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The Impact of Integrated Stem Approaches on Students' Academic Writing Skills: A Systematic Review

Sofia Dwi Sanzain[1]
Universitas Muhammadiyah Mataram, Mataram, Indonesia
sanzainsofiadwi@gmail.com

Ilham[2]
Universitas Muhammadiyah Mataram, Mataram, Indonesia
ilham.ummataram@gmail.com

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ABSTRACT

This systematic literature review examines the pedagogical impact of integrated Science, Technology, Engineering, and Mathematics (STEM) approaches on students' academic writing skills. The review synthesizes empirical studies published between 2016 and 2026 retrieved from the Scopus, Web of Science, and ERIC databases. The selected studies were identified through the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework and analyzed using thematic analysis to identify major trends in the implementation of integrated STEM approaches for academic writing instruction. The findings indicate that integrated STEM approaches, particularly Project-Based Learning and the Engineering Design Process, are consistently associated with improvements in students' academic writing skills, including structural organization, text cohesion, and scientific argumentation. Moreover, embedding writing activities within authentic STEM contexts promotes students' learning motivation, critical thinking, and learner autonomy. Nevertheless, the review also identifies several implementation challenges, including disciplinary boundaries between STEM and language education, limited cross-disciplinary assessment practices, and time constraints within STEM curricula. Overall, this review highlights the potential of integrated STEM approaches to strengthen students' academic writing skills while emphasizing the importance of interdisciplinary collaboration, teacher professional development, and balanced curriculum design for effective implementation.

Keywords: *Academic Writing; Disciplinary Literacy; Integrated STEM; Scientific Argumentation; Systematic Literature Review.*

INTRODUCTION

In the contemporary educational landscape, Science, Technology, Engineering, and Mathematics (STEM) education has rapidly evolved from isolated disciplinary instruction into a robust, integrated pedagogical framework (Kelley & Knowles, 2016). This paradigm shift emphasizes interdisciplinary connections, conceptual harmony, and real-world problem-solving through student centered approaches such as Project-Based Learning, Problem-Based Learning, and the Engineering Design Process (Braßler, 2016). Crucially, modern STEM frameworks recognize that technical expertise cannot exist in a vacuum, meaning that future scientists and engineers must possess strong disciplinary literacy to read, interpret, evaluate, and design specialized texts (Hubbard, 2021). Within this domain, academic writing stands out as a foundational cognitive tool rather than a mere mechanism for reporting results (Strobl et al., 2019). It serves as an active vehicle for knowledge construction, enabling students to

synthesize complex data, articulate logical claims, and engage in evidence-based scientific argumentation that is essential for academic success (Ala, 2018).

Despite the undeniable synergy between scientific inquiry and written communication, a persistent educational disconnect remains because writing instruction and STEM education have historically been confined to institutional silos (Burns, 2026). Language arts classes often teach writing using subjective or narrative models, while STEM classes frequently relegate writing to passive, formulaic laboratory reports that prioritize fill-in-the-blank responses over deep critical analysis. Consequently, students across all educational tiers, from K-12 to higher education, frequently struggle with academic writing skills (Hossain, 2022). These challenges typically manifest as structural logic deficiencies, where students find it difficult to organize complex technical ideas into a cohesive academic text structure (Siekmann et al., 2022). Furthermore, a widespread inability to engage in robust scientific argumentation hinders students from formulating clear hypotheses, backing claims with empirical data, or justifying engineering design choices logically, which is compounded by a profound weakness in critically evaluating and synthesizing existing scientific literature (Nussbaum, 2021).

Integrated STEM approaches offer a potential solution to this pedagogical crisis by providing students with hands-on, high-stakes contexts that naturally demand rigorous documentation, peer review, and argumentative justification (K. Larkin & Lowrie, 2022). When writing is embedded into authentic STEM projects, it ceases to be a superficial chore and becomes an essential component of the scientific process where students must defend their designs or explain their findings textually (Harrison & Parks, 2016). While an increasing number of primary studies have begun exploring this intersection of STEM interventions and literacy, the existing body of literature remains highly fragmented and decentralized (López et al., 2022). Individual studies often focus on narrow contexts, such as evaluating a specific writing to learn strategy in a single middle school science classroom or assessing engineering logbooks in a university seminar, without offering a unified picture of the broader educational landscape.

