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Enhancing the Science Literacy of Elementary School Students by a STEAM Approach

Ika Anung Juliyastuti*
Department of Elementary Education, Universitas Negeri Semarang, Semarang, Indonesia

Nanik Wijayati
Universitas Negeri Semarang, Semarang, Indonesia

Sri Sumartiningsih
Universitas Negeri Semarang, Semarang, Indonesia

Tri Joko Raharjo
Universitas Negeri Semarang, Semarang, Indonesia

***Corresponding Author:** ikaanungjuliyastuti@students.unnes.ac.id

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Abstract
Science literacy remains a critical challenge in elementary education, with many students struggling to connect scientific concepts to real-world contexts. This study investigated the effectiveness of implementing a STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach to enhance science literacy among third-grade students in integrated IPAS learning within the Indonesian Merdeka Curriculum. A classroom action research design employing Kemmis and McTaggart's cyclical model was conducted over two cycles at SDN Cempaka Putih Barat 01, Central Jakarta, involving 32 third-grade students. Data were collected through performance-based assessments, systematic classroom observations, and documentation, with analysis following Miles and Huberman's interactive model. The intervention achieved substantial improvements in science literacy outcomes. Student pass rates increased dramatically from 43.75% at baseline to 71.87% after Cycle 1 and 90.63% after Cycle 2, while mean achievement scores rose from 66.47 to 74.71 and ultimately to 83.24. Observational data documented progressive improvements in both teacher pedagogical practices (2.58 to 2.87) and student engagement levels (1.96 to 2.23). The findings provide empirical evidence that STEAM-based instruction effectively enhances science literacy by promoting interdisciplinary integration, constructivist learning, and student-centered pedagogy. The results extend existing literature by demonstrating STEAM's effectiveness within the Indonesian educational context and offering detailed implementation insights for practitioners seeking evidence-based strategies to improve elementary science education.

INTRODUCTION

The advent of the 21st century has fundamentally transformed educational paradigms, necessitating a shift from traditional knowledge transmission to the cultivation of competencies essential for navigating an increasingly complex and interconnected global landscape. Contemporary educational discourse emphasizes the imperative of developing four critical competencies—commonly referred to as the 4Cs: critical thinking, communication, collaboration, and creativity—as foundational skills for learners to thrive in modern society (Care et al., 2018; Fajriyah, 2022; Trilling & Fadel, 2009). Research demonstrates that these competencies not only improve academic success but are essential across all aspects of life, as hard skills prepare students for jobs while soft skills prepare them for life itself (Bassachs et al., 2020; Saavedra & Opfer, 2012). These competencies are particularly crucial in science education, where learners must not only acquire conceptual knowledge but also develop the capacity to apply scientific reasoning to real-world challenges. In response to these evolving demands, educational systems worldwide have undergone substantial curricular reforms aimed at fostering student autonomy, creativity, and interdisciplinary thinking. Within the Indonesian context, the implementation of the Merdeka Curriculum represents a significant pedagogical innovation designed to enhance student independence and adaptive capabilities. A notable feature of this curriculum is the integration of Natural Sciences (IPA) and Social Sciences (IPS) into a unified subject known as Ilmu Pengetahuan Alam dan Sosial (IPAS), or Natural and Social Sciences. This curricular integration reflects an intentional effort to promote holistic thinking and enable students to comprehend the interconnectedness of natural and social phenomena in their environment. Such integrated approaches align with international trends emphasizing interdisciplinary curriculum design that dissolves traditional disciplinary boundaries and facilitates powerful connections between classroom learning and real-world applications (Drake & Burns, 2004; Vasquez et al., 2013).

Central to the IPAS curriculum is the development of science literacy, which has been identified as one of the most essential competencies for 21st-century learners. The National Science Education Standards define scientific literacy as the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity (National Research Council, 1996). More comprehensively, science literacy encompasses not only the comprehension of fundamental concepts and principles but also the capacity for critical thinking, problem-solving, and the application of knowledge in everyday contexts (Roberts & Bybee, 2014; Vieira & Tenreiro-Vieira, 2016; Zakarina et al., 2024). A scientifically literate person can ask questions, find answers derived from curiosity about everyday experiences, describe and explain natural phenomena, and engage meaningfully in social conversations about the validity of scientific conclusions (National Research Council, 1996; Osborne, 2023). According to Khoiriya (2023), science literacy represents an individual's capacity to understand scientific concepts and processes in ways that enable participation in civic affairs, cultural discourse, and economic development while exercising domain-specific abilities. When students possess strong science literacy skills, they are better equipped to understand scientific phenomena and apply this knowledge to address everyday challenges and contribute meaningfully to their communities. Science literacy in IPAS learning extends beyond the mere acquisition of scientific facts and social concepts; it emphasizes the recognition of how these phenomena are interrelated and mutually influential in daily life contexts. Consequently, science literacy serves as a critical literacy domain that empowers students to solve problems encountered in their lived experiences (Fajriyah, 2022; Vieira & Tenreiro-Vieira, 2016).

