & Lim, 2021).

Despite the strong global emphasis on 21st-century skills, teaching practices in many high schools remain largely teacher-centered. Learning activities often prioritize content mastery over critical thinking and creativity. (Aguilera & Ortiz-Revilla, 2021; Allina, 2018; Bicer et al., 2017; Zahru, Rasyid, & Usman, 2025), and collaborative engagement. As a result, students have limited opportunities to construct knowledge and apply skills in meaningful contexts actively. Empirical studies have shown that these conventional approaches often lead to passive learning and low student participation. (Juliastuti, Suherman, & Hasani, 2024; Sonet & Klufallah, 2024; Sriyanto, Suyatno, & Ishafit, 2025). This situation highlights the urgent need for pedagogical models that intentionally integrate the cognitive, creative, and social dimensions of learning. Educational innovation is therefore required to transform passive classroom environments into active learning spaces where students can develop higher-order competencies. (Asmoni, 2025; Calliera et al., 2026).

In response to these teaching challenges, STEAM-based learning has emerged as a prominent and innovative pedagogical approach. Starting in 2007, an innovative educational concept was introduced in the United States by integrating the arts into STEM (Science, Technology, Engineering, and Mathematics) education, giving rise to what is now known as STEAM education. Since its emergence, STEAM has emphasized students' creativity, innovation, and design thinking as essential components of learning. (Zhang & Jia, 2024). STEAM integrates science, technology, engineering, the arts, and mathematics to create interdisciplinary and meaningful learning experiences. Through project-based and inquiry-oriented activities, STEAM-based learning encourages students to explore problems from multiple perspectives and construct knowledge collaboratively. (Upadhyay, Coffino, Alberts, & Rummel, 2021).

Internationally, STEAM education has been implemented and studied in various educational contexts, including the United States. , Russia, South Korea (Kang, 2019; Park, Byun, Sim, Han, & Baek, 2016), Nepal, and other Asia-Pacific countries (Chu, 2021). These studies demonstrate that STEAM-based learning has the potential to increase student engagement and higher-order thinking. As a result, STEAM is rapidly gaining recognition and popularity in secondary education worldwide. Previous studies have also reported that STEAM-based learning environments can support inquiry-based learning, encourage creativity, and promote collaborative problem-solving among students. (Shukshina et al., 2021).

The widespread adoption of STEAM-based learning raises critical academic questions about its true effectiveness. However, existing studies have explored the benefits of STEAM, such as the study from Butera et al. They have only focused on isolated learning outcomes or specific subject domains. Research that simultaneously examines critical thinking, creativity, and collaboration is still limited, especially at the high school level. (Belbase, 2019). Furthermore, evidence from non-Western educational contexts is still insufficient to draw comprehensive conclusions. This indicates a clear research gap that requires further empirical investigation beyond the scope of pedagogical trends. Most existing studies tend to examine these competencies separately, making it difficult to understand how STEAM-based learning contributes to the integrated development of multiple 21st-century skills (Butera, Horn, Palmer, Friesen, & Lieber, 2016; Harris & de Bruin, 2018).

Addressing this research gap is crucial for strengthening evidence-based educational practices. This study examines the impact of STEAM-based learning on high school students' critical thinking, creativity, and collaboration skills using a quantitative approach. By focusing on multiple learning outcomes, this study builds on fragmented prior research and provides empirical evidence on the integrated development of these competencies. In addition, the study contributes empirical evidence from a secondary school context in Indonesia, a setting that remains underrepresented in the global literature on STEAM education. Practically, these findings offer guidance for teachers and school leaders in designing learning environments aligned with 21st-century demands and can inform curriculum and policy development in secondary education.

METHOD

Quantitative research designs are widely used in educational studies to examine relationships between instructional approaches and measurable learning outcomes (Creswell & Guetterman, 2019; Fischer, 2022). Survey-based methods, in particular, allow researchers to collect empirical data efficiently and analyze patterns across student populations. (Braun & Clarke, 2013). The population consisted of all twelfth-grade students at SMA Telkom Bandung, totaling 354 students across 10 classes: six science-track (MIPA) and four social science-track (IPS). The MIPA stream included 211 students (XII MIPA 1 = 36, MIPA 2 = 36, MIPA 3 = 34, MIPA 4 = 36, MIPA 5 = 35, MIPA 6 = 34), while the IPS stream comprised 143 students (XII IPS 1 = 36, IPS 2 = 36, IPS 3 = 36, IPS 4 = 35).

The sample was drawn using purposive sampling, selecting three advanced classes, two MIPA classes, and one IPS class that actively implemented STEAM-based learning, resulting in a total sample of 108 students, approximately 36 students per class. This sampling approach aligns with, emphasizing relevance to research objectives over proportional representation. The selection of these classes was based on their consistent implementation of STEAM-based learning activities and their active engagement in interdisciplinary learning projects (Miles & Huberman, 1994). The independent variable was STEAM-based learning, which refers to interdisciplinary instructional practices that integrate science, technology, engineering, arts, and mathematics into problem-based learning activities. The dependent variables were critical thinking, creativity, and collaboration, key competencies associated with 21st-century learning. Critical thinking was operationalized as students' ability to analyze problems, evaluate information, and draw logical conclusions.

