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Meta-Analysis of the Impact of the STEAM Approach on Science Learning

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Abstract

The STEAM approach (Science, Technology, Engineering, Arts, and Mathematics) has emerged as a widely adopted instructional strategy aimed at developing essential 21st-century competencies such as critical thinking, creativity, collaboration, and scientific literacy. Numerous studies have explored the implementation of STEAM in science education, yet the results remain inconsistent due to variations in context, research variables, and educational levels. This inconsistency highlights the need for a comprehensive review that consolidates previous findings. Meta-analysis is a suitable method for this purpose, as it enables the calculation of the overall magnitude of STEAM's impact. This study aims to examine the overall effect of the STEAM approach in science education. The analysis is categorized by educational level, research variables, and instructional models integrated with STEAM. A quantitative meta-analysis method was employed. Data were collected using Publish or Perish software with sources from Google Scholar and Scopus. The selection process followed PRISMA guidelines. From an initial pool of 1,197 articles, 12 studies met the inclusion criteria and were further analyzed using JASP software version 0.19.3.0.The results indicate that the STEAM approach has a positive influence on science learning. The overall effect size was 0.213, which falls within the moderate category. When analyzed by educational level, the effect size was 0.200 (low category); by research variable, 0.221 (moderate category); and by instructional model, 0.234 (moderate category). These findings suggest that STEAM is an effective approach for enhancing the quality of science education and holds considerable potential as a pedagogical strategy across diverse learning contexts.

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INTRODUCTION

21st-century education in the era of the 5.0 revolution emphasizes the development of essential competencies such as literacy, collaboration, creativity, and problem-solving, while seamlessly integrating technology into the learning process. In this context, the role of the teacher shifts from being the sole source of knowledge to that of a facilitator, guiding students as they independently explore and cultivate their own abilities under appropriate supervision. This paradigm shift is essential for effectively addressing the challenges posed by the 5.0 revolution in education. Within this framework, science education or Natural Sciences holds a strategic role in fostering the skills demanded by this era, including problem-solving, creative thinking, critical thinking, and scientific literacy, commonly referred to as science literacy (Fricticarani et al., 2023).

Science learning as implemented across various educational levels, is still deemed ineffective due to its predominantly teacher-centered approach. This method often leads to student disengagement and boredom during the learning process. As a result, students tend to be less active in class, are not given sufficient opportunities to explore their own potential, and consequently, their conceptual understanding becomes limited. This condition not only contributes to declining academic performance but also reinforces the perception of science as a dull and uninteresting subject (Intan et al., 2024).

Given the prevalence of issues in science education at schools such as the continued reliance on lecture-based methods, summarizing textbook content, and the lack of hands-on practice either in laboratories or in the field it becomes increasingly clear that science teachers must be creative in designing instructional models, methods, approaches, and relevant learning media for their students. One viable solution is to implement an appropriate teaching approach tailored to students' needs. A promising alternative is the STEAM approach, which integrates multiple disciplines: Science, Technology, Engineering, Art, and Mathematics (Adlina, 2022).

The STEAM approach is highly relevant to science education, as it actively engages students in the learning process while positioning the teacher primarily as a facilitator in the classroom (Salmi et al., 2023). Numerous studies have been conducted on the implementation of the STEAM approach in education, particularly in subjects such as Biology, Chemistry, and Physics.

The aforementioned studies represent only a small portion of the existing research related to the STEAM approach in science education. These studies consistently indicate that the STEAM approach has a significant impact on students in the classroom. However, the exact magnitude of this effect remains unclear. Therefore, a more in-depth procedure is required to determine the extent of the influence exerted by the STEAM approach in science learning. In light of this, an additional analytical method is needed to examine the effect size more precisely. The analytical method in question is Meta-Analysis. Meta-Analysis is a systematic procedure within quantitative research that synthesizes findings from previous studies to draw conclusions about the strength of the effect whether it is categorized as low, moderate, or high (Glass, 1976).

