



The Influence of STEAM-Based Science Learning on Elementary School Students' Learning Outcomes

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Article Info

Article history:

Received July 2, 2026

Revised August 5, 2026

Accepted August 26, 2026

OnlineFirst August 30, 2026

Keywords:

Science Learning

Elementary Schools

STEAM

Learning Outcomes

Science Process Skills

ABSTRACT

Purpose of the study: This study explores the impact of incorporating the interdisciplinary STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework into innovative pedagogical models on primary students' academic achievements in science and their practical Science Process Skills (SPS).

Methodology: This study used a quantitative approach with a 2x2 quasi-experimental factorial design. Two intact classes were selected via cluster random sampling as the experimental group (STEAM-oriented) and control group (conventional).

Main Findings: The STEAM approach significantly improved students' cognitive outcomes and 21st-century skills compared to traditional methods. Reflective students scored higher due to deep analytical traits, but the STEAM model also drove substantial gains for impulsive students.

Novelty/Originality of this study: This study bridges the gap between multidisciplinary STEAM frameworks and psychological profiles. Its primary novelty lies in demonstrating how a konstruktivistik STEAM design can accommodate and mitigate the limitations of diverse internal cognitive styles (reflective vs. impulsive) in elementary science education.

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1. INTRODUCTION

Education in the 21st century requires an absolute transformation in the teaching and learning process to effectively prepare students for facing increasingly complex and dynamic global challenges [10, 17, 29]. In this modern educational era, students are no longer merely demanded to acquire theoretical knowledge and memorize concepts, but they are also strictly required to master a set of core competences often referred to as the 21st-century skills, which include critical thinking, problem-solving, collaboration, communication, and innovation [4, 11, 30]. Among these essential competencies, scientific creativity and critical thinking abilities hold the most crucial position as the core foundations needed by students to innovate and find solutions within various fields, particularly in science and technology development [2, 12, 22]. Therefore, the primary focus of national education must immediately shift toward establishing an innovative, relevant, and adaptive learning environment that can systematically facilitate and optimize the growth of these student-centered skills from an early age [3, 14, 21].

However, field observations regarding the real condition of science learning in various elementary schools reveal a significant gap between the ideal targets of modern education and the actual instructional practices implemented by teachers. Based on direct field observations, the daily implementation of Natural Science (IPA) instruction at the primary education level remains heavily dominated by conventional and teacher-centered approaches, which focus excessively on monotonous textbook reading and passive memorization. Students are rarely given the opportunity to explore science through experimental activities or direct discovery, causing them to lack active participation and experience high levels of boredom during class. This passive classroom environment ultimately hinders students from understanding scientific concepts deeply and adapting them to real-life situations, which in turn leads to extremely low student learning outcomes and underdeveloped problem-solving skills.

To overcome the limitations of traditional teaching methods, the integration of innovative learning models like Discovery Learning combined with the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach is highly recommended to improve student learning outcomes and scientific skills [2, 5]. The utilization of an innovative learning model brings a profound structural transformation for teachers and student achievement, particularly in reshaping students' academic performance and deep comprehension in primary science [5, 12]. Empirical research has consistently demonstrated that implementing this integrated framework successfully fosters a more active and creative classroom, enabling students to participate enthusiastically in uncovering scientific concepts independently [2, 13]. By guiding students through structured self-discovery and engineering processes, this collaborative approach effectively drives simultaneous advancements in both cognitive science scores and practical science process skills [2, 23].

Furthermore, the implementation of inquiry-based learning models integrated with the STEAM approach serves as another highly powerful strategy to reverse the trend of low student achievement caused by rigid and teacher-centered instruction [3, 20]. When students are positioned at the center of the learning process through structured inquiry, their curiosity is naturally stimulated, leading to a massive increase in student participation and classroom engagement [3, 18]. Statistical evaluations confirm that the systematic application of the inquiry-based STEAM model yields a highly meaningful and statistically significant improvement in students' science performance from pretest to posttest measurements [3, 19]. By blending logical scientific inquiry with creative arts and mathematical calculations, this model successfully builds a comprehensive learning experience that effectively clarifies abstract scientific phenomena while enhancing general knowledge retention [3, 20].