Despite the recognized importance of science literacy in elementary education, empirical evidence suggests that many students continue to struggle with developing adequate science literacy competencies. Previous studies have documented persistent challenges in science education, including students' difficulties in connecting abstract scientific concepts to concrete, contextual events in their surroundings and limitations in applying scientific knowledge to problem-solving situations (Harahap et al., 2022; Marshall et al., 2017; Pratiwi et al., 2019). These challenges are particularly pronounced in the early grades of elementary school, where foundational scientific thinking skills are established. At SDN Cempaka Putih Barat 01 in Central Jakarta, preliminary observations revealed that third-grade students exhibited notably low science literacy skills, especially in connecting IPAS learning materials to real-world contexts. Analysis of pre-assessment data indicated that fewer than half of the students (43.75%, or 14 out of 32 students) achieved scores meeting the Learning Objective Achievement Criteria (KKTP ≥75), suggesting significant deficiencies in their conceptual understanding and application abilities. Further investigation revealed that instructional practices remained predominantly textbook-dependent, with limited integration of experiential or contextual learning approaches. This pedagogical approach resulted in rote memorization without meaningful connections to students' lived environments, consequently diminishing their natural curiosity and reducing active engagement in classroom learning activities.

The knowledge gap identified in existing literature concerns the limited empirical evidence regarding effective pedagogical interventions specifically designed to enhance science literacy among early elementary students within integrated science curricula. While previous research has examined various instructional approaches for promoting science literacy, few studies have systematically investigated the application of the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach in the context of IPAS learning at the elementary level. The STEAM approach represents a pedagogical innovation that integrates multiple disciplinary perspectives into cohesive learning experiences, potentially addressing the multifaceted nature of science literacy development. STEAM is an educational approach that uses science, technology, engineering, arts, and mathematics as access points for guiding student inquiry, dialogue, and critical thinking, with its foundations lying in inquiry-based, process-oriented, and problem-centered learning (Quigley & Herro, 2019; Yakman & Lee, 2012). Research demonstrates that STEAM education enhances students' cognitive flexibility, innovative problem-solving abilities, creativity, and critical thinking skills while increasing motivation and engagement in learning (Brown et al., 2011; Conradty & Bogner, 2020; Land, 2013; Perignat & Katz-Buonincontro, 2019). According to Khoiriya (2023), the STEAM approach positions teachers as facilitators who guide students in collaborative problem-solving, provide technology-enhanced learning resources, familiarize students with science literacy activities, and create learning experiences tailored to diverse learning styles. Studies conducted in elementary settings have shown that students who received STEAM instruction demonstrated improvements in science achievement, literacy skills, and mathematical performance compared to control groups (Belbase et al., 2021; Cunnington et al., 2014). The STEAM framework provides an interdisciplinary approach that emphasizes hands-on, experiential learning and real-world problem-solving (Hayati et al., 2023). The STEM framework, which forms the foundation of STEAM, has been shown to provide learning experiences that help students utilize technology and conduct experiments to validate scientific concepts supported by mathematically organized data (Lestari & Rahmawati, 2020). Moreover, the STEM approach has been found to make learning more innovative and varied (Banila et al., 2021), while guiding students to think logically, critically, evaluatively, and creatively in solving problems and making decisions relevant to real-life situations (Ceylan & Ozdilek, 2015).

