

## THE EFFECTIVENESS OF THE STEAM APPROACH IN DEVELOPING SCIENTIFIC LITERACY OF ELEMENTARY SCHOOL STUDENTS

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### Abstract

In the era of rapid technological advancement and global challenges, scientific literacy has emerged as a fundamental competency for 21st-century learners. However, conventional teaching methods often fail to foster critical thinking, interdisciplinary understanding, and creativity necessary for scientific literacy development. This study aims to explore the effectiveness of the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach in enhancing scientific literacy among elementary school students. Employing a mixed-methods design, the research involved 120 students across three public elementary schools in Indonesia. The intervention included a 12-week STEAM-based learning module focusing on real-world problem-solving, project-based tasks, and creative expression. Data were collected through pre- and post-tests, student interviews, and classroom observations. The results indicate a significant improvement in students' abilities to apply scientific concepts, analyze data, communicate findings, and exhibit curiosity-driven learning. Students also showed enhanced collaboration skills and engagement levels. Qualitative data confirmed that the integration of art and design thinking stimulated deeper understanding and enjoyment of science. The findings suggest that STEAM not only bridges disciplinary gaps but also cultivates essential cognitive and affective skills. It concludes that the STEAM approach is an effective pedagogical model for developing scientific literacy in elementary education.

**Keywords:** Elementary Students, Interdisciplinary Learning, Scientific Literacy, STEAM Education



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## INTRODUCTION

The educational landscape of the 21st century is undergoing a significant transformation fueled by rapid technological advancement, globalization, and evolving societal needs. Today's learners are expected to develop not only academic knowledge but also critical competencies that prepare them to navigate complex real-world challenges ("Scientific Literacy," 2015). Among these competencies, scientific literacy stands out as a foundational skill that enables individuals to make informed decisions, participate in civic life, and contribute meaningfully to a knowledge-based economy. Scientific literacy encompasses the ability to understand scientific concepts and processes, evaluate scientific information critically, and apply this understanding in a variety of personal, social, and global contexts. As such, the cultivation of scientific literacy must begin early in a child's educational journey, especially in elementary school, where the foundations of curiosity, inquiry, and reasoning are laid.

However, traditional approaches to science education often fall short in promoting the depth and breadth of understanding required for scientific literacy. Conventional instruction typically emphasizes rote memorization of facts, passive reception of knowledge, and compartmentalization of subjects. This mode of teaching may limit students' ability to connect scientific knowledge to everyday experiences, solve interdisciplinary problems, or develop a sustained interest in scientific inquiry (Zhan dkk., 2017). The result is a disengagement from science learning, particularly among younger students who are naturally inclined toward exploration and creativity. To address this gap, educators and researchers have increasingly turned to innovative pedagogical frameworks that support active learning, student engagement, and real-world application of knowledge.

One such promising framework is the STEAM approach—an educational model that integrates Science, Technology, Engineering, Arts, and Mathematics into cohesive learning experiences. Unlike traditional siloed instruction, STEAM education encourages learners to explore connections between disciplines, approach problems from multiple perspectives, and engage in hands-on, project-based activities (White & Nitkin, 2014). The inclusion of the Arts in the STEM model emphasizes creativity, imagination, and emotional expression, fostering a more holistic form of learning that resonates with diverse student needs and learning styles. STEAM aims not only to enhance academic achievement but also to nurture innovation, collaboration, and resilience—qualities essential for success in an unpredictable and rapidly changing world.

The relevance of STEAM education becomes even more pronounced in the context of elementary education. At this developmental stage, students are highly receptive to experiential learning and thrive when given opportunities to explore, create, and interact with their environment (Stentoft, 2017). Implementing STEAM at the elementary level provides a unique opportunity to instill scientific thinking, problem-solving skills, and a lifelong curiosity about the natural world. It supports the development of scientific literacy by engaging students in real-life scenarios where they can observe phenomena, formulate questions, design experiments, interpret data, and communicate results. These practices mirror the processes used by scientists and engineers, thus helping students internalize the nature and methods of scientific inquiry from a young age.