Data analysis involved both descriptive and inferential statistical techniques. Descriptive statistics were used to summarize data distributions, including mean and standard deviation values for each variable. Inferential analysis employed simple linear regression to examine the effect of STEAM-based learning on critical thinking, creativity, and collaboration (Glejser, 1969). All statistical analyses were conducted using statistical software at a significance level of 0.05 to test the research hypotheses and address the study objectives. Prior to conducting regression analysis, several classical assumption tests were performed to ensure the validity of the regression model. A normality test using the Kolmogorov Smirnov and Glejser test was conducted to assess whether the data met the assumption of normality (Glejser, 1965; Goodman, 1954).

RESULT AND DISCUSSION

Result

Prior to conducting hypothesis testing, it was necessary to assess whether the research data met the fundamental assumptions of regression analysis. Classical assumption testing was performed to ensure the accuracy, reliability, and validity of the statistical models used in this study. Specifically, the tests aimed to confirm that the residuals were normally distributed and that their variance was constant across observations. The fulfillment of these assumptions is crucial, as violations may bias parameter estimates and weaken the credibility of regression results. Therefore, normality and heteroscedasticity tests were conducted for all regression models examining the effect of STEAM-based learning (X) on critical thinking (Y^1), creativity (Y^2), and collaboration (Y^3). These preliminary tests were conducted to confirm that the regression models met the statistical assumptions required for valid hypothesis testing.

Normality Test

The normality test was conducted to determine whether the data followed a normal distribution, a key requirement for parametric statistical analysis. In this study, the Kolmogorov–Smirnov test was conducted in SPSS to assess the normality of residuals for each regression model. The decision criterion states that data are considered normally distributed if the significance value exceeds 0.05. The results of the normality test for all regression models are presented in Table 1.

Table 1. Normality Test Results

Regression Model	Sig. Value	Interpretation
X → Y1	0.200	Normal distribution
X → Y2	0.058	Normal distribution
X → Y3	0.077	Normal distribution

Source: Primary Data Processed, 2025

Table 1 indicates that all regression models produced p-values greater than the 0.05 threshold. These results show that the data for critical thinking, creativity, and collaboration were normally distributed. Consequently, the normality assumption required for regression analysis was satisfied. This finding confirms that the regression analysis could proceed because the residuals met the normality assumption.

Heteroscedasticity Test

The heteroscedasticity test was conducted to examine whether the variance of residuals remained constant across different values of the independent variable. A regression model that exhibits heteroscedasticity may produce inefficient and biased estimates, thereby reducing the accuracy of statistical conclusions. In this study, the Glejser test was used to detect heteroscedasticity by examining the significance of the regression residuals. A model is considered free of heteroscedasticity if the p-value exceeds 0.05. The results of the heteroscedasticity test for all regression models are presented in Table 2.

Table 2. Heteroscedasticity Test Results

Regression Model	Sig. Value	Interpretation
X → Y1	0.482	No heteroscedasticity
X → Y2	0.327	No heteroscedasticity
X → Y3	0.070	No heteroscedasticity

Source: Primary Data Processed, 2025

As shown in Table 2, all regression models yielded significance values above 0.05. These findings indicate that no heteroscedasticity was detected in any of the models. Thus, the assumption of homoscedasticity was fulfilled, and the regression models were deemed appropriate for further statistical testing. The absence of heteroscedasticity indicates that the regression estimates are statistically reliable for examining the relationships between STEAM-based learning and the three dependent variables.

Simple Linear Regression Analysis

Simple linear regression analysis was conducted to examine the direction and magnitude of the effect of STEAM-based learning on each dependent variable. This analysis aimed to identify whether changes in STEAM-based learning were associated with changes in students' critical thinking, creativity, and collaboration. The regression coefficients provide information about the strength and direction of the relationship between the independent and dependent variables.

Additionally, the regression equations provide predicted values of the dependent variables as a function of the independent variable. The results of the regression analysis are summarized in Table 3.

Table 3. Simple Linear Regression Results

Regression Model	Constant	Coefficient (X)	Regression Equation
X → Y1	14.152	0.377	Y1 = 14.152 + 0.377X
X → Y2	0.936	0.427	Y2 = 0.936 + 0.427X
X → Y3	13.669	0.338	Y3 = 13.669 + 0.338X

Source: Primary Data Processed, 2025

Table 3 shows that all regression coefficients were positive, indicating a positive relationship between STEAM-based learning and the three student competencies. The regression equations demonstrate that increases in STEAM-based learning scores were associated with increases in critical thinking, creativity, and collaboration scores. These results indicate that STEAM-based learning has a positive directional relationship with all three dependent variables.

t-Test Results

The t-test was conducted to determine whether the effect of STEAM-based learning on each dependent variable was statistically significant. This test compares the calculated t-values with the critical t-value to assess whether the regression coefficients differ significantly from zero. A significance level of 0.05 was applied in this study to determine statistical significance.

Table 4. t-Test Results

Regression Model	t-value	t-table	Sig.
X → Y1	13.120	1.98	0.000
X → Y2	14.200	1.98	0.000
X → Y3	12.106	1.98	0.000

Source: Primary Data Processed, 2025

Table 4 shows that all calculated t-values exceeded the critical t-value of 1.98, with significance values of 0.000. These findings indicate that STEAM-based learning has a statistically significant effect on each dependent variable.