A meta-analysis study is a type of research that synthesizes findings from previous studies to generate a comprehensive conclusion. It involves systematically combining quantitative data from selected prior research that meets specific inclusion criteria, which serve as the primary boundaries for data collection, data analysis, and the formulation of the final conclusion (Utami, 2017). Considering the limited number of studies that have comprehensively analyzed the magnitude of the effect (effect size) of the STEAM approach in science education, this study aims to, measure the overall impact of the STEAM approach in science learning identify the educational levels examined in the implementation of the STEAM approach, identify the variables investigated in its application and evaluate the instructional models integrated with the STEAM approach.

RESEARCH METHODS

This study adopts a quantitative research design utilizing the meta-analysis method. Meta-analysis is a statistical technique used to synthesize and systematically analyze results from multiple studies that examine a similar research topic, with the goal of determining the magnitude of the effect size (Borenstein et al., 2009). Data were collected through searches on Google Scholar and Scopus using the Publish or Perish software. A coding sheet was employed as the primary research instrument for extracting and organizing relevant data.

The data collection process was conducted through a structured literature review following the PRISMA 2020 protocol (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), which consists of key stages: identification, screening, and eligibility assessment (Ramayanti et al., 2023). During the identification phase, inclusion criteria were applied to assist in selecting studies that were most relevant and aligned with the research objectives. This systematic approach ensured a rigorous and transparent selection process for the studies included in the meta-analysis. The inclusion criteria and exclusion criteria used are presented in Table 1 as follows:

Table 1. Inclusion and Exclusion Criteria

No.	Exclusion Criteria	Inclusion Criteria
1.	The data lacks a title that aligns with the keywords.	Data analyzed involved the implementation of the STEAM approach in science education
2.	Published before the year 2021.	published between 2021 - 2025
3.	Not indexed in SINTA 1–6 or Scopus Q1–Q4.	Indexed in SINTA (levels 1–6) and Scopus (Q1–Q4)
4.	Does not contain the mean scores of the experimental and control groups, nor the standard deviation	Included the average scores and standard deviations of both experimental and control groups

The selection of articles in this study was restricted to those meeting the criteria outlined in Table 1. Article retrieval was conducted via Google Scholar and Scopus, utilizing the Publish or Perish software, during the period from May to June 2025. The search employed the keywords "STEAM approach and science learning," yielding an initial database of 1,197 records. This database then underwent a systematic screening process, resulting in a final selection of 12 articles that met the established inclusion criteria. The detailed procedure of the meta-analysis is illustrated in Figure 1.

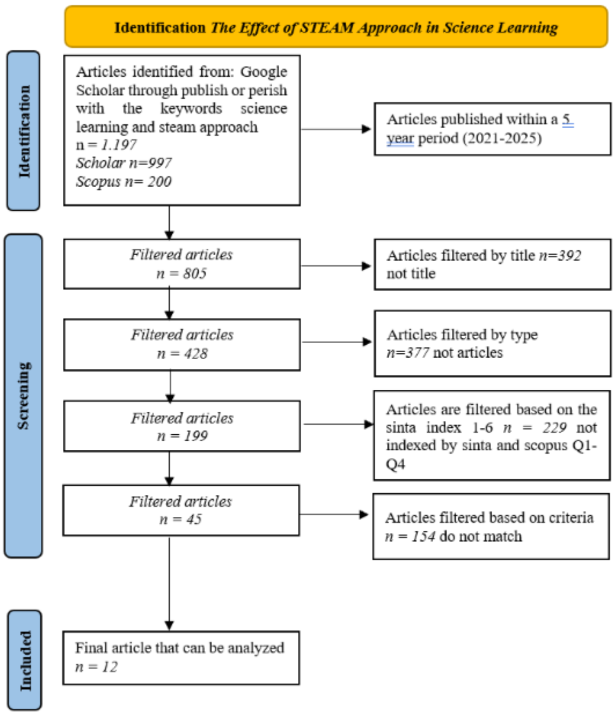

Figure 1. Meta-Analysis Procedure

The data analysis technique in this study employs the effect size criterion known as Cohen's d. The classification criteria for Cohen's d effect size are as follows:

Table 2. Cohen's d Standard

Cohen's Standard	*Effect Size*
High	0,6 - 2,0
Moderate	0,3 - 0,5
Low	0,0 - 0,2

The subsequent data analysis will be conducted using the Normalized Gain test. The formula and criteria are presented as follows:

$$N - gain = \frac{posttest\ score - pretest\ score}{ideal\ score - pretest\ score}$$

In accordance with the criteria detailed below.