The present study addresses this knowledge gap by investigating the effectiveness of implementing a STEAM-based instructional approach to enhance science literacy among third-grade elementary students in the context of IPAS learning. This research is justified by the urgent need to develop evidence-based pedagogical strategies that can effectively cultivate science literacy skills in young learners while aligning with contemporary curriculum frameworks. Given that 85% of professions expected to exist in 2030 have not yet been created, with most anticipated to be STEAM-related, preparing students with integrated competencies has become imperative. The specific objectives of this classroom action research are twofold: first, to enhance the science literacy skills of third-grade students at SDN Cempaka Putih Barat 01 in IPAS learning focused on the concept of energy; and second, to measure the extent of improvement in students' science literacy learning outcomes following the implementation of the STEAM approach. The significance of this research lies in its potential to contribute both theoretical insights and practical implications for elementary science education. Theoretically, it extends the existing literature on STEAM pedagogy by examining its application within the integrated IPAS curriculum framework, addressing calls for more research on interdisciplinary approaches in elementary science education (Bush & Cook, 2019; Rabalais, 2014). Practically, it offers educators a contextually appropriate instructional model that aligns with student developmental characteristics while equipping them with critical thinking skills fundamental to science literacy development. By demonstrating how the STEAM approach can be effectively implemented in resource-constrained classroom settings, this study provides actionable guidance for teachers, school administrators, and curriculum developers seeking to enhance science literacy outcomes among elementary students.

METHODS

This study employed a classroom action research design, a systematic and collaborative approach to investigating classroom practices with the explicit purpose of improving educational outcomes through iterative cycles of reflection and action (Mertler, 2017). The research was structured following Kemmis and McTaggart's (1988) cyclical model, which consists of four interconnected phases: planning, action, observation, and reflection. This iterative process enables researchers to systematically examine pedagogical interventions while maintaining the flexibility to adapt strategies based on emerging insights from each cycle. The investigation was conducted over two complete cycles during the first semester of the 2025/2026 academic year at SDN Cempaka Putih Barat 01, Central Jakarta. Each cycle comprised two instructional sessions, with each session lasting 70 minutes (2 × 35 minutes), allowing sufficient time for comprehensive implementation of the STEAM-based learning activities and authentic assessment of student engagement and learning outcomes.

The research participants consisted of 32 third-grade students (aged 8-9 years) enrolled at SDN Cempaka Putih Barat 01, representing the entire class cohort and thus eliminating sampling bias. This purposive selection was justified by the preliminary assessment data indicating that this particular class demonstrated significant deficiencies in science literacy competencies, with only 43.75% of students achieving the minimum mastery criteria. The focal content area for this intervention was the energy concept within the IPAS curriculum, selected for its fundamental importance in developing students' understanding of natural phenomena and its rich potential for interdisciplinary STEAM integration. Data collection utilized a triangulated approach incorporating multiple sources and methods to ensure comprehensive capture of the intervention's effects. Primary data sources included classroom teachers and the student participants themselves, while secondary sources encompassed instructional documents such as syllabi, teaching modules, and lesson plans.

Three complementary data collection techniques were employed to capture different dimensions of the learning process and outcomes. First, performance-based assessments measured students' science literacy achievement across four key indicators: communicating scientific concepts, solving problems, answering inquiry-based questions, and applying knowledge to real-world contexts. These assessments were administered at three critical junctures—pre-intervention, post-cycle one, and post-cycle two—to track developmental trajectories. Second, systematic classroom observations documented both teacher pedagogical practices and student learning behaviors during STEAM implementation, utilizing structured observation protocols with predetermined indicators aligned with the five STEAM components (science, technology, engineering, arts, and mathematics). Third, comprehensive documentation captured artifacts of student work, instructional materials, and photographic evidence of classroom activities, providing contextual richness to quantitative findings.

To ensure methodological rigor, the study incorporated multiple validity verification procedures. Content validity was established through expert judgment by experienced science education faculty members who reviewed all assessment instruments to ensure alignment with learning objectives and developmental appropriateness. Triangulation techniques enhanced credibility through systematic cross-verification of findings across different data sources (teacher and student perspectives) and different methods (tests, observations, and documentation). Data analysis followed the Miles and Huberman (1994) interactive model, which involves three concurrent flows of activity: data reduction through systematic coding and categorization, data display through matrices and visual representations, and conclusion drawing through pattern identification and verification. Quantitative data from performance assessments were analyzed using descriptive statistics to calculate mean scores and percentage of students achieving mastery criteria (KKTP ≥75), while qualitative observational data underwent thematic analysis to identify emergent patterns in teaching practices and student engagement. The study established a success criterion whereby the intervention would be considered effective if 90% of students achieved scores equal to or exceeding the KKTP threshold, representing a substantial improvement from the baseline pass rate of 43.75%.

RESULTS AND DISCUSSION

Results

This classroom action research was implemented across two complete cycles to systematically investigate the effectiveness of the STEAM approach in enhancing science literacy among third-grade students at SDN Cempaka Putih Barat 01. Each cycle comprised two instructional sessions of 70 minutes duration. The investigation focused on energy concepts within the IPAS curriculum, selected for its fundamental importance and rich potential for interdisciplinary STEAM integration.