Hypothesis 1 (H1): STEAM-based learning significantly affects students' critical thinking. The regression coefficient for this relationship is 0.377, with a t-value of 13.120 and $p = 0.000$ (<0.05). Therefore, H1 is accepted.

Hypothesis 2 (H2): STEAM-based learning significantly affects students' creativity. The regression coefficient for this relationship is 0.427, with a t-value of 14.200 and $p = 0.000$ (<0.05). Therefore, H2 is accepted.

Hypothesis 3 (H3): STEAM-based learning significantly affects students' collaboration. The regression coefficient for this relationship is 0.338, with a t-value of 12.106 and $p = 0.000$ (<0.05). Therefore, H3 is accepted.

Coefficient of Determination

The coefficient of determination (R^2) was calculated to measure how well STEAM-based learning explained the variance in each dependent variable. R^2 values closer to 1 indicate stronger explanatory power of the regression model. This analysis provides insight into the proportion of variance in students' competencies attributable to STEAM-based learning.

Table 5. Coefficient of Determination

Regression Model	R	R^2	Interpretation
X → Y1	0.787	0.619	High
X → Y2	0.810	0.655	High
X → Y3	0.762	0.580	High

Source: Primary Data Processed, 2025

As shown in Table 5, STEAM-based learning explained 61.9% of the variance in critical thinking, 65.5% in creativity, and 58.0% in collaboration. All R^2 values were categorized as high, indicating strong explanatory power of the regression models. These values demonstrate that STEAM-based learning substantially contributes to explaining variation in the three student competencies.

Overall, the statistical analysis demonstrates that STEAM-based learning has a positive and significant effect on critical thinking, creativity, and collaboration. The regression results supported all three hypotheses (H1, H2, and H3). The relatively high R^2 values indicate that STEAM-based learning has strong explanatory power in predicting variations in students' competencies.

DISCUSSION

The findings of this study indicate that STEAM-based learning contributes substantially to the development of students' critical thinking, creativity, and collaboration. These results can be understood through the theoretical lens of constructivist and social constructivist learning perspectives, which emphasize that knowledge is actively constructed through engagement, inquiry, and social interaction. In a STEAM-based learning environment, students are not just recipients of information but active participants who investigate problems, generate ideas, and collaborate to build meaningful solutions. Such learning conditions naturally stimulate cognitive, creative, and social competencies simultaneously. The integration of science, technology, engineering, arts, and mathematics encourages students to approach problems from multiple perspectives, thereby deepening and broadening their thinking.

The inquiry-oriented nature of interdisciplinary learning activities can explain the development of critical thinking in STEAM-based learning environments. Constructivist theory suggests that meaningful learning occurs when learners actively engage with problems that require interpretation, evaluation, and reasoning. In STEAM classes, students often face complex, authentic tasks that cannot be solved through rote learning alone. Instead, they must analyze information, identify patterns, evaluate alternative solutions, and justify their decisions based on evidence. These processes align with the fundamental elements of critical thinking described in contemporary educational literature (Ghafar, 2020; Rios, Ling, Pugh, Becker, & Bacall, 2020). When students participate in interdisciplinary problem-solving activities, they are required to synthesize knowledge across domains, thereby deepening their analytical reasoning. This learning structure differs significantly from traditional teaching, which often prioritizes procedural knowledge over reflective assessment. (Belbase, 2019).

Another factor explaining the development of critical thinking in STEAM-based learning is the emphasis on authentic problem contexts. Real-world problems rarely exist within the boundaries of a single discipline, and STEAM learning reflects this complexity by integrating multiple knowledge domains (Butera et al, 2016). Therefore, students must evaluate constraints, consider diverse sources of information, and propose feasible and innovative solutions. These cognitive demands stimulate higher-order thinking processes, including analysis, evaluation, and metacognitive reflection. Previous studies have also emphasized the role of interdisciplinary learning environments in promoting advanced cognitive skills. Butera and Stround Highlight that interdisciplinary learning models encourage students to question assumptions and engage in deeper reasoning processes. The findings of this study strengthen this argument by demonstrating that STEAM-based learning environments provide structural conditions that consistently support the development of critical thinking (Stroud & Baines, 2019) .

The results also align with a growing body of literature emphasizing the cognitive benefits of STEAM integration. (Henriksen, Mehta, & Mehta, 2019) argue that STEAM education broadens students' intellectual engagement by combining analytical reasoning with creative exploration. In such an environment, students are encouraged to ask questions, test hypotheses, and reflect on their findings. These activities activate cognitive processes essential for developing critical thinking. However, many previous studies examining STEAM outcomes have relied primarily on qualitative observations or case studies. By using quantitative analysis to examine the relationship between STEAM-based learning and various competencies, this study provides stronger empirical evidence that an interdisciplinary learning approach can significantly improve students' analytical reasoning abilities (Belbase, 2019). Consequently, these findings contribute to the growing recognition of STEAM-based learning as a structured pedagogical strategy for developing higher-order cognitive skills.