Although previous studies have explored the integration of STEM and writing instruction, the findings remain fragmented across different educational contexts and instructional models. Most existing studies have primarily emphasized STEM-related outcomes, such as problem-solving skills, scientific literacy, and academic achievement, while relatively limited attention has been given to the development of students' academic writing skills. Consequently, there is still a lack of comprehensive evidence synthesizing how integrated STEM approaches contribute to improving academic writing across different educational settings. Therefore, this systematic literature review aims to synthesize existing empirical studies, identify the dominant instructional approaches, examine their impact on students' academic writing skills, and highlight current research gaps to provide directions for future research and educational practice.

Consequently, this systematic literature review aims to provide a rigorous, transparent, and comprehensive synthesis of peer-reviewed research mapping the impact of integrated STEM approaches on students' academic writing skills. To achieve this objective, the review systematically addresses three overarching research questions in a narrative format. The first objective investigates what integrated STEM pedagogical models or instructional strategies are most frequently utilized by researchers to foster students' academic writing skills across different educational levels. The second objective explores the extent and the specific dimensions, such as argumentative structure, synthesis of evidence, or text cohesion, in which these integrated STEM approaches impact students' academic writing proficiency. Lastly, the third objective examines the primary pedagogical, logistical, and operational challenges identified in the literature regarding the integration of STEM and academic writing instruction to map out future directions for research and practice.

METHOD

This study employs a systematic literature review design conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines. This approach ensures that the process of locating, selecting, and synthesizing relevant literature remains transparent, objective, and fully replicable. The primary data collection was executed by searching major electronic databases, including Scopus, Web of Science, and ERIC, to capture peer-reviewed articles published over a ten-year window from 2016 to 2026. The article selection process followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which consists of four stages: identification, screening, eligibility, and inclusion. This framework ensured a transparent and systematic procedure for selecting relevant studies included in this review. The search architecture utilized a specialized Boolean string combining terms related to the intervention and the target outcome, namely integrated STEM or STEM education or STEM approach or STEAM, which was then combined using the AND operator with academic writing or scientific writing or writing skills or argumentative writing or research writing.

To ensure high academic rigor, strict eligibility criteria were applied during the screening process. Inclusion was restricted to full-text, peer-reviewed journal articles written in English that explicitly evaluated an integrated STEM framework and measured its direct impact on students' academic or scientific writing skills. Conversely, the study excluded conference abstracts, book chapters, dissertations, non-English publications, and studies that focused purely on technical STEM outcomes without evaluating any dimension of literacy or writing proficiency. The initial search results underwent a multi-stage screening process consisting of an initial title screening, a subsequent abstract review, and a final, rigorous full-text assessment to determine ultimate eligibility.

Articles that successfully met all inclusion criteria were subjected to systematic data extraction using a standardized matrix. The extracted parameters focused heavily on capturing the specific educational contexts, the distinct pedagogical STEM models implemented such as Project-Based or Problem-Based Learning and the concrete metrics or rubrics used to assess writing development. These extracted data points were then synthesized using thematic analysis to address the three guiding research questions of this review. This qualitative synthesis allowed for the identification of overarching trends regarding the effectiveness of integrated STEM on academic writing, as well as the recurring operational challenges faced by educators in the field.

RESULTS AND DISCUSSION

RESULT

The integration of STEM approaches within the educational landscape has advanced rapidly, particularly concerning the instruction of academic writing across various educational levels. Integrated STEM-driven platforms and methodologies, such as Project-Based Learning, Problem-Based Learning, and the Engineering Design Process, are increasingly utilized as essential instructional aids due to their capacity to deliver authentic, contextualized inquiry contexts. These pedagogical tools significantly assist students in refining structural logic, scientific argumentation, evidence synthesis, and the overall coherent organization of ideas in scholarly texts. Furthermore, the incorporation of integrated STEM fosters a more collaborative and interactive learning environment, enabling students to undertake continuous draft revisions and active knowledge construction.