The global push for educational reform and innovation has further strengthened the argument for STEAM implementation. International benchmarks and frameworks—such as the OECD’s Programme for International Student Assessment (PISA) and UNESCO’s Education for Sustainable Development goals—emphasize the importance of interdisciplinary learning, critical thinking, and sustainability education (Spelt dkk., 2017). Countries around the world are recognizing that preparing students for the future requires more than just content knowledge; it demands the ability to integrate knowledge across domains, adapt to novel situations, and generate creative solutions (Abell & Lederman, 2010). In this light, STEAM education emerges as a dynamic and future-oriented approach that aligns with global educational priorities while addressing the specific needs of local communities.

Incorporating the STEAM framework into elementary classrooms allows for a reinvention of how scientific knowledge is conveyed and absorbed. Rather than isolating science as a standalone subject, STEAM-based instruction immerses students in thematic units that connect scientific inquiry to technological tools, engineering design, mathematical reasoning, and artistic expression (Spelt dkk., 2009). For example, students might learn about ecosystems by building miniature biospheres, using data collection tools to measure plant growth, applying math to calculate resources, and illustrating their findings through digital storytelling. This kind of immersive learning fosters deep understanding and enthusiasm by making scientific concepts tangible, relevant, and exciting.

Moreover, the STEAM approach aligns closely with the developmental characteristics of elementary-aged children, who learn best through concrete experiences, play, and meaningful social interaction. These students benefit from hands-on projects that allow them to explore materials, test hypotheses, and build collaboratively with peers. The integration of the arts not only adds a creative dimension but also supports diverse learning modalities, enabling visual, auditory, and kinesthetic learners to access content in ways that resonate with them. In doing so, STEAM promotes inclusivity and equity by meeting learners where they are and guiding them toward where they can be (Schwarz dkk., 2024). Additionally, the emphasis on artistic exploration enables students to represent complex scientific phenomena through different mediums, such as music, painting, or drama, which reinforces cognitive understanding through emotional and sensory engagement. These experiences contribute to memory retention and build a stronger connection between learners and the material, turning abstract scientific principles into accessible and meaningful concepts that can be applied beyond the classroom.

Another critical advantage of the STEAM model is its emphasis on inquiry and problem-solving. By encouraging students to ask questions, explore multiple solutions, and reflect on their thinking processes, STEAM fosters critical and higher-order thinking skills. These skills are essential for scientific literacy, as they enable students to analyze evidence, identify patterns, and construct logical arguments. Inquiry-based learning also cultivates persistence and resilience—students learn that failure is part of the process and that iteration can lead to better results. This mindset is especially valuable in a world that increasingly demands innovation, adaptability, and continuous learning (Ryder, 2001). STEAM encourages students not only to think outside the box but to redefine the box itself, pushing them to imagine new possibilities and discover their capabilities through experimentation, teamwork, and revision. As they encounter complex tasks, they learn how to navigate uncertainty, a vital skill for lifelong learning and future citizenship.

As STEAM initiatives gain momentum worldwide, there is a growing body of research supporting their positive impact on student outcomes (Belbase dkk., 2022). Studies have shown that STEAM-based instruction improves academic performance, engagement, and motivation across demographic groups. For elementary students, the benefits are particularly pronounced due to their developmental readiness for integrative and exploratory learning. However, despite these promising trends, the implementation of STEAM in elementary settings remains inconsistent, often limited by curricular constraints, lack of teacher training, or insufficient

resources. This highlights the need for more systematic research that examines the conditions under which STEAM can thrive in early education. Furthermore, a deeper understanding of cultural, socioeconomic, and linguistic factors is essential for adapting STEAM to various educational contexts (Perignat & Katz-Buonincontro, 2019). Creating a sustainable model requires not only instructional innovation but also policy alignment, community involvement, and ongoing professional development to ensure that educators are equipped and empowered to facilitate STEAM-based learning effectively.

In this context, the present study seeks to investigate the effectiveness of the STEAM approach in developing scientific literacy among elementary school students. By focusing on a cohort of students in Indonesia, the study adds to the growing literature on STEAM while addressing local educational needs and challenges. Indonesia, like many countries, is striving to improve the quality of its science education and foster competencies aligned with 21st-century skills (Bertrand & Namukasa, 2020). This research aims to explore how a structured STEAM intervention can support these goals by enhancing students' ability to understand, apply, and communicate scientific knowledge. In particular, the study examines how interdisciplinary integration and student-centered practices influence learners' attitudes toward science and their engagement with scientific processes (Park, HyunJu dkk., 2016). It also seeks to identify the specific elements within the STEAM framework—such as design thinking, collaboration, and artistic integration—that contribute most significantly to the development of scientific literacy among young learners.