In addition to its influence on analytical reasoning, STEAM-based learning also plays a crucial role in fostering student creativity. Creativity in educational contexts is increasingly seen as a skill that can be developed intentionally through appropriate instructional design, rather than as a purely innate characteristic (Belbase, 2019). The integration of artistic elements in a STEAM learning environment provides opportunities for students to express ideas through various forms, such as visual representations, design prototypes, or innovative models. This process encourages students to explore unconventional approaches to problem-solving, thereby stimulating divergent thinking. Divergent thinking, which involves generating multiple possible solutions to a problem, is widely recognized as a key component of creative cognition (Bicer et al., 2017). When students are encouraged to experiment, design, and iterate on solutions, they develop the ability to generate new and original ideas.

The integration of the arts into STEAM education further strengthens the creative dimension of learning. The artistic process allows students to visualize abstract scientific or mathematical concepts in a tangible form. For example, students can translate engineering ideas into physical prototypes or express mathematical relationships through visual models. Such activities encourage imaginative exploration while strengthening conceptual understanding. (Belbase, 2019). emphasized that the inclusion of artistic design in STEM learning environments significantly increases students' creative engagement. The findings of this study support this perspective by demonstrating that creativity can emerge from structured learning when interdisciplinary instructional practices intentionally combine analytical reasoning with artistic expression (Valls, Albó-Canals, & Canaleta, 2018).

Another important mechanism supporting creativity in STEAM-based learning is the presence of open-ended tasks. Traditional instructional models often emphasize standard answers and fixed procedures, which can limit opportunities for creative exploration. In contrast, STEAM-based learning often involves project-based tasks that allow for multiple possible solutions. This openness encourages students to experiment with different ideas, evaluate alternative approaches, and refine their solutions through an iterative process (Conradty & Bogner, 2020); and Conradty, Sotiriou, & Bogner, 2020) highlighted that interdisciplinary STEAM projects stimulate ideational recombination, a cognitive mechanism through which individuals integrate existing knowledge to generate innovative solutions. When students engage in the process, they develop greater cognitive flexibility and become more willing to explore unconventional possibilities. As a result, creativity becomes an integral part of the learning process, not just a byproduct (Belbase, 2019).

In addition to fostering cognitive and creative competencies, STEAM-based learning environments develop collaborative skills. Social constructivist theory emphasizes that learning occurs through interaction and shared meaning-making in a social context (Henriksen, Mehta, & Mehta, 2019). In STEAM classes, students often work in teams to design solutions, conduct experiments, or develop project outcomes. These collaborative activities require students to communicate ideas clearly, negotiate roles within the group, and coordinate their efforts toward a common goal. Through these interactions, learners develop important social competencies such as communication, cooperation, and collective problem-solving (Abdullah, Nurdin, Lisnawati, Marakarma, & Yamani, 2025) and Jaya, Rafin, Nurrohman, Ghofur, & Nastiar, 2025) emphasize the increasing importance of collaborative competencies in contemporary educational and professional environments.

The interdisciplinary demands of complex projects can also explain the collaborative nature of STEAM-based learning. Tasks that integrate science, engineering, and artistic design often require diverse forms of expertise, making collaboration essential for successful problem solving. Students must therefore share knowledge, coordinate strategies, and integrate multiple perspectives. Hasanah explained that group-based learning environments encourage learners to develop communication and negotiation skills as they work toward collective solutions. Similarly, Ilma argued that interdisciplinary projects create opportunities for students to practice collaborative problem solving in contexts that closely resemble real-world professional situations (Neliwati, Hasanah, Pringadi, Sirojuddin, & Arif, 2023). The findings of this study reinforce these perspectives by demonstrating that STEAM-based learning environments can significantly enhance students' collaborative competence. (Ilma, Wilujeng, Nurtanto, & Kholifah, 2023).

Collaboration within STEAM learning environments also fosters social accountability among students. When learners participate in group-based projects, they become responsible not only for their individual contributions but also for the collective outcome. This shared responsibility encourages active participation and mutual support among group members. (MacDonald et al, 2020) suggested that collaborative learning environments strengthen students' sense of responsibility and collective engagement. (Liu & Wu, 2022) Similarly, they emphasized that cooperative learning activities promote social awareness and group cohesion. In STEAM-based classrooms, these social dynamics encourage students to respect diverse perspectives and work constructively with peers. Consequently, collaboration becomes both a learning process and a learning outcome (Liu & Wu, 2022).

An important contribution of this study lies in its demonstration that STEAM-based learning simultaneously influences multiple student competencies. Rather than developing independently, the findings suggest that critical thinking, creativity, and collaboration develop in interconnected ways within interdisciplinary learning environments (Upadhyay et al., 2021). Cognitive reasoning, creative exploration, and social interaction are mutually reinforcing processes that emerge naturally when students engage in authentic problem-solving tasks. This integrated perspective aligns with contemporary educational frameworks that emphasize the interconnectedness of twenty-first-century skills (Ilma et al., 2023). Within such frameworks, student competence is not viewed as a collection of isolated abilities but as a holistic set of skills that support adaptive learning and innovation (Liu & Wu, 2022).