Numerous studies underscore the positive impacts of utilizing integrated STEM in academic writing instruction, noting notable enhancements in students' writing proficiency, cognitive development, learning motivation, and learner autonomy. Nevertheless, the implementation of integrated STEM in educational settings is accompanied by significant challenges, including concerns regarding institutional subject silos, a lack of shared assessment

rubrics, and disparities in teachers' cross-disciplinary grading readiness. Consequently, it is imperative to comprehensively understand the role of integrated STEM in facilitating academic writing, alongside its associated advantages and limitations. Drawing upon these empirical findings, the discourse surrounding the application of integrated STEM approaches to enhance academic writing skills can be categorized into the following primary dimensions:

Table 1. Previous Studies on STEM-Assisted Academic Writing

No	Area or Focus	Authors	Main Finding
1.	Improvement of academic writing skills through integrated STEM	Awad (2023); Siekmann et al. (2022); Chen & Zhang (2019); Apridayani & Waluyo (2025); Jelodari et al. (2026)	Improvement in structural logic, text cohesion, scientific argumentation, technical organization, and iterative writing practices through STEM-based learning environments.
2.	Cognitive benefits and learner autonomy through STEM integration	Malik et al. (2023); Wang et al. (2025); Papaneophytou & Nicolaou (2025); Çini et al. (2023); Rasmi et al. (2025)	Reduction of cognitive load, enhancement of critical thinking, metacognitive awareness, self-regulated learning, and learner autonomy in academic writing.
3.	Students' motivation and perceptions toward STEM tools	Davies et al. (2022); Teng et al. (2021); Mcdonald (2016); Waller & Papi (2017); Long & Magerko (2020)	STEM-assisted writing is perceived as engaging, practical, and motivating. Students become more confident in generating ideas and revising texts through real-world learning contexts.
4.	Challenges and limitations of STEM implementation in academic writing	Burns (2026); Kazemy et al. (2026); Nadelson & Seifert (2017); Fei et al. (2024); Margot & Kettler (2019)	Institutional separation between disciplines, lack of shared assessment rubrics, limited teacher readiness, and curriculum time constraints remain significant implementation challenges.