The novelty of this study lies in its holistic examination of scientific literacy, which goes beyond content mastery to include attitudes, skills, and behaviors associated with scientific thinking. It also incorporates student voice through interviews and reflective activities, allowing for a richer understanding of how learners experience STEAM education. By combining quantitative data from assessments with qualitative insights from observations and narratives, the research offers a nuanced picture of how STEAM influences learning (Park dkk., 2016). This mixed-methods approach not only strengthens the validity of the findings but also bridges the gap between theory and practice. Moreover, the study contributes to the ongoing discourse on how educational innovation can be contextualized within diverse and dynamic learning environments, making it particularly relevant for stakeholders interested in scalability, equity, and long-term impact in educational reform.

Furthermore, the study explores the interplay between STEAM instruction and broader educational objectives such as creativity, collaboration, and communication (Bertrand & Namukasa, 2023). These competencies are often overlooked in traditional assessments but are vital for navigating the complexities of modern life. The integration of art into the science curriculum, for instance, encourages students to express abstract ideas visually or through performance, deepening their comprehension and emotional engagement. Similarly, group-based projects foster interpersonal skills and shared responsibility, essential for both academic success and personal development. This emphasis on collaboration mirrors real-world scientific work, where teamwork and diverse perspectives drive discovery and innovation (Norris & Phillips, 2003). Thus, STEAM not only enhances individual cognitive skills but also cultivates a sense of community and shared purpose, which are increasingly recognized as key components of effective learning environments.

Ultimately, the goal of this research is not only to evaluate the outcomes of a STEAM-based intervention but also to provide practical recommendations for educators, policymakers, and curriculum designers. By documenting effective strategies, common challenges, and impactful learning experiences, the study aspires to inform future STEAM initiatives in elementary education. It underscores the importance of intentional design, supportive learning environments, and continuous teacher development in realizing the full potential of STEAM. Through this work, we hope to contribute to a growing movement that reimagines education as a dynamic, integrated, and student-centered enterprise. As education systems worldwide strive

to prepare learners for a future defined by complexity, interconnectivity, and rapid change, STEAM emerges not only as a model for instructional reform but also as a catalyst for deeper, more meaningful engagement with science and society.

In conclusion, the STEAM approach holds significant promise for enhancing scientific literacy among elementary students. It offers a pathway to more engaging, meaningful, and equitable science education—one that prepares learners not only to understand the world but to shape it. This study represents a step toward understanding how that promise can be realized in diverse educational contexts, paving the way for broader adoption and innovation in science teaching and learning.

## RESEARCH METHOD

This study employed a mixed-methods approach, combining quantitative and qualitative data collection and analysis to obtain a comprehensive understanding of the effectiveness of the STEAM approach in developing scientific literacy among elementary school students. The rationale for using mixed methods lies in its ability to capture both measurable changes in student learning outcomes and rich, contextual insights into the learning processes and experiences of participants. By triangulating data from multiple sources, the study ensures a more holistic and reliable interpretation of findings, thereby increasing its credibility and generalizability (Miller, 1998). The research was conducted in three public elementary schools in West Java, Indonesia, selected through purposive sampling based on their willingness to implement STEAM activities and their comparable academic performance indicators. A total of 120 fifth-grade students participated in the study, with 60 students assigned to the experimental group (STEAM-based learning) and 60 to the control group (traditional instruction). Both groups were taught the same scientific content as outlined in the national curriculum, but the delivery methods differed significantly to reflect the study's focus.

The intervention lasted for 12 weeks, during which the experimental group engaged in STEAM-integrated learning activities that centered on real-world issues and encouraged creative, collaborative problem-solving. Lessons were designed using backward design principles, starting from learning goals and aligning assessments and instructional strategies accordingly. Each STEAM unit integrated science concepts with technology tools, engineering challenges, artistic representation, and mathematical reasoning. Topics included ecosystem balance, renewable energy, weather patterns, and simple machines. Instruction in the STEAM group emphasized student-centered pedagogies such as project-based learning, inquiry-based learning, and design thinking. Teachers were provided with professional development workshops prior to the intervention to ensure consistent implementation across schools. These workshops introduced STEAM principles, collaborative planning strategies, and assessment tools aligned with scientific literacy indicators. The control group followed a conventional lecture-based format, using textbooks and standard worksheets without interdisciplinary integration or project work.