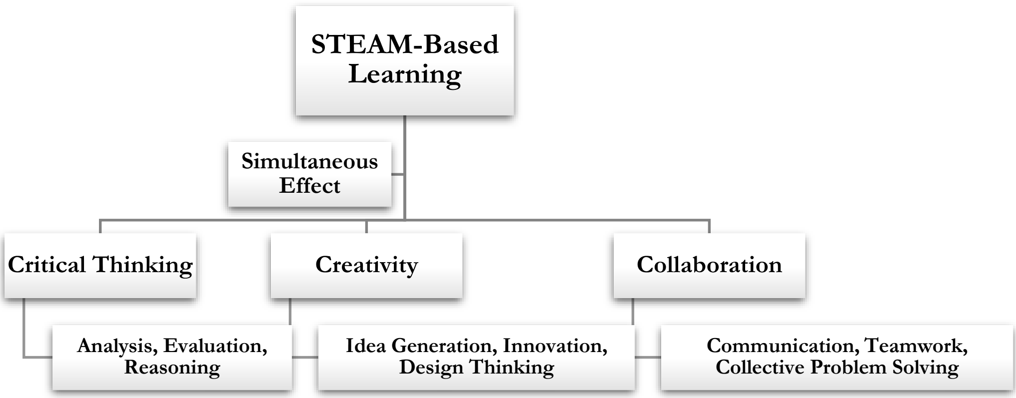
The integrated model proposed in this study highlights STEAM-based learning as a fundamental pedagogical approach that supports multiple learning outcomes simultaneously. This perspective contributes to the ongoing discussion about the educational value of interdisciplinary teaching. Many previous studies have examined the effects of STEAM-based learning on individual competencies separately (Aguilera & Ortiz-Revilla, 2021; Allina, 2018; Chistyakov et al., 2023). However, fewer studies have explored how these competencies develop collectively within an integrated teaching framework (Jamil, Linder, & Stegelin, 2018; Kang, 2019). By demonstrating that STEAM-based learning simultaneously contributes to critical thinking, creativity, and collaboration, this study provides empirical evidence of the holistic impact of interdisciplinary education.

These findings further highlight the importance of providing professional development opportunities for educators to implement STEAM-based learning effectively. Teachers may need training in interdisciplinary curriculum design. (Clear et al., 2020), project-based learning strategies (Priyohutomo, Komarudin, & Sridadi, 2025), and collaborative classroom management techniques

(Yusuf, Pajarianto, & Sulaiman, 2025). By equipping educators with these skills, schools can create learning environments that support inquiry, creativity, and collaboration. Furthermore, educational policymakers may consider promoting STEAM integration as part of broader educational reform initiatives to prepare students for complex global challenges.

Another important contribution of this study lies in its contextual relevance. Most of the existing literature on STEAM education comes from Western educational contexts. (Farah, Jarum, & Sumarsono, 2025), which raises questions about the generalizability of these findings across different educational systems. By examining the impact of STEAM-based learning across different educational contexts, this study provides evidence that interdisciplinary pedagogical approaches can be effective in diverse cultural and institutional environments. These findings support the broader application of STEAM education and contribute to efforts to diversify perspectives in educational research. To illustrate the integrated relationship between STEAM-based learning and the development of students' competencies, a hierarchical conceptual structure is presented in Figure 1. The figure demonstrates how STEAM-based learning functions as a foundational instructional approach that simultaneously supports the development of critical thinking, creativity, and collaboration.

Figure 1. Hierarchical Relationship Between STEAM-Based Learning and Students' Competencies



Source: Primary Data Processed, 2025

The hierarchical structure in Figure 1 illustrates how STEAM-based learning functions as a central instructional approach that simultaneously supports the development of critical thinking, creativity, and collaboration. This structure emphasizes that these competencies develop in an integrated manner through interdisciplinary learning experiences. Consequently, STEAM-based learning promotes the holistic development of students' cognitive, creative, and social abilities.

Overall, the findings of this study highlight the potential of STEAM-based learning as a comprehensive educational framework that supports cognitive, creative, and social development simultaneously. The integration of interdisciplinary inquiry, artistic expression, and collaborative problem-solving creates a dynamic learning environment that encourages students to think critically, generate innovative ideas, and work effectively with others. These competencies are increasingly recognized as essential for success in a rapidly changing technological and social landscape. By demonstrating the integrated impact of STEAM-based learning on a range of student competencies, this study contributes to the growing body of evidence supporting the adoption of interdisciplinary learning models in modern education.

CONCLUSION

The results of this study provide robust empirical evidence that STEAM-based learning serves as a highly effective pedagogical framework for simultaneously enhancing the critical thinking, creativity, and collaboration skills of senior high school students. Statistical analysis using simple linear regression confirmed a significant positive impact across all three dependent variables, with high coefficients of determination (R^2) indicating strong explanatory power. Specifically, STEAM-based learning contributed to 65.5% of the variance in creativity (t=14.200), 61.9% in critical thinking (t=13.120), and 58.0% in collaboration (t=12.106), all of which were statistically significant at a level of P<0,05. These findings suggest that the integration of artistic elements into STEM subjects does not merely add aesthetic value but fundamentally transforms the learning process by encouraging divergent thinking, evidence-based reasoning, and complex problem-solving. By engaging in interdisciplinary projects, students moved beyond rote memorization to actively analyze information and construct innovative solutions, proving that STEAM is a vital catalyst for mastering the holistic competencies required in the 21st-century landscape.