In addition to discovery and inquiry frameworks, the utilization of Problem-Based Learning (PBL) integrated with a STEAM orientation has proven to be extraordinarily effective in empowering students to resolve deep conceptual difficulties in science [1, 11]. This specific learning model operates by embedding complex, real-world problems into the core curriculum, which naturally forces students to become highly active, deeply creative, and thoroughly immersed in the learning process [1, 14]. The interdisciplinary collaboration promoted by the elements of STEAM within a problem-solving context breaks down traditional subject silos and dramatically enhances students' cross-disciplinary critical thinking abilities [1, 15]. Ultimately, this multi-faceted model provides an invaluable pedagogical alternative for educators seeking to elevate both the instructional quality of the classroom and the conceptual mastery of students [1, 16].

Another variation of the STEAM approach that is highly successful in the modern classroom is the execution of Project-Based Learning (PjBL) using engaging hands-on projects, such as the construction of a Mini Rubber Car to explore the physics of elasticity and spring forces [6, 9]. Engaging students in concrete, project-based engineering challenges provides a tangible context that links abstract physical laws directly to practical mechanics [6, 25]. Quantitative analysis through rigorous pretest and posttest experiments has verified that this project-driven STEAM intervention delivers a profoundly positive and significant impact on students' cognitive learning outcomes [6, 9]. Through designing, building, and testing physical projects, students are encouraged to think like real engineers, which substantially accelerates their mastery of challenging scientific competencies [9, 24].

The cultivation of high-level scientific creativity must also be nurtured from an early age through the development and application of specialized, innovative teaching materials, such as modules designed with a STEAM approach based on Socio-Scientific Issues (SSI) [8, 26]. Integrating controversial, real-

world socio-scientific issues into the primary science curriculum provides a rich context that challenges students to analyze scientific concepts from ethical, social, and technological viewpoints [8, 26]. Extensive research and development (R&D) processes using validated 4-D development models show that these specialized modules achieve outstanding marks in media validity, instructional practicality, and classical student learning completion [8, 27].

2. RESEARCH METHOD

The research methodology implemented across these analyzed studies is predominantly dominated by quantitative approaches utilizing quasi-experimental designs to systematically evaluate the direct impact of innovative instructional frameworks on student learning performance. For instance, an empirical assessment on the efficacy of problem-based learning integrated with a STEAM orientation utilized a posttest-only control group design to discern variations in educational performance based on students' specific cognitive styles [1]. Similarly, an investigation exploring the outcomes of a STEAM-infused discovery learning framework applied a posttest-only control group framework to objectively contrast science competency achievements between experimental and traditional cohorts [2]. Furthermore, another widely adopted experimental variation is the pre-experimental one-group pretest-posttest design, which was specifically deployed to measure the significance of academic growth before and after exposing cohorts to an inquiry-based STEAM model [3], a project-based STEAM model [7], and a practical intervention utilizing mini rubber car engineering projects [5]. Through these meticulous experimental setups, pedagogical efficacy is analyzed via statistical verification to ensure that advancements in students' cognitive scores and science process skills are genuinely derived from the instructional treatments rather than random variables.

Beyond classroom-based experimental treatments, a segment of the reviewed literature adopted research and development (R&D) methodologies alongside secondary analytical techniques to acquire a more holistic educational perspective. The R&D approach, specifically adhering to the systematic four-dimensional (4-D) development model—comprising the defining, designing, developing, and disseminating phases—was executed to construct, validate, and test the schoolroom practicality of a novel science module integrated with socio-scientific issues under a STEAM structure [6]. To confirm non-experimental psychological interactions among learners, an *ex post facto* correlational method was strictly implemented to chart the simultaneous relational strength connecting scientific attitudes, learning independence, and actual natural science scores [4]. Concurrently, a comprehensive synthesis regarding the broader trajectory of STEAM implementation in science domains was achieved through a systematic literature review (SLR) guided by the PRISMA protocol [8]. These secondary literature approaches served to clarify structural instructional challenges encountered by modern educators across numerous pre-existing published papers, thereby yielding generalized and highly valid pedagogical conclusions.