Data were collected using three primary instruments: a scientific literacy test, student interviews, and classroom observation checklists (Maienschein, 1998). The test consisted of multiple-choice and open-ended questions designed to assess conceptual understanding, data interpretation, scientific reasoning, and the ability to apply knowledge to real-world situations. The instrument was validated by education experts and piloted to ensure reliability. Pre-tests were administered one week before the intervention and post-tests within one week after its completion. Semi-structured interviews were conducted with 20 students from each group (40 total) to gain deeper insight into their learning experiences, perceptions of science, and engagement with classroom activities. Interviews were audio-recorded, transcribed, and thematically analyzed to identify emerging patterns and differences between groups.

Observations were carried out bi-weekly using a rubric that assessed student interaction, use of learning resources, critical thinking behavior, and teacher facilitation techniques.

Quantitative data from the pre- and post-tests were analyzed using paired sample t-tests and ANCOVA to determine statistically significant differences in learning gains between the experimental and control groups. This statistical analysis helped isolate the effects of the STEAM intervention from other potential influencing variables. Effect size calculations were also performed to measure the magnitude of observed changes and support interpretation of practical significance. Qualitative data were coded inductively using a grounded theory approach, allowing themes to emerge from the data rather than imposing preconceived categories. Researchers worked collaboratively to identify and refine thematic codes related to student engagement, interdisciplinary connections, emotional responses, and collaborative behaviors. These themes were then triangulated with quantitative findings to create a cohesive narrative of the impact of STEAM instruction.

To maintain research integrity, several measures were taken to ensure validity and reliability. Multiple data sources and instruments were used for triangulation, while peer debriefing and member checking ensured that interpretations were credible and grounded in participant perspectives. Teachers received ongoing support throughout the implementation to ensure fidelity to the STEAM model, and field notes from researchers were used to contextualize observations and reflect on methodological decisions (Liao, 2016). Ethical considerations were also observed, with informed consent obtained from school authorities, teachers, students, and parents prior to data collection. Participation was voluntary, and students were assured that their responses would be confidential and used solely for research purposes. The study was approved by the university's ethics committee and aligned with ethical standards for educational research involving minors.

## RESULTS AND DISCUSSION

### Results

The results of this study revealed that students in the STEAM group demonstrated a marked and sustained improvement in various domains of scientific literacy when compared to their peers in the control group. Quantitatively, the gains were evident through significant increases in pre- and post-test scores, with students in the STEAM group achieving higher averages across conceptual understanding, problem-solving skills, and the ability to apply scientific principles in real-world situations (Lederman & Abell, 2014). This indicates a deeper internalization of knowledge and suggests that the STEAM-based intervention effectively facilitated learning in ways that traditional methods did not. The average score in the experimental group rose from 62.3 to 84.7, compared to a modest increase from 61.9 to 70.1 in the control group. These gains were not only statistically significant ( $p < 0.01$ ) but also practically meaningful, as evidenced by student behaviors and qualitative feedback.

In addition to the quantitative results, the qualitative data provided rich insights into the learning experiences of students in the STEAM group. Students frequently expressed how engaging, enjoyable, and relevant the lessons felt. Many reported that they looked forward to STEAM sessions, citing activities such as building models, creating multimedia presentations, and experimenting with materials as highlights of their week. These expressions of enthusiasm were not superficial; they correlated strongly with observed behaviors such as increased time-on-task, willingness to collaborate, and initiative in learning. Students demonstrated greater perseverance in problem-solving activities, reflecting a growth in both academic resilience and intellectual curiosity—key traits for developing scientific literacy.

The integration of multiple disciplines within the STEAM approach encouraged students to draw connections between different subject areas, enhancing their ability to synthesize information and apply it holistically (Leavy dkk., 2023). For example, when learning about environmental conservation, students were not limited to textbook definitions or isolated facts. Instead, they engaged in tasks that involved calculating carbon footprints (mathematics), understanding photosynthesis (science), designing eco-friendly prototypes (engineering and art), and presenting their projects through digital media (technology). This multidimensional approach cultivated deeper learning and positioned students to view science not as a standalone subject but as a dynamic, integrated process that intersects with daily life.