Table 3. Normalized Gain Criteria

N-Gain Score	Criteria
$0{,}70 < g < 100$	High
$0{,}30 < g < 0{,}70$	Moderate
$0{,}00 < g < 0{,}30$	Low
$g = 0{,}00$	There was no decreas
$-1{,}00 < g < 0{,}00$	A decline occurred

RESULTS AND DISCUSSION

This study utilized data from 12 journal articles indexed in Sinta (levels 1–6) and Scopus (Q1–Q4) published between 2021 and 2025, systematically filtered from an initial pool of 1,197 articles through multiple selection stages based on title, publication type, indexation, and predefined inclusion criteria, with the aim of exploring the effectiveness of the STEAM approach in enhancing students' conceptual understanding of science, viewed through the lenses of variables, educational levels, and integrated instructional models. the results are presented in Table 4 as follows.

Table 4. Data Extractions Results

Code	Researchers	Educational Level	Variable	Index
A43	Nugraha et al. (2023)	Primary School	Critical Thinking	Sinta 4
A40	Putri & Zulfadewina (2023)	Primary School	Scientifik Literacy	Sinta 3
A41	Setyawan et al. (2023)	Senior High School	Critical Thinking	Sinta 4
A42	Kusumayuni et al. (2023)	Primary School	Learning Outcomes	Sinta 2
A34	Khoirrunnisa & Isdaryanti (2024)	Primary School	Learning Outcomes	Sinta 5
A18	Aulia et al. (2024)	Primary School	Learning Outcomes	Sinta 5
A21	Iljannah et al. (2025)	Senior High School	Critical Thinking	Sinta 3
A45	Azalia et al. (2024)	Primary School	Creative Thinking	Sinta 2
A29	Mantulangi et al. (2025)	Senior High School	Scientific Process Skill	Sinta 4
A44	Ramadhan (2023)	Primary School	Scientifik Literacy	Sinta 4
A9	Wang et al. (2022)	Primary School	Computational Thinking	Q2
A1	Suryanti et al. (2024)	Primary School	Scientifik Literacy	Q3

Table 4 above presents the filtered article data, comprising 12 articles selected for comprehensive analysis based on region, educational level, measured variables, and integrated learning models. These 12 articles exhibit diverse characteristics, with one article published in 2022, five articles in 2023, four articles in 2024, and two articles in 2025.

The Overall Effect Size Results

For each article, an Effect Size calculation will be conducted to obtain an average value for the data to be analyzed comprehensively. Subsequently, a more in-depth data analysis will be carried out to determine the significant influence of the STEAM approach in science education, based on the measured dependent variables, educational level, instructional models integrated with the STEAM approach, and the variables assessed. The overall results of the Effect Size calculations are presented as follows.

Table 5. Overall Effect Size Results

Code	Researcher	Educational Level	*Effect Size*
A43	Nugraha et al. (2023)	Primary School	0,407
A40	Putri & Zulfadewina (2023)	Primary School	0,178
A41	Setyawan et al. (2023)	Senior High School	0,127
A42	Kusumayuni et al. (2023)	Primary School	0,222
A34	Khoirrunnisa & Isdaryanti (2024)	Primary School	0,374
A18	Aulia et al. (2024)	Primary School	0,155
A21	Iljannah et al. (2025)	Senior High School	0,245
A45	Azalia et al. (2024)	Primary School	0,416
A29	Mantulangi et al. (2025)	Senior High School	0,188
A44	Ramadhan (2023)	Primary School	0,183
A9	Wang et al. (2022)	Primary School	0,077
A1	Suryanti et al. (2024)	Primary School	0,065
		Average	**0,213**

Based on Table 5 above, the calculated average effect size of the STEAM approach in science learning is 0.213. This average falls within the medium category, indicating that the STEAM approach has a positive impact on science education. The highest effect size was reported by Azalia et al. (2024) in a study conducted at the elementary school level, with a value of 0.416, which is categorized as medium. Conversely, the lowest effect size was reported by Suryanti et al. (2024) in an elementary-level study, with a value of 0.065. Overall, it can be concluded that the STEAM approach has a positive impact on science learning, with effect sizes ranging from low to medium categories.