The STEAM approach integrated five distinct but interconnected components. The science component encompassed IPAS learning material focused on identifying various types of energy in everyday life. The technology component involved the deliberate integration of digital tools including interactive videos, LCD projectors, and laptop computers. The engineering component consisted of hands-on activities wherein students utilized various equipment to demonstrate different types of energy through practical experimentation. The arts component emphasized students' creative capacities, requiring them to design and construct products applying principles of kinetic and wind energy, resulting in aesthetically pleasing and functional artifacts such as water wheels and windmills. The mathematics component involved students' application of measurement skills and quantitative reasoning as they calculated dimensions and specifications for their products.

Science literacy was operationalized through four key indicators: communicating science (articulating concepts and explaining phenomena), problem-solving (identifying scientific problems and generating solutions), answering questions (responding to inquiry-based questions requiring higher-order thinking), and applying knowledge to the surrounding environment (transferring abstract concepts to real-world situations).

The implementation was systematically observed across both cycles to document instructional quality and student engagement. Table 1 presents the observational data capturing both teacher pedagogical practices and student learning behaviors.

Table 1. Results of Observations on the Application of the STEAM Approach in IPAS Learning

Component	Teacher Mean	Student Mean
Cycle 1 Session 1	2.67	2.00
Cycle 1 Session 2	2.50	1.94
Cycle 1 Average	2.58	1.96
Cycle 2 Session 1	2.83	2.27
Cycle 2 Session 2	2.91	2.20
Cycle 2 Average	2.87	2.23

During Cycle 1, teacher performance achieved an average score of 2.58 ("good" level), indicating general success in integrating the five STEAM components, though areas requiring improvement were identified, particularly in transitioning between components and scaffolding complex tasks. Student activity levels achieved an average of 1.96 ("moderate" category), suggesting participation was not yet fully characterized by autonomous inquiry and sustained focus.

The reflection phase following Cycle 1 identified areas for pedagogical refinement, leading to modifications including more explicit modeling of scientific inquiry, increased peer collaboration opportunities, enhanced visual aids, and strategic questioning techniques. These refinements yielded marked improvements in Cycle 2. Teacher performance increased to 2.87, reflecting growing confidence and competence, while student engagement rose to 2.23 ("good" category), characterized by more active participation, increased student-initiated questions, enhanced collaborative behaviors, and greater connections to real-world phenomena.

The primary outcome measure was student achievement in science literacy, assessed at three time points: pre-intervention baseline, post-Cycle 1, and post-Cycle 2. Table 2 presents the quantitative learning outcomes.

Table 2. Science Literacy Learning Outcomes in the Implementation of the STEAM Approach

Component	Average Science Literacy Achievement Scores	Passing Rate (%)
Pre-cycle	66.47	43.75
Cycle 1	74.71	71.87
Cycle 2	83.24	90.63

Pre-intervention assessment revealed significantly underdeveloped science literacy competencies, with a mean score of 66.47 and pass rate of 43.75% (14 out of 32 students achieving KKTP ≥75). This baseline confirmed the problematic situation and provided empirical justification for intervention, with deficiencies likely stemming from textbook-dependent instructional approaches emphasizing rote memorization.

Following Cycle 1 implementation, mean achievement increased to 74.71 (8.24-point gain), while pass rate rose dramatically to 71.87% (23 out of 32 students), representing a 28.12 percentage point improvement. Students demonstrated stronger capacities for scientific communication, enhanced problem-solving abilities, more elaborate responses to inquiry-based questions, and more frequent connections between energy concepts and daily phenomena.

Despite these improvements, the 71.87% pass rate remained below the 90% success criterion, necessitating Cycle 2. Reflection identified insufficient time for hands-on activities, inadequate scaffolding, limited individualized feedback, and classroom management challenges. Targeted modifications implemented in Cycle 2 included extending time allocations, implementing structured scaffolding protocols, establishing peer feedback mechanisms, enhancing formative assessment practices, and refining classroom management procedures.

Cycle 2 yielded remarkable results. Mean achievement increased to 83.24 (additional 8.53-point gain, total 16.77-point improvement from baseline), while pass rate rose to 90.63% (29 out of 32 students), meeting the predetermined success criterion. The three non-achieving students exhibited distinct profiles: one struggled with problem-solving and application despite strong communication; another showed collaborative strength but writing challenges; the third demonstrated inconsistent performance across all indicators. These patterns suggest some learners may require additional differentiated supports beyond generally effective STEAM instruction.