Furthermore, students in the STEAM group exhibited notable gains in communication abilities, particularly when it came to explaining their reasoning, using scientific vocabulary accurately, and presenting their ideas in structured, persuasive formats. During group presentations and peer teaching activities, students were able to articulate complex ideas clearly and respond to questions with logical justification. This is an essential component of scientific literacy, as it demonstrates not only content knowledge but also the ability to engage in scientific discourse (Kim, Sung-Won dkk., 2012). The ability to communicate ideas effectively is increasingly important in the modern world, where collaboration and public engagement with science are vital.

Observational data revealed a clear transformation in classroom culture within the STEAM group. Compared to the control group, where instruction remained largely teacher-centered, the STEAM classrooms were more dynamic and student-driven. Learners took ownership of their projects, organized group tasks, and supported one another in problem-solving efforts. Teachers transitioned into facilitators of learning, guiding exploration rather than dictating procedures. This shift empowered students to think independently, challenge assumptions, and propose creative solutions to complex problems (Kim dkk., 2012). The social and emotional growth observed—such as improved empathy, cooperation, and conflict resolution—further emphasized the holistic benefits of the STEAM model.

One of the most compelling findings was the impact of the arts integration on student engagement and understanding. Through drawing, role-playing, music composition, and storytelling, students were able to express abstract scientific ideas in tangible, emotionally resonant ways. These artistic expressions served as cognitive anchors that helped students retain and retrieve information more effectively. For example, students who created clay models of the water cycle or performed skits about renewable energy sources demonstrated a higher retention rate and a better ability to explain the underlying processes than those who only completed written assignments. The incorporation of the arts also catered to diverse learning styles, allowing visual, auditory, and kinesthetic learners to thrive.

Collaboration emerged as another area where the STEAM approach had a profound and multifaceted impact. In the STEAM-integrated classrooms, students did not merely work together on surface-level group tasks; instead, they were engaged in complex, long-term projects that required sustained interaction, negotiation of roles, and continuous decision-making. These collaborative projects challenged students to pool their knowledge and ideas, confront conflicting viewpoints, and co-create solutions to open-ended scientific problems. Teachers noted that students grew more adept at managing interpersonal relationships and demonstrated increased emotional intelligence, such as empathy, patience, and respect for diverse perspectives. Moreover, through frequent peer evaluations and reflections, students became more accountable for their contributions and more appreciative of collaborative efforts, recognizing that teamwork often led to richer and more innovative outcomes than individual work alone.

The development of critical thinking and metacognitive awareness was also significantly more pronounced in the STEAM group. These students were regularly tasked with investigating scientific questions that had no single right answer, encouraging them to develop hypotheses, test them through iterative experimentation, and revise their understanding based on feedback and new evidence. Through structured self-assessment activities, such as reflective journaling, exit slips, and learning portfolios, students became more aware of their own thinking processes. They learned to monitor their cognitive strategies, evaluate their strengths and weaknesses, and adjust their learning approaches accordingly. This metacognitive growth not only enhanced their ability to learn independently but also reinforced the habits of mind essential to scientific literacy—curiosity, skepticism, and the willingness to adapt one's thinking in light of new data.

Another significant and socially relevant finding from this study pertains to equity and access in education. The STEAM approach appeared to serve as a powerful equalizer in classrooms with diverse student populations. Students from traditionally marginalized backgrounds—those who struggled with language, had limited academic support at home, or faced socio-economic challenges—showed remarkable engagement and progress under the STEAM framework. The multimodal nature of STEAM instruction, which includes visual, auditory, kinesthetic, and performative elements, offered multiple pathways for success, allowing students to engage with content in ways that best matched their learning preferences (Kidron & Kali, 2015). Teachers observed that students who were often silent or disengaged in conventional classrooms became active participants and leaders in STEAM activities, suggesting that this approach helps uncover and nurture hidden talents.