The following presents the results of the N-Gain Score analysis for the overall dataset obtained from the screening of studies on the STEAM approach in science education. The results of the N-Gain analysis are as follows.

Table 6. Normalized Gain Results

Mean	Experimental Class	Control Class
Pretest	57.17	50.17
Posttest	84.58	71.53
N-Gain	0.62	0.42

Based on Table 6 above, the calculated N-Gain for the experimental class is 0.62, which, being less than 0.7, falls within the moderate category. Similarly, the N-Gain obtained for the control class is 0.42, also indicating a moderate category. This suggests that the STEAM approach has a positive impact on science learning, as evidenced by a notable difference in N-Gain scores between the experimental and control groups, where 0.62 > 0.42.

Furthermore, the overall effect size calculation is visualized through a forest plot using the JASP software. The visualization is presented as follows.

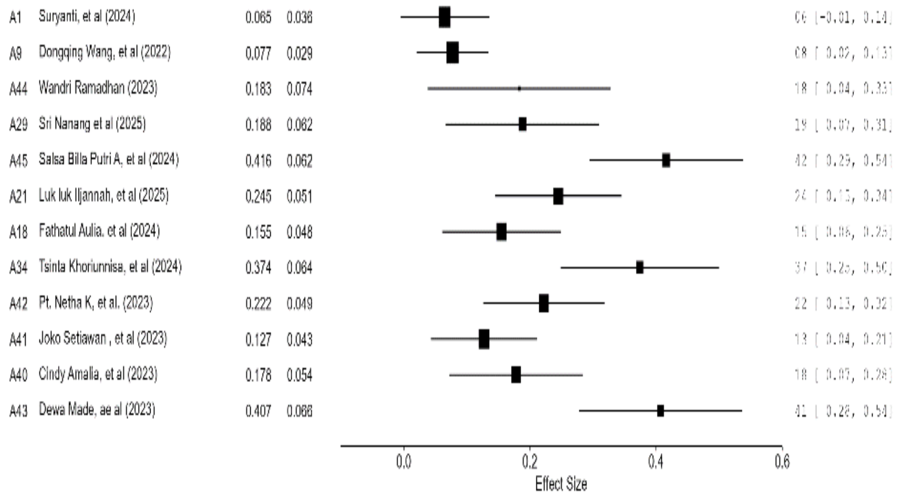

Figure 2. Pooled Effect Size as Depicted in the Forest Plot

In Figure 2 above, the STEAM approach demonstrates an overall influence on science education. This is evident from the forest plot visualization, where none of the studies intersect the null effect line at 0.00. Therefore, it can be concluded that the STEAM approach exerts a significant impact on science learning.

Overall, the research findings indicate that the effect size of the STEAM approach in science education is 0.213. This result suggests that, in general, the STEAM approach has a positive impact on science learning. The effect size falls within the medium-effect category, indicating that STEAM can enhance science education, although the magnitude of its impact remains within a low to moderate range. Additionally, there is considerable variation in effect sizes across studies, with the highest recorded effect size being 0.416 and the lowest 0.065.

The variation among these studies also indicates that the implementation of the STEAM approach in science education has yet to demonstrate consistent contribution and effectiveness. This inconsistency may stem from various factors in the implementation process, such as instructional design, teachers' ability to apply STEAM in a comprehensive manner, limited supporting infrastructure and facilities, as well as students' readiness for learning. This statement aligns with the findings of Nurfadilah & Siswanto (2020), which highlight the availability of resources and supporting facilities such as technology and project materials along with students' preparedness and motivation to engage actively and collaboratively in the learning process.