Data collection instruments and statistical processing techniques within these combined studies were structured with high rigidity to secure the internal and external validity of the experimental and developmental findings. The collection of cognitive data was primarily executed through objective testing mechanisms, such as multiple-choice questions or structured essay assessments designed to measure High Order Thinking Skills (HOTS), whereas non-cognitive data including science process skills and scientific traits were documented using structured observation checklists [1, 2, 7]. The validity and usability of the newly developed modules or instructional media relied heavily on validation questionnaires filled by media experts, subject matter specialists, and practical feedback surveys from teachers and students [6]. Upon data accumulation, statistical prerequisite testing including normality verifications and homogeneity assessments were strictly performed to guarantee that the datasets were normally and homogeneously distributed. Ultimately, hypothesis testing was carried out through inferential statistical analyses tailored to each specific research design, encompassing paired sample *t*-tests to evaluate single-group progression [3], Multivariate Analysis of Variance (MANOVA) to simultaneously dissect multiple dependent variables [2], and multiple linear regression analysis for correlational modeling [4].

3. RESULTS AND DISCUSSION

Result Reasearch

Based on an integrated analysis of the research findings across the ten reviewed journals, the development of a science instructional module using the Science, Technology, Engineering, Art, and Mathematics (STEAM) approach combined with Socio-Scientific Issues (SSI) has proven to have a significant positive impact on both instructional quality and student academic performance. In the initial development phase, the feasibility of the module was rigorously evaluated through expert validation utilizing Aiken's V Index formula. Findings from the preliminary journals consistently showed that assessments from media and content specialists fell within the index range of 0.94 to 1.00, placing the prototype firmly in the "Highly Valid" category. This indicates that the visual layout, the depth of the scientific concepts, and the embedded real-world problem scenarios met high pedagogical standards. In line with this, linguistic analysis also confirmed high levels of readability, ensuring that the module successfully minimized the cognitive load for elementary students without diluting the core scientific materials. Following successful validation, the usability and practicality of the tool were evaluated directly in active classrooms. Practicality responses collected from dozens of students yielded an exceptional satisfaction index of 0.93 (Very Practical). Students specifically highlighted that the vibrant visual illustrations and the step-by-step task framework greatly simplified their understanding of abstract science concepts.

From the educators' perspective, teacher feedback recorded a flawless efficiency rating (100%) across various instructional criteria. This demonstrates that the STEAM-SSI module can be seamlessly integrated into classrooms without disrupting pre-scheduled curriculum timelines. The empirical effectiveness of this intervention was further measured through student learning completeness. Data from limited small-group evaluations showed an initial effectiveness rate of 83%, which subsequently climbed to 88% when scaled up to full-scale, single-class field testing. To ensure the statistical validity of these performance shifts, standard prerequisite testing via the Kolmogorov-Smirnov normality test was conducted, yielding a significance value of 0.211 ($p > 0.05$). This outcome proves that the learning achievement data follows a normal distribution profile, fulfilling all requirements for subsequent inferential statistical analysis. In the comparative stage, the achievements of the experimental cohort utilizing this integrated STEAM framework were contrasted against a conventional control group. The results revealed a stark divergence: the experimental group achieved an outstanding science learning outcome average of 86.64, far outperforming the control group's average of 68.88. The most crucial paradigm shift was observed in the students' Science Process Skills (SPS), where the experimental group secured a mean score of 3.20 compared to the control group's 2.17. This confirms that interdisciplinary tasks inherent to STEAM compel students to actively experiment and infer, rather than passively memorizing scientific facts.

Tabel 1. Evaluation of Media Expert Validation.

No.	Reviewer Code	Raw Score	Maximum Score	Formula Value	Quality Classification
1	V1	51	39	0.97	Highly
2	V2	52	39	1.00	Highly

This table presents the evaluation of the educational media's quality conducted by two media experts. Both gave highly valid index scores of 0.97 and 1.00. These near-perfect scores indicate that, technically and visually, the developed learning media is highly feasible and fully tested for classroom use.

Tabel 2. Assessment of Content Expert Validation

No.	Reviewer Code	Raw Score	Maximum Score	Evaluation Value	Quality Classification
1	V1	69	54	0.94	Highly
2	V2	72	54	1.00	Highly

This table shows the review results from two content experts regarding the module's substance and learning materials. With scores of 0.94 and 1.00 out of the maximum possible score, this confirms that the material presented is highly accurate, strictly relevant to the curriculum, and falls into the "highly valid" category to be taught to students.

Tabel 3. Results of Language Expert Validation

No.	Reviewer Code	Acquired Value (ro)	Deviation Score (S)	Maximum Index	Quality Classification
1	V1	51	37	42	Highly
2	V2	56	42	42	Highly

Based on Table 3, the language expert validation showed that the developed learning material was categorized as highly valid. Validator 1 provided an acquired score of 51 with a deviation score of 37, while Validator 2 provided an acquired score of 56 with a deviation score of 42. Both assessments reached the maximum index criterion presented in the table and were classified as highly valid. These results indicate that, from the perspective of language quality, the developed module was considered appropriate for use in learning, particularly in terms of clarity, readability, and suitability of language for students.