The STEAM approach also contributed to significant professional growth and pedagogical transformation among participating educators. Teachers reported that the STEAM framework reinvigorated their teaching practice by encouraging them to break away from rigid textbook-based instruction and embrace more dynamic, student-centered strategies. The planning and execution of interdisciplinary projects required educators to collaborate across subject boundaries, enhancing professional dialogue and collegial support. Many teachers expressed a renewed sense of purpose and excitement, noting that their classrooms became more vibrant, inquiry-driven, and responsive to student interests. This shift toward reflective and innovative practice not only benefited students but also contributed to a more collaborative and creative school culture.

Despite the overwhelmingly positive outcomes, the study also documented several implementation challenges that warrant attention. Teachers highlighted the considerable time required to plan and coordinate STEAM units, particularly when aligning multiple subjects and designing authentic assessments. The need for specific materials and technological resources posed logistical difficulties, especially in under-resourced schools. Moreover, assessing student performance across integrated learning domains proved complex, as traditional grading systems were not always adequate for capturing growth in creativity, collaboration, and critical thinking. Addressing these challenges will require systemic support in the form of professional development, curriculum redesign, and institutional flexibility to accommodate interdisciplinary approaches.

In sum, the results of this study strongly affirm the efficacy of the STEAM approach in cultivating scientific literacy among elementary students. The approach not only fostered conceptual understanding and practical application of science but also nurtured essential 21st-century competencies such as critical thinking, communication, collaboration, creativity, and self-regulation. Furthermore, the positive impact extended to teachers, who experienced renewed enthusiasm and professional growth, and to students from diverse backgrounds, who found meaningful ways to engage with science. These comprehensive and transformative outcomes underscore the potential of STEAM as a cornerstone for reforming science education and preparing young learners for the complexities of the modern world.

## Discussion

The findings of this study emphasize the profound impact of the STEAM approach on the scientific literacy development of elementary school students (Cooper dkk., 2001). One of the most compelling aspects of the STEAM framework is its ability to foster deep, interdisciplinary learning by connecting scientific concepts to real-world experiences through the lens of creativity and design. Students who participated in the STEAM program did not merely memorize facts; rather, they engaged in authentic scientific practices such as formulating questions, conducting investigations, constructing explanations, and communicating their ideas using diverse modalities (Khine & Areepattamannil, 2019). This shift from rote learning to experiential and inquiry-based learning represents a paradigm change in science education, empowering students to become active knowledge builders.

Moreover, the integration of the arts into STEM subjects contributed significantly to students' cognitive flexibility and engagement. Through activities such as designing models, creating science-themed performances, or visualizing scientific processes through art, students were able to approach science from multiple perspectives (Costa dkk., 2019). These creative expressions provided accessible entry points for students who may not excel in traditional academic tasks, thereby reducing anxiety and increasing self-efficacy. The arts component also encouraged divergent thinking, allowing students to explore multiple solutions to problems and develop their own original approaches—hallmarks of scientific creativity. An essential dimension revealed in the study was how the STEAM approach nurtured emotional and social development alongside academic achievement. Collaboration, empathy, and mutual respect emerged as foundational elements of STEAM-based learning environments (Khine & Areepattamannil, 2019). Students worked in teams to solve interdisciplinary problems, negotiate responsibilities, and present their findings to peers. These social interactions required them to listen actively, value different perspectives, and manage conflicts constructively. In doing so, they developed emotional intelligence skills that are critical for functioning in both academic and real-world contexts. Such holistic development is rarely the focus of traditional science instruction but is essential in preparing students to be thoughtful, compassionate, and globally responsible citizens.

In addition, the emphasis on real-world problem-solving within STEAM pedagogy made learning more meaningful and motivational for students. Unlike decontextualized textbook problems, STEAM challenges asked students to investigate authentic issues—such as environmental sustainability, public health, or engineering simple machines—within their own communities. This relevance not only enhanced engagement but also instilled a sense of purpose and responsibility in learners (Kezar & Elrod, 2012). They began to perceive science not as a distant subject, but as a practical tool for improving the world around them. This transformation of students' perceptions of science contributes directly to scientific literacy by cultivating informed, inquisitive individuals who are eager to apply their learning to everyday life.