Effect Size Results by Educational Level

The results of the journal analysis related to the STEAM approach in science education indicate its applicability across all educational levels, from early childhood education to higher education. However, based on the data analysis conducted, the focus was narrowed down to two specific educational levels: Elementary School and Senior High School. The corresponding Effect Size results based on these educational levels are presented in the following table.

Table 7. Effect Size by Educational Level

Code	Educational Level	*Effect Size*	Average
A1	Primary School	0,077	
A9	Primary School	0,065	
A43	Primary School	0,407	
A40	Primary School	0,178	
A42	Primary School	0,222	0,230
A18	Primary School	0,155	
A45	Primary School	0,416	
A44	Primary School	0,183	
A34	Primary School	0,374	
A41	Senior High School	0,127	
A21	Senior High School	0,245	0,187
A29	Senior High School	0,188	
	Average		**0,200**

In Table 7 above, the effect size based on educational level yielded an average effect size of 0.200, which falls into the low category. At the elementary school level, the effect size was 0.213, categorized as moderate, while at the senior high school level, the effect size was 0.187, which falls into the low category. Based on these findings, it can be inferred that the STEAM approach has an influence on science learning across educational levels, with effect sizes ranging from low to moderate.

The subsequent effect size results based on educational level will be visualized in the form of a forest plot. The visualization is presented as follows.

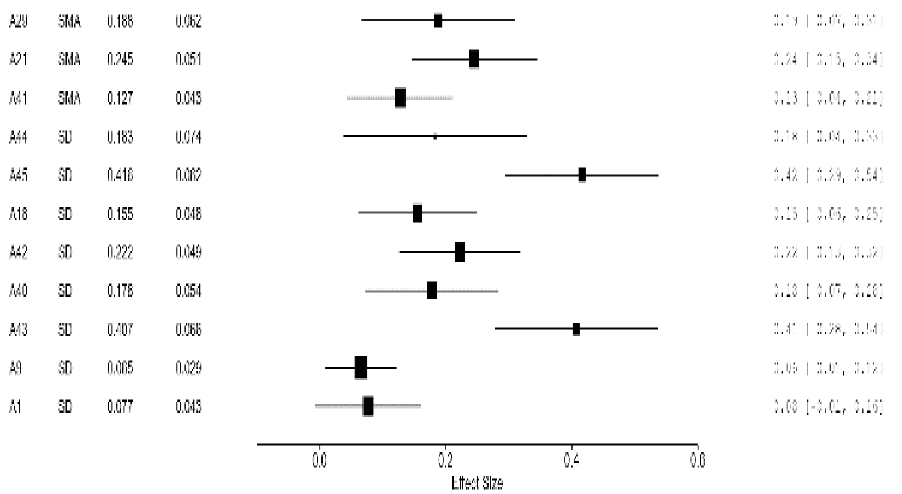

Figure 3. Forest plot categorized by educational level

In Figure 3 above, the STEAM approach overall demonstrates an effect on science education across different educational levels. This is evident from the forest plot visualization, where none of the studies intersect the zero-effect line at 0.00 indicating that all included studies reported a measurable effect size. Therefore, it can be concluded that the STEAM approach has a significant impact on science learning, regardless of the educational level, whether at the elementary or senior high school level.

This study demonstrates an uneven scope due to several influencing factors, such as the limited number of indexed articles published across all educational levels namely kindergarten, elementary school, junior high school, senior high school, and higher education. As a result, many published articles lack indexing, which affects their inclusion based on the predetermined criteria.

Based on the analysis presented in Table 7, the effect size is categorized as moderate for the elementary school level and low for the senior high school level. Further data analysis indicates that the effect size at the elementary level is higher compared to the senior high school level, with values of 0.213 and 0.187, respectively. These findings suggest that the contribution and effectiveness of the STEAM approach in science learning are more pronounced at the elementary school level. These findings are consistent with the study conducted by Atiaturrahmaniah et al. (2022), which revealed that at the elementary school level, children are still in the cognitive developmental stage of concrete operations.