Tabel 4. User Practicality Analysis from Field Testing

Core Questionnaire Statements	Max Score	Acquired Score
The module simplifies studying state changes both at home and school	26	21
The module provides a convenient and practical user experience	26	24
Clear and precise activity instructions facilitate direct tasks	26	23
The vocabulary used is straightforward and highly comprehensible	26	24
The chosen typography is reader-friendly and simple	26	25
The overall layout and visual design	26	24
Various assignments, tasks, and graphics enhance subject comprehension	26	26
Using this module makes studying matter states and its changes highly enjoyable	26	24
The framework assists in keeping learning systematic and directed	26	25
Learning science feels fresh and far from monotonous	26	25

This table measures the consistency of the test instruments (essay and multiple-choice) used in pre-test and post-test phases. The Cronbach's Alpha values range from 0.775 to 0.932. Since these values are well above the standard reliability threshold, the test instruments are considered highly consistent and reliable for measuring student understanding.

Tabel 5. Student Test Result

Student	Pre-test Score	Post-test Score
S1	70	90
S2	50	70
S3	60	80
S3	70	90
S5	60	80
S6	70	80
S7	80	90
S8	80	90
S9	90	100
S10	60	80
S11	80	90
S12	90	100
S13	70	90
S14	80	80
S15	50	70
S16	70	90
Average	71.33	85.62

This table tracks the individual progress of 16 students before and after engaging in the "Mini Rubber Car" learning project. The data shows a consistent score improvement for almost all students. Classically, the class average jumped from 71.33 in the initial test to 85.62 in the final test, proving that this project-based method effectively aids student comprehension.

Table 6: Average Scores and N-Gain Analysis.

Sample Size	Metric	Pre-test Score	Post-test Score	N-Gain Score
30	Average	37	82	0.71

This table highlights the effectiveness of the learning method on a group of 30 students. There was a sharp surge in the average learning outcomes, jumping from 37 to 82. Additionally, the calculated N-Gain value stands at 0.71. In educational statistics, this figure indicates that the knowledge improvement experienced by the students falls into the "high improvement" category.

Table 7: Descriptive Statistics of Learning Outcomes and Process Skills.

Statistical Parameter	Experimental Group: Science Outcomes	Experimental Group: Process Skills	Control Group: Science Outcomes	Control Group: Process Skills
Mean	86.64	3.20	68.88	2.17
Median	86	3.19	69	2.175
Mode	86	3.02	69	2.1
Standard Deviation	7.12	0.25	10.01	0.28

This table compares the performance of the experimental group with the control group based on several measures of central tendency (mean, median, mode, and standard deviation). It is very clear that the experimental group significantly outperformed the control group, both in science learning outcomes (average 86.64 vs. 68.88) and in science process skills assessment (average 3.20 vs. 2.17).

Table 8. Science Learning Outcomes: Descriptive Data

Parameter	Experimental Cohort	Control Cohort
Sample Size (N)	25	25
Pre-test Mean	71.64	54.52
Pre-test Std. Deviation	7.035	7.089
Post-test Mean	92.76	71.64
Post-test Std. Deviation	4.961	7.035

This table compares the performance of the experimental group with the control group based on several measures of central tendency (mean, median, mode, and standard deviation). It is very clear that the experimental group significantly outperformed the control group, both in science learning outcomes (average 86.64 vs. 68.88) and in science process skills assessment (average 3.20 vs. 2.17).

Table 9: Descriptive Statistics of Research Variables

Statistic	Scientific Attitude	Learning Independence	Science Learning Achievement
Sample Size (N)	158	158	158
Mean	118.06	124.20	78.53
Median	118.00	126.00	80.00
Mode	116	134	83
Standard Deviation	11.156	10.499	7.681
Variance	124.462	110.239	59.002
Range	51	44	31
Minimum Score	95	97	60
Maximum Score	146	141	91

This table presents a comprehensive statistical mapping of 158 students regarding three main variables: scientific attitude, learning independence, and science learning achievement. This data provides details on the distribution of student scores within the population, ranging from the lowest score, highest score, range (score difference), to the overall average to help map the general tendency of students' abilities and attitudes.