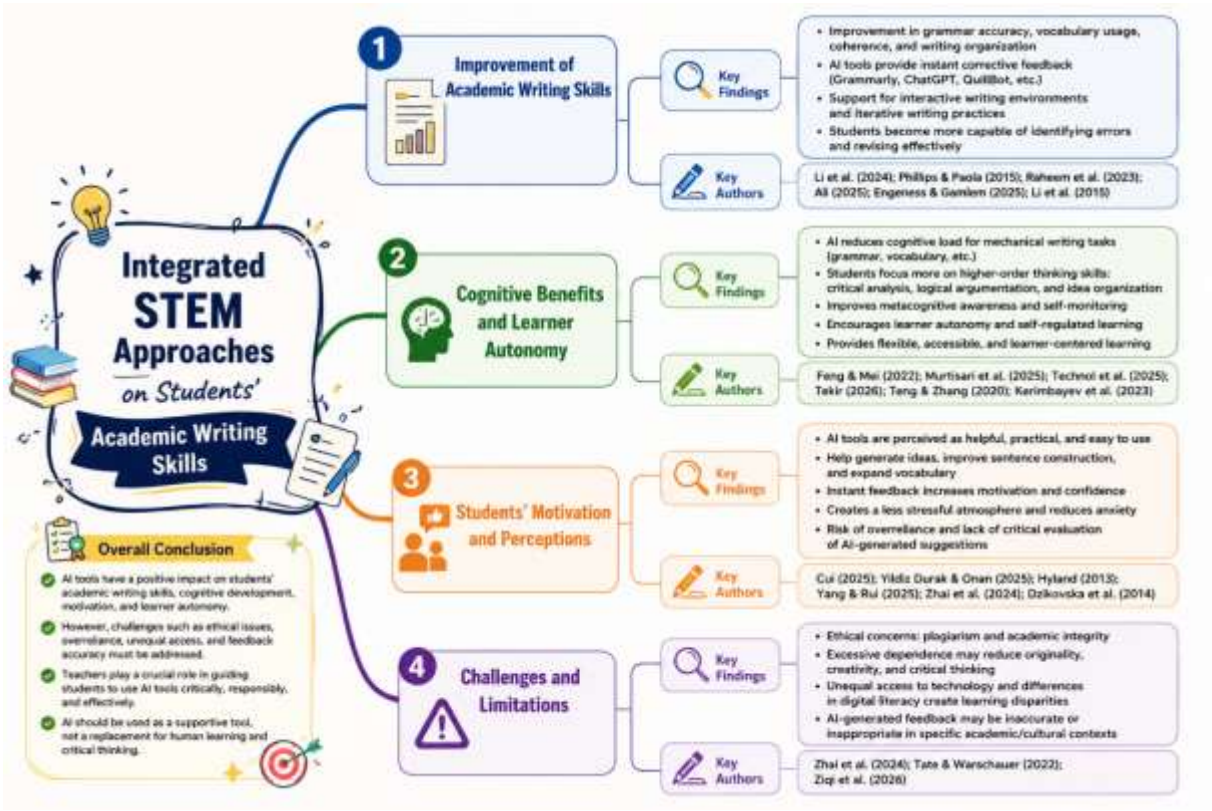


Figure 1. Mind map of Integrated STEM Approaches in Academic Writing

The mind map illustrates the synthesis of previous studies regarding the implementation of integrated STEM approaches in academic writing. Overall, the reviewed literature highlights four major areas of discussion, namely the improvement of academic writing skills, cognitive benefits and learner autonomy, students' motivation and perceptions toward STEM tools, as well as the challenges and limitations associated with STEM integration in writing instruction.

The first area, Improvement of Academic Writing Skills Through Integrated STEM, demonstrates that frameworks such as Project-Based Learning and the Engineering Design Process contribute significantly to the enhancement of students' writing performance. Previous studies indicate that the use of integrated STEM approaches improves several essential components of academic writing, including structural logic, text cohesion, data reporting, and technical writing organization. In addition, the provision of contextualized writing environments enables students to identify evidence gaps more effectively and revise their writing continuously, resulting in improved clarity and overall writing quality.

The second area focuses on Cognitive Benefits and Learner Autonomy Through STEM Integration. Research findings suggest that integrated STEM approaches function as supportive scaffolding systems that help reduce students' cognitive burden regarding abstract conceptualization during the writing process, particularly in lower-level descriptive tasks. As a result, students are able to concentrate more on higher-order thinking skills, including critical analysis, data-driven scientific argumentation, and complex idea organization. Furthermore, continuous interaction with active peer evaluation enhances students' metacognitive awareness and promotes self-regulated learning, leading to greater learner autonomy in academic writing activities.

The third discussion concerns Students' Motivation and Perceptions Toward STEM Tools. Various studies reveal that students generally perceive integrated STEM writing platforms as practical, engaging, and beneficial for supporting the writing process. STEM

projects assist learners in generating ideas, constructing data-backed sentences, and enhancing technical vocabulary selection, which subsequently increases students' confidence and motivation in completing writing tasks. Moreover, the availability of real-world relevance creates a more flexible and less stressful learning environment, particularly for students who experience traditional writing boredom during academic writing activities. Nevertheless, some studies also emphasize the potential risk of superficial data analysis, as certain students may focus heavily on the physical project outcome without critically evaluating their written reports.

The final area, Challenges and Limitations of STEM Implementation in Academic Writing, addresses several concerns related to the use of interdisciplinary frameworks in educational settings. Pedagogical issues, particularly strict separation between science and language disciplines, remain significant challenges in integrated STEM writing practices. Excessive time constraints in already packed curricula may reduce students' opportunities for multiple revisions and deep critical thinking abilities. In addition, disparities in teacher professional development regarding cross-disciplinary work may create unequal learning opportunities among students. Another limitation is that teachers often report a lack of shared assessment rubrics, which indicates that institutional collaboration and instructional guidance remain necessary throughout the learning process.