Despite these promising results, several limitations must be acknowledged to provide a balanced perspective on the study's scope. The research was primarily constrained by its quantitative survey design and its implementation within a single institutional setting at SMA Telkom Bandung, which may limit the generalizability of the findings to broader or more diverse educational systems. Furthermore, the reliance on a specific student cohort in the twelfth grade means that the developmental impact on younger students remains unexplored. Consequently, future research should aim to expand the geographical and cultural scope by involving larger, multi-site samples and adopting mixed-method or longitudinal approaches to track the long-term sustainability of these skill gains. It is also recommended that educational policymakers and school leaders prioritize systematic teacher professional development, focusing on interdisciplinary curriculum design and collaborative classroom management. Investigating the specific challenges teachers face during the transition from traditional to STEAM-based models would provide valuable insights for creating more resilient and adaptive modern learning environments.

REFERENCES

Abdullah, J., Nurdin, N., Lisnawati, S. D., Marakarma, A., & Yamani, G. (2025). Management of Research Collaboration in the Era of Merdeka Belajar Kampus Merdeka (MBKM). *Al-Tanzim: Jurnal Manajemen Pendidikan Islam*, *9*(3), 857–871. https://doi.org/10.33650/al-tanzim.v9i3.11319

Aguilera, D., & Ortiz-Revilla, J. (2021). STEM vs. STEAM Education and Student Creativity: A Systematic Literature Review. *Education Sciences*, *11*(7), 331. https://doi.org/10.3390/educsci11070331

Allina, B. (2018). The development of STEAM educational policy to promote student creativity and social empowerment. *Arts Education Policy Review*, *119*(2), 77–87. https://doi.org/10.1080/10632913.2017.1296392

Asmoni, A. (2025). Enhancing Primary Students' Critical Thinking through School Quality Management Practices and Deep Learning. *Al-Tanzim: Jurnal Manajemen Pendidikan Islam*, *9*(4), 1203–1216. https://doi.org/10.33650/al-tanzim.v9i4.12118

Bagheri Noaparast, K. (2022). Challenges Facing the Philosophy of Education in the Twenty-First Century. In Y. Alpaydın & C. Demirli (Eds), *Educational Theory in the 21st Century* (pp. 3–

23). Singapore: Springer Nature Singapore. https://doi.org/10.1007/978-981-16-9640-4_1

Belbase, S. (2019). STEAM Education Initiatives in Nepal. *Steam*, *4*(1), 1–8. https://doi.org/10.5642/steam.20190401.07

Bicer, A., Nite, S. B., Capraro, R. M., Barroso, L. R., Capraro, M. M., & Lee, Y. (2017). Moving from Stem to Steam: The Effects of Informal STEM Learning on Students' Creativity and Problem-Solving Skills with 3D Printing. *2017 IEEE Frontiers in Education Conference (FIE)*, 1–6. https://doi.org/10.1109/FIE.2017.8190545

Braun, V., & Clarke, V. (2013). *Successful Qualitative Research: A Practical Guide for Beginners*. London: SAGE Publications Ltd.

Butera, G., Horn, E. M., Palmer, S. B., Friesen, A., & Lieber, J. (2016). Understanding Science, Technology, Engineering, Arts, and Mathematics (STEAM). In B. Reichow, B. A. Boyd, E. E. Barton, & S. L. Odom (Eds), *Handbook of Early Childhood Special Education* (pp. 143–161). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-28492-7_9

Calliera, M., Capri, E., Bertuzzi, S., Tediosi, A., Pomilla, C., Juan, S. de, … Sacchettini, G. (2026). Enhancing a Youth Culture of Sustainability Through Scientific Literacy and Critical Thinking: Insights from the Erasmus+ YOU4BLUE Project. *Sustainability*, *18*(2), 913. https://doi.org/10.3390/su18020913

Chistyakov, A. A., Zhdanov, S. P., Avdeeva, E. L., Dyadichenko, E. A., Kunitsyna, M. L., & Yagudina, R. I. (2023). Exploring the Characteristics and Effectiveness of Project-based Learning for Science and STEAM Education. *Eurasia Journal of Mathematics, Science and Technology Education*, *19*(5), em2256. https://doi.org/10.29333/ejmste/13128

Chu, H.-E. (2021). Editorial: STEAM Education in the Asia Pacific Region. *Asia-Pacific Science Education*, *7*(1), 1–5. https://doi.org/10.1163/23641177-bja10026

Clear, A., Clear, T., Vichare, A., Charles, T., Frezza, S., Gutica, M., … Szynkiewicz, J. (2020). Designing Computer Science Competency Statements: A Process and Curriculum Model for the 21st Century. *Proceedings of the Working Group Reports on Innovation and Technology in Computer Science Education*, 211–246. Trondheim Norway: ACM. https://doi.org/10.1145/3437800.3439208

Conradty, C., & Bogner, F. X. (2020). STEAM Teaching Professional Development Works: Effects on Students' Creativity and Motivation. *Smart Learning Environments*, *7*(1), 26. https://doi.org/10.1186/s40561-020-00132-9

Conradty, C., Sotiriou, S. A., & Bogner, F. X. (2020). How Creativity in STEAM Modules Intervenes with Self-Efficacy and Motivation. *Education Sciences*, *10*(3), 70. https://doi.org/10.3390/educsci10030070

Creswell, J. W., & Guetterman, T. C. (2019). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research* (Sixth edition). Saddle River, New Jersey: Pearson.