The magnitude of improvement—nearly 47 percentage point increase in pass rate and more than 16 points in mean scores—provides compelling quantitative evidence that the STEAM approach substantially enhanced science literacy. The progressive improvement pattern demonstrates the value of iterative action research methodology for continuous instructional refinement.

Discussion

This classroom action research provides substantive empirical evidence that STEAM-based instruction can significantly enhance science literacy among elementary students within integrated IPAS learning contexts. The dramatic improvement from 43.75% to 90.63% pass rate represents a nearly complete reversal of the initial problematic situation, confirming that STEAM-based instruction proves more effective than traditional textbook-dependent approaches in developing students' capacities across all four science literacy indicators.

The theoretical foundation for these outcomes can be understood through multiple complementary lenses. First, the STEAM framework's emphasis on interdisciplinary integration aligns with contemporary learning theories emphasizing connections across knowledge domains (Drake & Burns, 2004; Vasquez et al., 2013). By deliberately connecting science with technology, engineering, arts, and mathematics, students constructed more robust and interconnected mental models of energy phenomena. This integrated understanding proved more resilient and transferable than discipline-specific knowledge, as evidenced by improved performance on items requiring application to novel situations. The interdisciplinary nature made learning more authentic by reflecting how knowledge is actually applied in real-world contexts (Quigley & Herro, 2019; Yulianti et al., 2024).

Second, constructivist learning principles embedded within STEAM—including hands-on experimentation, collaborative problem-solving, and active knowledge construction—proved particularly effective in promoting deep understanding rather than superficial memorization (Conradty & Bogner, 2020). Unlike traditional passive instruction, STEAM activities positioned students as active investigators generating knowledge through direct interaction with materials, phenomena, and peers. When students physically constructed water wheels and windmills, they developed embodied understanding rooted in concrete experience rather than merely memorizing abstract definitions. This experiential foundation proved more durable and accessible, as evidenced by students' enhanced ability to explain concepts in their own words.

Third, the student-centered pedagogical approach wherein teachers function as facilitators created learning environments fostering critical thinking, curiosity, and intellectual autonomy (Quigley et al., 2019; Ramey & Stevens, 2019). By allowing students to direct aspects of their learning, teachers enabled development of agency and ownership. This autonomy proved motivating, as students invested greater effort in self-chosen activities. The facilitative role also created space for productive peer interaction, generating rich learning opportunities. The observational data documenting increased student engagement reflects this shift toward more active and autonomous participation.

The present findings align strongly with existing STEAM education literature. Previous studies documented that students receiving STEAM instruction show improvements in science achievement. Belbase et al. (2021) found that students receiving just nine hours of STEAM instruction showed measurable improvements in grades 3-5, while Cunnington et al. (2014) reported positive impacts on cognitive development and both literacy and mathematics skills. The 28.12 percentage point increase after Cycle 1 and additional 18.76 point increase after Cycle 2 compares favorably with effect sizes in previous research. Similarly, Oh et al. (2013) demonstrated STEAM's positive effects on creativity and science-related affective characteristics.

However, this research contributes unique insights extending beyond existing literature. First, while most STEAM research occurs in Western contexts, this study demonstrates effectiveness within the Indonesian educational system and specifically within the Merdeka Curriculum's integrated IPAS structure. This suggests STEAM principles may have cross-cultural applicability despite differences in educational systems, addressing calls for more research across diverse contexts (Yulianti et al., 2024). Second, the specific focus on science literacy operationalized through four distinct indicators provides precise understanding of which competencies STEAM instruction enhances, enabling more targeted pedagogical decisions and precise theoretical claims.

Third, the action research methodology generated practical knowledge about implementing STEAM in real classroom conditions. Documentation of Cycle 1 challenges—insufficient time, classroom management difficulties, inadequate scaffolding—and targeted Cycle 2 modifications provides actionable guidance for practitioners. This process knowledge is particularly valuable given that recent research identified significant implementation challenges teachers face with STEAM approaches (Herro et al., 2019; Ramey & Stevens, 2019). The demonstration that challenges can be systematically addressed through reflective practice offers practical strategies for teachers navigating similar transitions.