In conclusion, the mind map demonstrates that integrated STEM approaches provide substantial benefits for the development of academic writing skills from linguistic, cognitive, and motivational perspectives. However, the effective implementation of integrated STEM in academic writing requires balanced integration, cross-disciplinary rubrics, and continuous guidance from educators to ensure that STEM serves as a supportive learning tool that enhances human reasoning and critical thinking.

DISCUSSION

1. Improvement of Academic Writing Skills Through Integrated STEM Approaches

Various studies indicate that integrated STEM approaches have a significant contribution in improving university students' academic writing skills (Awad, 2023). The integration of science, technology, engineering, and mathematics into a single framework allows students to engage with language in a practical context (Chalmers et al., 2017). The aspects that showed the greatest improvement include structural logic, text cohesion, data reporting, technical organization, and overall writing quality (Siekmann et al., 2022).

STEM-powered frameworks such as Project-Based Learning and the Engineering Design Process provide immediate data or physical feedback that helps students revise and refine their writing more effectively. When students encounter physical or mathematical discrepancies in their projects, they are forced to adjust their written explanations immediately (Schoenfeld, 2022). This practical loop helps them understand that accuracy in technical communication is just as vital as accuracy in calculations.

Several reviewed studies reported that students became more capable of identifying logical flaws, improving technical sentence structure, and organizing arguments systematically after regularly participating in integrated STEM writing contexts. The availability of instant feedback from experimental outcomes also supports iterative writing practices (Menzel et al., 2023). This repetition allows students to continuously revise their drafts until higher levels of clarity and accuracy are achieved (Chen & Zhang, 2019).

In addition, STEM approaches create a more interactive writing environment that encourages students to engage actively in the revision process (Struyf et al., 2019). The active inquiry system enables learners to recognize mistakes independently and improve their writing performance without relying entirely on teacher correction (Apridayani & Waluyo, 2025). Consequently, students become more familiar with academic writing conventions and develop

stronger technical writing fluency over time, making the writing process more manageable and productive (Tabari et al., 2024).

2. Cognitive Benefits and Learner Autonomy Through STEM Integration

Beyond linguistic improvement, STEM integration also contributes significantly to students' cognitive development during the writing process (Malik et al., 2023). Academic writing is historically known to be a demanding task that requires learners to manage multiple complex cognitive activities simultaneously (A. F, 2018). These activities include idea generation, data control, coherence building, and critical argument development which can easily overwhelm developing scholars (Wise & Schwarz, 2017).

STEM frameworks function as supportive scaffolding systems that reduce this cognitive load by assisting students with active, concrete visualization (Wang et al., 2025). Through hands-on evidence and real-world experiments, abstract writing concepts become physically visible (Carreira & Baioa, 2018). This immediate connection between action and text helps students map out their thoughts more systematically before transforming them into formal academic prose (Van Drie & van de Ven, 2017).

Several studies reveal that the use of STEM feedback enables students to focus more on higher-order thinking skills, including critical analysis, data-driven scientific argumentation, and complex organization of ideas (Papaneophytou & Nicolaou, 2025). Repeated interaction with engineering or scientific problem-solving also increases students' metacognitive awareness (Çini et al., 2023). As a result, learners gradually become more capable of evaluating and monitoring their own writing performance based on physical project results (Yan & Brown, 2017).

Consequently, students develop stronger self-regulated learning strategies and become more independent writers over time (Abadikhah et al., 2018). Furthermore, STEM-assisted learning encourages students to take greater responsibility for their own academic progress (Rasmi et al., 2025). The flexibility and accessibility of integrated STEM writing tools allow students to practice writing through active observation and receive immediate empirical responses, creating a more autonomous and learner-centered learning experience (Article, 2020).

3. Students' Motivation and Perceptions Toward STEM Tools

In addition to improving technical writing abilities, integrated STEM tools also positively influence students' motivation and attitudes toward academic writing. Many studies report that students perceive STEM-assisted writing applications as helpful, practical, and highly engaging compared to traditional methods. Writing ceases to be seen as an isolated language requirement and is embraced as a natural extension of scientific inquiry.