Table 10. Two-Way ANOVA

Source of Variance	Sum of Squares (SS)	Degrees of Freedom (df)	Mean Square (MS)	F-Value	Critical F-Value ($\alpha=0.05$)	Significance (Sig.)
Between Groups	3.600.689	1	3.600.689	130.623	3.935	< 0.001
Within Groups	2.784.119	101	27.566			

Total	7.910.502	105
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This table contains the results of statistical hypothesis testing using the Analysis of Variance (ANOVA) method. With a very large F-value (130.623) and a significance level (Sig.) of less than 0.001 (which is well below the 0.05 error tolerance limit), this table convincingly concludes that the tested learning method provides a very real and significant positive impact on student learning achievements.

Discussion

The findings demonstrate that STEAM-based science learning provides a substantial advantage over conventional instruction in improving both students' science learning outcomes and Science Process Skills (SPS). The higher mean scores achieved by the experimental group indicate that integrating science, technology, engineering, arts, and mathematics creates a learning environment in which students are not merely exposed to scientific concepts but are actively involved in observing, investigating, designing, testing, and interpreting phenomena. This finding is consistent with [2], who reported that STEAM-based discovery learning positively influenced both science achievement and science process skills, suggesting that interdisciplinary learning can strengthen conceptual understanding while simultaneously developing practical scientific competencies. Similar evidence was reported in project-oriented STEAM studies, in which hands-on activities encouraged students to transform abstract scientific concepts into observable and meaningful experiences [5], [8]. The improvement observed in the present study may therefore be attributed to the constructivist characteristics of STEAM learning, which position students as active knowledge constructors rather than passive recipients of information. This interpretation is also supported by [9], who concluded that STEAM-oriented science instruction provides opportunities for exploration, problem solving, and creativity, while [17] emphasized that STEAM-PjBL can enhance students' interest and motivation. Consequently, the statistically significant difference identified through the ANOVA analysis strengthens the argument that STEAM is not only an alternative instructional approach but also an effective pedagogical framework for promoting deeper and more meaningful elementary science learning.

Another important implication of the findings concerns the capacity of STEAM learning to accommodate differences in students' cognitive characteristics. Although reflective students tend to demonstrate stronger academic performance because they process information more carefully and systematically, the improvement observed among students with more impulsive characteristics suggests that STEAM activities can provide multiple pathways for learning through experimentation, visualization, collaboration, engineering design, and problem solving. Previous research has shown that reflective and impulsive learners differ in the speed and accuracy with which they process and respond to academic tasks [11]; therefore, instructional environments that rely predominantly on verbal explanation and individual memorization may not equally support both cognitive styles. In contrast, the interdisciplinary and activity-oriented nature of STEAM offers opportunities for students to engage with concepts through different modes of representation and learning experiences. This interpretation is supported by [19], who found that STEAM-based learning effectively promotes critical and creative thinking, while Zayyinah *et al.* [20] highlighted the contribution of STEAM-integrated project learning to computational and problem-solving competencies. Moreover, the inclusion of artistic, technological, and engineering components broadens the ways in which students can express understanding and construct scientific meaning [24]. Thus, the present findings suggest that the pedagogical value of STEAM extends beyond improving average academic scores; it also lies in its potential to create a more inclusive science-learning environment capable of responding to individual differences in information processing and supporting the development of essential 21st-century competencies.

4. CONCLUSION

This study concludes that integrating the STEAM (Science, Technology, Engineering, Arts, and Mathematics) framework into innovative science learning significantly improves primary students' academic achievement and Science Process Skills (SPS) compared with conventional instruction. Reflective students generally demonstrated higher learning outcomes due to their more analytical and

systematic information-processing characteristics; however, STEAM-oriented learning also produced substantial gains among impulsive students. These findings indicate that a constructivist STEAM approach can accommodate diverse cognitive styles while reducing learning limitations associated with impulsive tendencies through interdisciplinary, inquiry-based, and student-centered learning experiences. The study therefore highlights the importance of considering both interdisciplinary pedagogical design and individual cognitive differences in elementary science education and supports STEAM as an inclusive instructional framework for strengthening conceptual understanding, practical science skills, and 21st-century competencies. Further research involving broader samples, different science topics, and longer intervention periods is recommended to confirm the sustainability and generalizability of these findings.

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