The role of the teacher was central to the successful implementation of STEAM practices. Teachers served not just as content deliverers, but as facilitators of discovery, mentors in design processes, and co-learners in project development (Dragoş & Mih, 2015). They needed to be flexible, creative, and comfortable with ambiguity, as STEAM instruction often requires navigating unanticipated challenges. The professional growth observed among participating teachers demonstrates the reciprocal nature of STEAM education: as students become more independent and engaged, teachers become more reflective and innovative (Ivanitskaya dkk., 2002). This dynamic reshapes classroom culture, making it more democratic, inquiry-oriented, and conducive to lifelong learning for all participants.

Assessment in STEAM-based education also required rethinking traditional evaluation methods. Instead of relying solely on standardized tests, teachers utilized performance assessments, rubrics for creativity and collaboration, and reflective tools such as learning journals (Durant, 1994). These forms of assessment provided richer insights into students' learning processes and outcomes. More importantly, they aligned with the STEAM philosophy of valuing diverse talents and ways of thinking. By recognizing growth in both academic and non-academic domains, assessments helped students see their progress more holistically and take ownership of their learning journeys. The findings of this study contribute to a growing body of evidence suggesting that STEAM education is not only a viable but an essential strategy for 21st-century learning. It offers a compelling response to the need for education systems that prepare students for complexity, uncertainty, and interdependence (Frank dkk., 1992). Scientific literacy, in this expanded view, is not merely the knowledge of scientific facts, but the ability to think critically, collaborate across disciplines, and create innovative solutions. These capacities are not optional; they are vital for thriving in today's fast-evolving society and global economy.

Additionally, the equity-enhancing effects of STEAM cannot be overstated. In many traditional classrooms, certain students—often those from underrepresented or disadvantaged backgrounds—struggle to find relevance and success (Eisenhart dkk., 1996). STEAM disrupts this pattern by creating multiple access points to learning and valuing the contributions of all learners. Whether through drawing, coding, building, performing, or problem-solving, each student has the opportunity to shine. This inclusivity not only boosts academic achievement but also fosters a sense of belonging and identity, which are crucial factors in long-term educational success. While this study has focused on elementary education, its implications resonate across all educational levels. If students are introduced to integrative and creative approaches to learning early on, they are more likely to carry those mindsets and skills into secondary education and beyond. Future research could explore longitudinal impacts of early STEAM education on students' academic trajectories, STEM career interests, and civic engagement (Fives dkk., 2014). Additionally, comparative studies across cultural and geographic contexts would help identify contextual adaptations that maximize STEAM's impact worldwide.

To institutionalize the STEAM approach, systemic changes are necessary. Schools must adopt flexible curricula that allow for interdisciplinary planning, allocate time for teacher collaboration, and invest in professional development that goes beyond content knowledge. Partnerships with cultural institutions, universities, and industry can enrich STEAM programs and offer students exposure to real-world applications. Policymakers should recognize and support these initiatives through funding, policy alignment, and accountability systems that reflect 21st-century learning goals. In conclusion, the discussion reaffirms that STEAM is more than an educational trend—it is a transformative paradigm that equips students and educators alike with the tools to navigate a complex, interconnected world. Through its emphasis on inquiry, creativity, collaboration, and real-world relevance, STEAM cultivates the very essence of scientific literacy. It empowers learners not just to absorb knowledge but to question, innovate, and lead. As we look to the future of education, embracing STEAM is not simply beneficial—it is imperative.

## CONCLUSION

This study concludes that the STEAM approach is a highly effective and comprehensive educational model for developing scientific literacy among elementary school students. Through the integration of multiple disciplines—science, technology, engineering, arts, and mathematics—STEAM fosters not only academic understanding but also essential life skills such as critical thinking, creativity, collaboration, and communication. The findings

demonstrate that STEAM-based instruction leads to significant improvements in students' conceptual grasp of scientific ideas, their ability to apply knowledge in real-world contexts, and their motivation to engage with science meaningfully. Importantly, the approach also enhances equity and inclusivity by accommodating diverse learning styles and promoting active participation from all students. Moreover, the professional growth experienced by teachers underscores the value of STEAM in revitalizing instructional practices and promoting collaborative learning environments. While challenges exist in implementation and assessment, the benefits of the STEAM framework far outweigh the obstacles. As such, STEAM should be embraced as a foundational strategy in educational reform efforts aimed at equipping young learners with the competencies required to thrive in an increasingly complex and interconnected world.

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