STEM projects help students generate writing ideas more easily, improve sentence construction through direct observation, and enhance technical vocabulary selection (Davies et al., 2022). This concrete foundation directly increases students' confidence in completing complex writing tasks (Teng et al., 2021). The availability of real-world relevance is considered one of the most beneficial aspects of STEM integration because it supports independent learning and encourages frequent revision (Mcdonald, 2016).

Students become more motivated to write because they can immediately identify and correct empirical mistakes based on their project outcomes without waiting for teacher feedback (Waller & Papi, 2017). Moreover, STEM-assisted learning environments create a less stressful atmosphere, particularly for students who often experience high levels of anxiety during traditional abstract writing activities (Panuganti & Education, n.d.). This shift in perception turns writing into a rewarding phase of discovery.

However, several studies also indicate that some students tend to focus too heavily on the physical project design without critically evaluating their written text (Long & Magerko, 2020). In some cases, learners accept superficial observations automatically without fully

understanding the underlying linguistic or contextual reasons (English, 2019). Therefore, teacher guidance remains essential to ensure that students use STEM tools critically, responsibly, and effectively within the learning process (Slavit et al., 2016).

4. Challenges and Limitations of STEM Implementation in Academic Writing

Despite the numerous benefits identified in the reviewed studies, several challenges and limitations regarding integrated STEM implementation in academic writing are consistently reported (Nadelson & Seifert, 2017). Pedagogical concerns, particularly the deep-rooted institutional separation between science and language disciplines, remain major issues in higher education (Bayne & Dopico, n.d.). This separation often isolates teachers into rigid departmental silos.

Furthermore, excessive time constraints within an already packed STEM curriculum may reduce students' originality, creativity, and deep reflective writing abilities (Fei et al., 2024). If STEM is used inappropriately without balanced scheduling, writing tasks are often rushed or reduced to simple summaries (T. L. Larkin, 2013). This structural issue limits the potential of interdisciplinary learning and places undue stress on both instructors and students (Ozkan et al., 2018).

Another important challenge relates to teacher professional development and unequal access to cross-disciplinary resources (Olaboye et al., 2024). Teachers who have limited experience in combining literacy with science may experience difficulties in utilizing STEM tools effectively, which can create disparities in learning outcomes (Margot & Kettler, 2019). STEM instructors frequently feel underprepared to grade grammar, while language teachers may struggle with technical scientific accuracy (Besterman et al., 2011).

Additionally, STEM-generated assessment is not always pedagogically balanced, as some instructors may provide writing suggestions that are technically correct but structurally weak within specific academic or cultural contexts. To address these limitations, teachers play an important role as facilitators and supervisors (Becuwe et al., 2016). Effective implementation of STEM requires balanced integration, proper instructional guidance, and shared assessment rubrics to ensure a successful cross-disciplinary process (Tytler et al., n.d.).

CONCLUSION

This systematic literature review underscores that integrated STEM approaches serve as a powerful catalyst for enhancing students' academic writing skills. By embedding writing tasks into authentic, data-driven frameworks like Project-Based Learning and the Engineering Design Process, students are able to develop stronger structural logic and scientific argumentation. The concrete feedback from physical experiments effectively scaffolds the writing process, turning an abstract language task into a meaningful communication tool. This integration not only improves the overall quality of technical texts but also boosts student motivation and fosters greater learner autonomy.

However, the successful integration of STEM and academic writing is not without significant structural challenges. The persistent institutional silos between science and language disciplines, coupled with a widespread lack of cross-disciplinary assessment rubrics, often hinder effective implementation. Additionally, time constraints within packed STEM curricula can lead to cognitive overload if not managed with balanced scheduling. To overcome these limitations, future educational models must prioritize professional development that equips STEM and literacy educators with shared pedagogical tools, ensuring that interdisciplinary writing becomes a sustainable and deeply reflective practice. Future studies are encouraged to investigate the long-term effectiveness of integrated STEM approaches across different educational levels and disciplines using more diverse research designs.

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