The finding regarding individual variation—three non-achieving students—warrants consideration regarding equity and differentiation in STEM education. While 90.63% success represents substantial improvement, nearly 10% continued struggling. The distinct profiles suggest effectiveness at group level doesn't guarantee effectiveness for every individual learner, aligning with recent emphases on equity-oriented approaches intentionally addressing diverse learner needs (Mohr-Schroeder et al., 2021). The differential patterns suggest STEAM might be most effective when implemented alongside differentiated supports targeting specific learner needs.

The substantial improvements in teacher pedagogical practices merit attention as both a finding and likely mediating mechanism for student outcomes. The increase from 2.58 to 2.87, while seemingly modest, represents important qualitative shifts in orchestrating complex learning environments. The action research process likely contributed to these improvements by creating structured reflection opportunities. The parallel trajectories of improvement in both teacher practices and student outcomes support theoretical models positing enhanced student learning results through improved teaching practices (Crawford, 2019; Mertler, 2017).

From a practical standpoint, this research offers actionable implications. First, schools would benefit from professional development helping teachers understand STEAM principles and develop implementation capacities. Second, curriculum materials should be designed to facilitate STEAM implementation rather than maintaining disciplinary separation. Third, schools might benefit from establishing systematic practitioner inquiry structures, including protected time for reflection and collaborative planning.

Several limitations warrant acknowledgment. First, the single-school focus with small sample (N=32) limits generalizability. Replication studies in diverse contexts would strengthen confidence in broader applicability. Second, the two-cycle duration doesn't address sustainability or transfer questions. Longitudinal research could illuminate whether gains are maintained. Third, while documenting substantial improvements, the design doesn't permit definitive causal claims. Future research employing experimental designs could provide stronger causal evidence regarding STEAM's specific contribution.

In conclusion, this research provides compelling evidence that STEAM-based instruction represents a viable and effective approach to addressing persistent elementary science education challenges, particularly underdeveloped science literacy. The magnitude of improvement—from fewer than half achieving mastery to more than 90%—suggests this approach merits serious consideration by educators seeking evidence-based strategies. The conceptual contribution demonstrates that abstract STEAM principles can be successfully operationalized in typical classroom conditions with positive impacts on multidimensional science literacy competencies that contemporary educational goals emphasize.

CONCLUSION

This classroom action research demonstrates that implementing a STEAM approach significantly enhances science literacy among third-grade elementary students within integrated IPAS learning contexts. The intervention achieved a remarkable transformation, elevating student pass rates from 43.75% at baseline to 90.63% following two iterative cycles of refined instruction, with mean achievement scores increasing from 66.47 to 83.24. These outcomes provide empirical validation that interdisciplinary, student-centered pedagogical approaches grounded in hands-on experimentation and authentic problem-solving effectively cultivate the multidimensional competencies constituting science literacy. The study contributes to existing scholarship by demonstrating STEAM's effectiveness within the Indonesian Merdeka Curriculum context, providing detailed process knowledge about implementation challenges and refinements, and offering fine-grained evidence regarding specific science literacy dimensions responsive to STEAM instruction. Practical implications suggest that educational stakeholders should prioritize professional development supporting teachers' capacity to facilitate integrated STEAM instruction, develop curriculum materials that deliberately bridge disciplinary boundaries, and establish structures enabling systematic practitioner inquiry and iterative instructional refinement. However, several limitations warrant consideration, including the single-site focus limiting generalizability, relatively short intervention duration precluding assessment of long-term sustainability, and absence of comparison groups constraining causal inference. Future research should examine STEAM implementation across diverse educational contexts, investigate long-term retention and transfer of science literacy competencies, employ experimental designs enabling stronger causal claims, and explore differentiated approaches addressing varied learner needs. Additionally, research examining how STEAM experiences influence students' science-related attitudes, career interests, and dispositions toward lifelong learning would provide valuable insights into broader educational impacts beyond immediate achievement outcomes.

REFERENCES

Banila, L., Lestari, H., & Siskandar, R. (2021). Penerapan blended learning dengan pendekatan STEM untuk meningkatkan kemampuan literasi sains siswa pada pembelajaran biologi di masa pandemi covid-19. *Journal of Biology Learning*, *3*(1), 25–32. https://doi.org/10.32585/jbl.v3i1.1348

Bassachs, M., Cañabate, D., Serra, T., & Colomer, J. (2020). Interdisciplinary cooperative educational approaches to foster knowledge and competences for sustainable development. *Sustainability*, *12*(20), Article 8624. https://doi.org/10.3390/su12208624

Belbase, S., Mainali, B. R., Kasemsukpipat, W., Tairab, H., Gochoo, M., & Jarrah, A. (2022). At the dawn of science, technology, engineering, arts, and mathematics (STEAM) education: prospects, priorities, processes, and problems. *International Journal of Mathematical Education in Science and Technology*, *53*(11), 2919-2955. https://doi.org/10.1080/0020739X.2021.1922943

Brown, R., Brown, J., Reardon, K., & Merrill, C. (2011). Understanding STEM: current perceptions. *Technology and Engineering Teacher*, *70*(6), 5.