Farah, R. R., Jarum, & Sumarsono, P. (2025). Navigating Western and Islamic Cultural Values in English Education: A Narrative Case Study of Teachers at International Islamic Boarding School. *Indonesian Journal of English Language Teaching and Applied Linguistics*, *10*(1), 57–72.

Fischer, A. (2022). Research Evaluation and Scientific Publications: Quantity or Quality? *Bulletin de l'Académie Nationale de Médecine*, *206*(7), 898–901. https://doi.org/10.1016/j.banm.2022.04.021

Ghafar, A. (2020). Convergence between 21st Century Skills and Entrepreneurship Education in Higher Education Institutes. *International Journal of Higher Education*, *9*(1), 218. https://doi.org/10.5430/ijhe.v9n1p218

Glejser, H. (1965). Inflation, Productivity, and Relative Prices—A Statistical Study. *The Review of Economics and Statistics*, *47*(1), 76–80. https://doi.org/10.2307/1924125

Glejser, H. (1969). A New Test for Heteroskedasticity. *Journal of the American Statistical Association*, *64*(325), 316–323. https://doi.org/10.1080/01621459.1969.10500976

Goodman, L. A. (1954). Kolmogorov-Smirnov tests for psychological research. *Psychological Bulletin*, *51*(2), 160–168. https://doi.org/10.1037/h0060275

Harris, A., & de Bruin, L. R. (2018). Secondary school creativity, teacher practice and STEAM education: An international study. *Journal of Educational Change*, *19*(2), 153–179. https://doi.org/10.1007/s10833-017-9311-2

Henriksen, D., Mehta, R., & Mehta, S. (2019). Design Thinking Gives STEAM to Teaching: A Framework That Breaks Disciplinary Boundaries. In M. S. Khine & S. Areepattamannil (Eds), *STEAM Education: Theory and Practice* (pp. 57–78). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-04003-1_4

Ilma, A. Z., Wilujeng, I., Nurtanto, M., & Kholifah, N. (2023). A Systematic Literature Review of STEM Education in Indonesia (2016-2021): Contribution to Improving Skills in 21st Century Learning. *Pegem Journal of Education and Instruction*, *13*(2), 134–146. https://doi.org/10.47750/pegegog.13.02.17

Jamil, F. M., Linder, S. M., & Stegelin, D. A. (2018). Early Childhood Teacher Beliefs About STEAM Education After a Professional Development Conference. *Early Childhood Education Journal*, *46*(4), 409–417. https://doi.org/10.1007/s10643-017-0875-5

Jaya, M., Rafin, M., Nurrohman, M., Ghofur, A., & Nastiar, M. F. (2025). Pengembangan Instrumen Evaluasi Pembelajaran Pai Dengan Menggunakan Model Taksonomi Bloom. *Educatioanl Journal: General and Spesific Research*, *5*, 122–129.

Juliastuti, Suherman, & Hasani, A. (2024). Analysis of the Relationship between Digital Literacy Program Development and Lecturer Productivity in Higher Education. *Nidhomul Haq : Jurnal Manajemen Pendidikan Islam*, *9*(3), 630–647. https://doi.org/10.31538/ndhq.v9i3.8

Kang, N.-H. (2019). A review of the effect of integrated STEM or STEAM (science, technology, engineering, arts, and mathematics) education in South Korea. *Asia-Pacific Science Education*, *5*(1), 6. https://doi.org/10.1186/s41029-019-0034-y

Liu, C.-Y., & Wu, C.-J. (2022). STEM without Art: A Ship without a Sail. *Thinking Skills and Creativity*, *43*, 100977. https://doi.org/10.1016/j.tsc.2021.100977

MacDonald, A., Wise, K., Tregloan, K., Fountain, W., Wallis, L., & Holmstrom, N. (2020). Designing STEAM Education: Fostering Relationality through Design-Led Disruption. *International Journal of Art & Design Education*, *39*(1), 227–241. https://doi.org/10.1111/jade.12258

Miles, M. B., & Huberman, A. M. (1994). *Qualitative data analysis: An expanded sourcebook* (2nd ed). Thousand Oaks: Sage Publications.