At this stage, project-based learning and direct experiential activities are particularly effective in fostering the development of critical thinking and creativity. The integrative thematic nature of the elementary school curriculum further facilitates the implementation of the STEAM approach across disciplines. Moreover, the flexibility in instructional management at the elementary level enables teachers to apply the STEAM approach in a more comprehensive and contextual manner, tailored to the specific needs of the learners (Atiaturrahmaniah et al., 2022). Additionally, this is supported by the Forest Plot visualization using JASP shown in Figure 3, which illustrates a positive impact of the STEAM approach, with no studies falling along the threshold line of effect size.

The higher effect size at the elementary school level is influenced by the greater mean score of the experimental group compared to the control group. Conversely, the smaller effect size at the senior high school level is reflected in the smaller difference between the control and experimental group means. Beyond the mean score differences between experimental and control groups, other contributing factors to the variation in effect size include students' readiness and maturity in learning, educational level, and the statistical tests employed (Hendra, 2021).

The analysis results indicate that the STEAM approach can contribute significantly to science education. Therefore, it can be concluded that the STEAM approach has a positive impact when integrated into science learning, serving as an effective strategy to foster innovative and creative learning experiences for students.

Effect Size Outcomes as Determined by the Research Variables

The results of the analysis of scientific journal publications were categorized based on the research variables measured in the implementation of the STEAM approach in science education. From this categorization, six (6) variables were identified as being measured using the STEAM approach. The effect size results based on the measured variables are presented in the following table.

Table 8. Effect Size According to Research Variables

Code	Variable	*Effect Size*	Average
A40	Scientifc Literacy	0,178	
A1	Scientifc Literacy	0,077	0,416
A44	Scientifc Literacy	0,183	
A43	Critical Thinking	0,407	
A41	Critical Thinking	0,127	0,260
A21	Critical Thinking	0,245	
A42	Learning Outcomes	0,222	
A34	Learning Outcomes	0,374	0,250
A18	Learning Outcomes	0,155	
A45	Creative Thinking	0,416	0,416
A9	Computational Thinking	0,065	0,065
A29	Scientific Process Skill	0,188	0,188
	Average		**0,221**

Based on Table 8 above, the average effect size for each measured variable is 0.221, which falls into the medium category. Each variable yields the following effect sizes: scientific literacy has an average effect size of 0.146 (low category); critical thinking has an average effect size of 0.260 (medium category); learning outcomes show an average effect size of 0.250 (medium category); creative thinking has an effect size of 0.416 (medium category); computational thinking records an effect size of 0.065 (low category); and scientific process skills show an effect size of 0.188 (low category). These findings indicate that the STEAM approach has an impact on science learning across the measured variables. Among these, the greatest effect is observed in creative thinking, followed by critical thinking, learning outcomes, scientific process skills, scientific literacy, and computational thinking.

Subsequently, the effect size results based on each variable will be visualized in the form of a forest plot. The visualization is presented as follows:

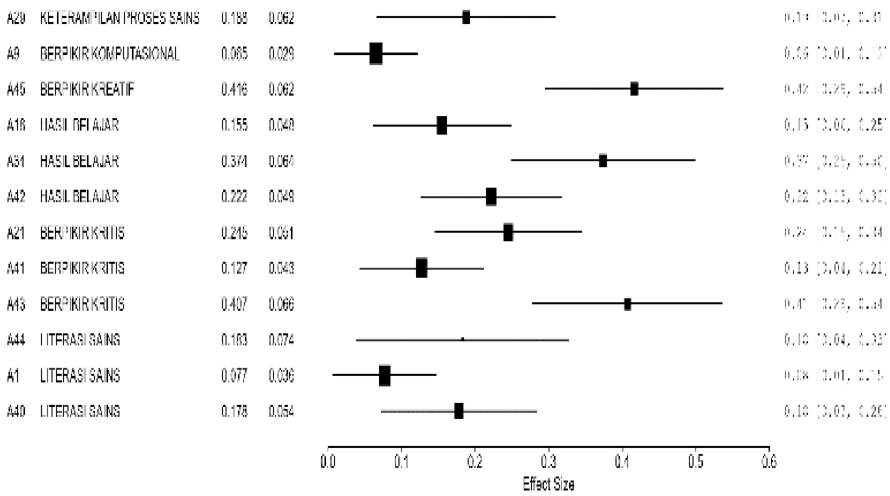

Figure 4. Forest plot based on research variables

In Figure 4 above, the STEAM approach overall demonstrates a significant impact on science learning based on the variables measured. This is evident from the forest plot visualization, where none of the studies intersect the reference line indicating a null effect size at 0.00. Therefore, it can be concluded that the STEAM approach exerts a measurable influence on science education outcomes across the examined variables.