Bush, S. B., & Cook, K. L. (2019). *Step into STEAM, K-5: Your standards-based action plan for deepening mathematics and science learning*. Corwin Press.

Care, E., Kim, H., Vista, A., & Anderson, K. (2018). *Education system alignment for 21st century skills: Focus on assessment*. Center for Universal Education at The Brookings Institution.

Ceylan, S., & Ozdilek, Z. (2015). Improving a sample lesson plan for secondary science courses within the STEM education. *Procedia - Social and Behavioral Sciences*, *177*, 223–228. https://doi.org/10.1016/j.sbspro.2015.02.395

Conradty, C., & Bogner, F. X. (2019). From STEM to STEAM: Cracking the code? How creativity & motivation interacts with inquiry-based learning. *Creativity Research Journal*, *31*(3), 284-295. https://doi.org/10.1080/10400419.2019.1641678

Crawford, B. A. (2019). Teacher research in science education. In C. V. McDonald & F. Abd-El-Khalick (Eds.), *Representations of nature of science in school science textbooks: A global perspective* (pp. 251–266). Routledge.

Cunnington, M., Kantrowitz, A., Harnett, S., & Hill-Ries, A. (2014). Cultivating common ground: Integrating standards-based visual arts, math and literacy in high-poverty urban classrooms. *Journal for Learning through the Arts*, *10*(1), Article 1. https://doi.org/10.21977/D910119294

Drake, S. M., & Burns, R. C. (2004). *Meeting standards through integrated curriculum*. Association for Supervision and Curriculum Development.

Fajriyah, E. (2022). Kemampuan literasi numerasi siswa pada pembelajaran matematika di abad 21. In *Seminar Nasional Pendidikan, FKIP UNMA 2022 "Transformasi Pendidikan Di Era Super Smart Society 5.0"* (pp. 172–183). Universitas Majalengka. https://prosiding.unma.ac.id/index.php/semnasfkip/article/view/824

Harahap, D. G. S., Nasution, F., Nst, E. S., & Sormin, S. A. (2022). Analisis kemampuan literasi siswa sekolah dasar. *Jurnal Basicedu*, *6*(2), 2089–2098. https://doi.org/10.31004/basicedu.v6i2.2400

Hayati, R., Prima, W., Wulandari, S., Yunita, A. P., Mulyati, A., & Azmi, K. (2023). Model pembelajaran STEAM (Science, Technology, Engineering, Art, and Math) dalam pembelajaran matematika sekolah dasar: Pembelajaran berdiferensiasi. *Edukatif: Jurnal Ilmu Pendidikan*, *5*(6), 2591–2603. https://doi.org/10.31004/edukatif.v5i6.5723

Herro, D., Quigley, C., Andrews, J., & Delacruz, G. (2019). Co-measure: Developing an assessment for student collaboration in STEAM activities. *International Journal of STEM Education*, *6*(1), Article 12. https://doi.org/10.1186/s40594-017-0094-z

Kemmis, S., & McTaggart, R. (1988). *The action research planner* (3rd ed.). Deakin University Press.

Khoiriya, R. M., Lestari, M. O. D., & Puspasari, R. (2023). Penerapan pendekatan STEAM dalam pembelajaran IPA untuk meningkatkan keterampilan berpikir kritis dan literasi sains siswa kelas IV SD Anak Saleh Malang. *JTIEE (Journal of Teaching in Elementary Education)*, *7*(2), 142–147. https://journal.umg.ac.id/index.php/jtiee/article/view/7482

Land, M. H. (2013). Full STEAM ahead: The benefits of integrating the arts into STEM. *Procedia Computer Science*, *20*, 547–552. https://doi.org/10.1016/j.procs.2013.09.317

Lestari, H., & Rahmawati, I. (2020). Integrated STEM through project based learning and guided inquiry on scientific literacy abilities in terms of self-efficacy levels. *Al Ibtida: Jurnal Pendidikan Guru MI*, *7*(1), 19–32. http://dx.doi.org/10.24235/al.ibtida.snj.v7i1.5883

Marshall, J. C., Smart, J. B., & Alston, D. M. (2017). Inquiry-based instruction: A possible solution to improving student learning of both science concepts and scientific practices. *International journal of science and mathematics education*, *15*(5), 777-796. https://doi.org/10.1007/s10763-016-9718-x

Mertler, C. A. (2017). *Action research: Improving schools and empowering educators* (5th ed.). SAGE Publications.