Moro, C., Phelps, C., & Birt, J. (2022). Improving serious games by crowdsourcing feedback from the STEAM online gaming community. *The Internet and Higher Education*, *55*, 100874. https://doi.org/10.1016/j.iheduc.2022.100874

Neliwati, N., Hasanah, U., Pringadi, R., Sirojuddin, A., & Arif, M. (2023). Curriculum Management in Improving The Quality of Student Learning and Academic Achievement. *Munaddhomah: Jurnal Manajemen Pendidikan Islam*, *4*(1), 115–121. https://doi.org/10.31538/munaddhomah.v4i1.233

Ogbonnaya, U. I., Loubser, N., & Lessing, M.-J. (2025). Social Media: A Transformative Tool in Mathematics Education in the Twenty-First Century. In J. Engelbrecht, G. Oates, & M. De Carvalho Borba (Eds), *Social Media in the Changing Mathematics Classroom* (pp. 27–42). Cham: Springer Nature Switzerland. https://doi.org/10.1007/978-3-031-82837-9_2

Park, H., Byun, S., Sim, J., Han, H.-S., & Baek, Y. S. (2016). Teachers' Perceptions and Practices of STEAM Education in South Korea. *Eurasia Journal of Mathematics, Science and Technology Education*, *12*(7), 1739–1753. https://doi.org/10.12973/eurasia.2016.1531a

Ping, H., Saibon, J., & Hamzah, A. (2025). Application of Behavior Change Techniques (BCTs) based on the ADDIE Model in University Tennis. *Environment-Behaviour Proceedings Journal*, *10*(SI24), 229–237. https://doi.org/10.21834/e-bpj.v10iSI24.6390

Pranata, A., & Syamsijulianto, T. (2025). Enhancing Civic Literacy in Primary Education Through and Team Games Tournament: A Bibliometric Review (2015–2025). *Journal of Elementary Education*, *2*(1), 42–52. https://doi.org/10.38040/jeleduc.v2i1.1248

Priyohutomo, A., Komarudin, & Sridadi. (2025). The Perspective of Physical Education Teachers: Challenges within the Project-Based Learning Model. *Physical Education Theory and Methodology*, *25*(3), 511–517. https://doi.org/10.17309/tmfv.2025.3.05

Rios, J. A., Ling, G., Pugh, R., Becker, D., & Bacall, A. (2020). Identifying Critical 21st-Century Skills for Workplace Success: A Content Analysis of Job Advertisements. *Educational Researcher*, *49*(2), 80–89. https://doi.org/10.3102/0013189X19890600

Shukshina, L. V., Gegel, L. A., Erofeeva, M. A., Levina, I. D., Chugaeva, U. Y., & Nikitin, O. D. (2021). STEM and STEAM Education in Russian Education: Conceptual Framework. *Eurasia Journal of Mathematics, Science and Technology Education*, *17*(10), em2018. https://doi.org/10.29333/ejmste/11184

Sonet, U. N., & Klufallah, M. (2024). Evaluation of Indicators for Participatory and Collaborative Design Process for Public Parks in Malaysia: Analytical Hierarchy Process. *Journal of Construction in Developing Countries*, *29*(S1), 1–18. https://doi.org/10.21315/jcdc.2024.29.S1.1

Sriyanto, Suyatno, & Ishafit. (2025). Efforts to Improve The Professionalism of High School Teachers In Bantul Regency: The Impact of Classroom Action Research On Teaching Performance. *Nidhomul Haq : Jurnal Manajemen Pendidikan Islam*, *10*(2), 489–500. https://doi.org/10.31538/ndhq.v10i2.167

Stroud, A., & Baines, L. (2019). Inquiry, Investigative Processes, Art, and Writing in STEAM. In M. S. Khine & S. Areepattamannil (Eds), *STEAM Education: Theory and Practice* (pp. 1–18). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-030-04003-1_1

Tan, A. L., Koh, D. J. Q., & Lim, X. Y. (2021). Science Teacher Education in Singapore: Developing Twenty-First-Century Readiness. In O. S. Tan, E. L. Low, E. G. Tay, & Y. K. Yan (Eds), *Singapore Math and Science Education Innovation* (pp. 227–240). Singapore: Springer Singapore. https://doi.org/10.1007/978-981-16-1357-9_13

Upadhyay, B., Coffino, K., Alberts, J., & Rummel, A. (2021). STEAM Education for Critical Consciousness: Discourses of Liberation and Social Change among Sixth-Grade Students. *Asia-Pacific Science Education*, *7*(1), 64–95. https://doi.org/10.1163/23641177-bja10020

Valls, A., Albó-Canals, J., & Canaleta, X. (2018). Creativity and Contextualization Activities in Educational Robotics to Improve Engineering and Computational Thinking. In W. Lepuschitz, M. Merdan, G. Koppensteiner, R. Balogh, & D. Obdržálek (Eds), *Robotics in Education* (pp. 100–112). Cham: Springer International Publishing. https://doi.org/10.1007/978-3-319-62875-2_9

Yusuf, M. S., Pajarianto, H., & Sulaiman, B. (2025). A Collaborative Parent-Teacher Model for Religious Moderation Education in Early Childhood in Indonesia. *South African Journal of Childhood Education*, *15*(1). Retrieved from https://eric.ed.gov/?id=EJ1464649

Zahru, N. A., Rasyid, S., & Usman, N. (2025). The Role of Madrasah Principal Leadership and Work Environment as Determinants of Teacher Performance. *Nidhomul Haq : Jurnal Manajemen Pendidikan Islam*, *10*(3), 766–780. https://doi.org/10.31538/ndhq.v10i3.259

Zhang, C., & Jia, B. (2024). Enriching STEAM education with visual art: Education benefits, teaching examples, and trends. *Discover Education*, *3*(1), 247. https://doi.org/10.1007/s44217-024-00354-w