The data analysis presented in Table 8 further supports the influence of the STEAM approach in science education, particularly when viewed through the lens of the specific variables assessed in the studies. The STEAM approach shows the strongest effect on students' creative thinking skills, as indicated by the highest effect size value of 0.416 in this category. Following this, the approach also demonstrates notable effects on critical thinking skills, academic achievement, science process skills, scientific literacy, and computational thinking, in that order. These findings align with the core characteristics of the STEAM approach, which emphasizes exploration, design, and the creation of products or innovative ideas in response to real-world problems.

Thus, based on both the supporting data and visual representation in the forest plot (Figure 4), it can be asserted that the STEAM approach is particularly effective in fostering creative thinking skills among students. However, this does not preclude the potential for other variables to show more positive outcomes if the STEAM approach is further optimized in instructional practices. The sequence depicted in Figure 5 reinforces the notion that the STEAM approach contributes significantly and effectively to science education.

Effect Size Results Based on Instructional Models

The results of the analysis of scientific journal publications were categorized based on the research variables measured in the implementation of the STEAM approach in science education. Within this category, four (4) instructional models were identified as being integrated with the STEAM approach. The corresponding effect size results based on each instructional model integrated with the STEAM approach are presented in the following table.

Table 9. Effect Size According to Instructional Models

Code	Models	*ES*	Average
A40	*RADEC*	0,178	0,199
A41	*RADEC*	0,127	
A42	*Discovery Learning*	0,222	0,248
A29	*Discovery Learning*	0,188	
A45	*PjBL*	0,416	0,225
A44	*PjBL*	0,183	
A1	*PjBL*	0,077	
A21	*SSCS*	0,245	0,245
A43	Not Integrated	0,407	0,250
A34	Not Integrated	0,374	
A9	Not Integrated	0,065	
A18	Not Integrated	0,155	
	Average		**0,234**

Based on Table 9 above, in the category of integrated instructional models, an effect size of 0.234 was obtained, which falls within the medium category. For each instructional model integrated with the STEAM approach in science learning, the following average effect sizes were recorded: the RADEC model yielded an average effect size of 0.199, which is categorized as low; the Discovery Learning model yielded an average effect size of 0.248, also falling into the low category; the Project-Based Learning model yielded an average effect size of 0.225, categorized as low as well; the SSCS model (Search, Solve, Create, and Share) yielded an effect size of 0.245, which is classified as medium.

Meanwhile, the overall STEAM-integrated approach yielded an average effect size of 0.250, also within the medium category. Based on these data, it can be inferred that the STEAM approach exerts a measurable influence on science learning, as indicated by the effect size categories across the integrated instructional models.

Subsequently, the effect size results based on variables will be visualized using a forest plot. The visualization is as follows:

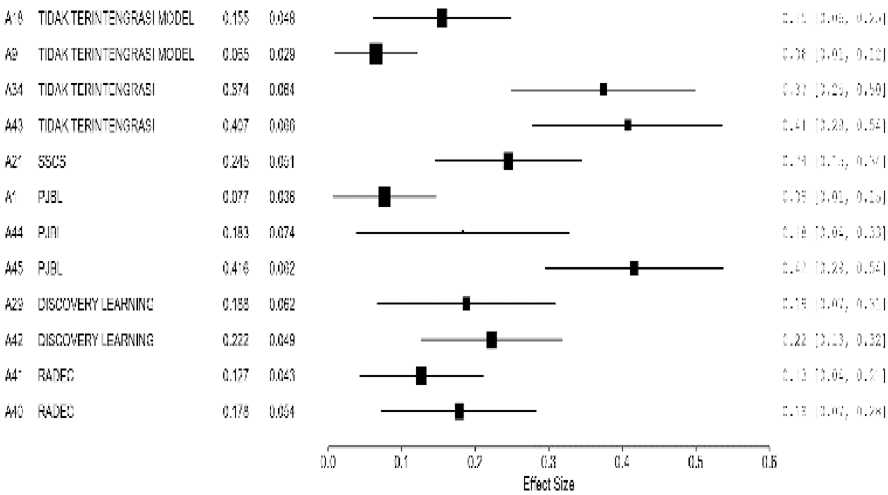

Figure 4. Forest Plot Stratified by Instructional Models

In Figure 5 above, the STEAM approach overall demonstrates an effect in science learning based on the integration of instructional models. This is evident from the forest plot visualization, where none of the studies intersect the reference line indicating no effect size, which is set at 0.00. Therefore, it can be concluded that the STEAM approach exerts a significant influence in science education when integrated with various instructional models.

According to Table 9, the analysis reveals an interesting finding: the STEAM approach that is not integrated with any specific instructional model shows the highest level of effectiveness, followed by the SSCS model in second place, discovery learning in third, project-based learning in fourth, and RADEC in fifth. The standalone implementation of STEAM exhibits the strongest effect size, indicating that STEAM is a robust approach capable of functioning independently in instructional settings. However, its flexible nature also allows it to be effectively integrated with a range of learning models.

The strongest impact of the STEAM approach is observed when integrated with the SSCS model (Search, Solve, Create, and Share), followed by other commonly used models such as project-based learning, discovery learning, and RADEC. This finding is further supported by the forest plot visualization in Figure 4, generated using JASP, which shows that all studies report a positive effect size, with none falling on the zero line, and the standalone STEAM approach occupying the topmost position. The lower effectiveness of the STEAM approach when combined with the RADEC model, compared to SSCS, can be explained by the differences in their respective syntaxes.

The SSCS model guides students through a sequence of active learning stages, including problem identification and formulation (Search), problem-solving (Solve), product creation (Create), and sharing results (Share) (Maimun & Bahtiar, 2022). These stages align closely with the core principles of the STEAM approach, which emphasizes project-based learning, collaboration, exploration, and innovation.

In contrast, the RADEC model focuses more on conceptual understanding through structured activities such as reading, answering, discussing, and explaining activities that tend to be teacher-centered and limit opportunities for student-driven exploration and creativity. Therefore, the syntactical alignment between SSCS and the characteristics of the STEAM approach makes it more effective than RADEC in enhancing the quality of science learning.

In conclusion, the The STEAM approach in science education, whether integrated with instructional models or implemented independently, demonstrates a positive and meaningful impact. Nevertheless, further development is needed to optimize its integration with various teaching models in order to enhance the overall effectiveness of education. However, potential biases in this study must be acknowledged, including the limited number of articles analyzed, methodological variations across studies, and the possibility of publication bias favoring statistically significant results all of which may affect the generalizability of the findings.

CONCLUSIONS AND SUGGESTIONS

This study concludes that the STEAM approach holds significant potential in enhancing science education through its interdisciplinary nature, fostering students' critical thinking, creativity, and problem-solving skills. Whether applied independently or in combination with various instructional models, STEAM has proven to be an effective pedagogical strategy across educational levels. Its alignment with current educational demands, particularly in developing 21st-century competencies, further reinforces its relevance in the classroom. However, successful implementation depends on appropriate contextualization, teacher readiness, and the integration of meaningful, real-world learning experiences.

Future research is encouraged to explore the long-term impacts of STEAM implementation across diverse learning environments and student demographics. Educators and policymakers should consider professional development programs to enhance teachers' competence in designing and delivering STEAM-based instruction. In addition, curriculum developers are advised to support the integration of STEAM into national curricula in a structured and adaptable manner, ensuring that learning objectives, resources, and assessments align with the goals of interdisciplinary education.

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