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

Mohr-Schroeder, M. J., Cavalcanti, M., & Blyman, K. (2021). STEM education: Understanding the changing landscape. In M. J. Mohr-Schroeder & C. C. Johnson (Eds.), *Handbook of research on STEM education* (pp. 3–16). Routledge. https://doi.org/10.1007/978-94-6300-019-2

National Research Council. (1996). *National science education standards*. National Academy Press.

Oh, Y., Jia, Y., Lorentson, M., & LaBanca, F. (2013). Development of the educational and career interest scale in science, technology, and mathematics for high school students. *Journal of Science Education and Technology*, *22*(5), 780–790. https://doi.org/10.1007/s10956-012-9430-8

Osborne, J., & Pimentel, D. (2023). Science education in an age of misinformation. *Science Education*, *107*(3), 553-571. https://doi.org/10.1002/sce.21790

Perignat, E., & Katz-Buonincontro, J. (2019). STEAM in practice and research: An integrative literature review. *Thinking Skills and Creativity*, *31*, 31–43. https://doi.org/10.1016/j.tsc.2018.10.002

Pratiwi, S. N., Cari, C., & Aminah, N. S. (2019). Pembelajaran IPA abad 21 dengan literasi sains siswa. *Jurnal Materi dan Pembelajaran Fisika*, *9*(1), 34–42. https://jurnal.uns.ac.id/jmpf/article/view/31612

Quigley, C. F., & Herro, D. (2019). An educator's guide to STEAM: Engaging students using real-world problems. *Teachers College Record*, *121*(8), 1–21. https://eric.ed.gov/?id=ED594059

Rabalais, M. (2014). *STEAM: A national study of the integration of the arts into STEM instruction and its impact on student achievement* [Doctoral dissertation, University of Louisiana at Lafayette]. ProQuest Dissertations and Theses Global.

Ramey, K. E., & Stevens, R. (2019). Interest development and learning in choice-based, in-school, making activities: The case of a 3D printer. *Learning, Culture and Social Interaction*, *23*, Article 100262. https://doi.org/10.1016/j.lcsi.2018.11.009

Roberts, D. A., & Bybee, R. W. (2014). Scientific literacy, science literacy, and science education. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 545–558). Routledge. https://doi.org/10.4324/9780203097267

Saavedra, A. R., & Opfer, V. D. (2012). Learning 21st-century skills requires 21st-century teaching. *Phi Delta Kappan*, *94*(2), 8–13. https://doi.org/10.1177/003172171209400203

Trilling, B., & Fadel, C. (2009). *21st century skills: Learning for life in our times*. Jossey-Bass.

Vasquez, J. A., Sneider, C., & Comer, M. (2013). *STEM lesson essentials, grades 3-8: Integrating science, technology, engineering, and mathematics*. Heinemann.

Vieira, R. M., & Tenreiro-Vieira, C. (2016). Fostering scientific literacy and critical thinking in elementary science education. *International Journal of Science and Mathematics Education*, *14*(4), 659–680. https://doi.org/10.1007/s10763-014-9605-2

Yakman, G., & Lee, H. (2012). Exploring the exemplary STEAM education in the U.S. as a practical educational framework for Korea. *Journal of the Korean Association for Science Education*, *32*(6), 1072–1086. https://doi.org/10.14697/jkase.2012.32.6.1072

Yulianti, E., Suwono, H., Abd Rahman, N. F., & Phang, F. A. (2024). State-of-the-Art of STEAM Education in Science Classrooms: A Systematic Literature Review. *Open Education Studies*, *6*(1), 20240032. https://doi.org/10.1515/edu-2024-0032

Zakarina, U., Ramadya, A. D., Sudai, R., & Pattipeillohi, A. (2024). Integrasi mata pelajaran IPA dan IPS dalam kurikulum merdeka dalam upaya penguatan literasi sains dan sosial di sekolah dasar. *Damhil Education Journal*, *4*(1), 50–59. https://doi.org/10.37905/dej.v4i1.2487