Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

The Intersection of STEM Education and Social-Emotional Learning: Global Trends and Future Directions

Thoriqi Firdaus

thoriqi.firdaus@pelitabangsa.ac.id

Universitas Pelita Bangsa https://orcid.org/0009-0005-2340-8468

Nuraida Ameliana Putri

Alinea Research Institute https://orcid.org/0009-0004-5442-4084

Isna Silfiatul Ismawati

Alinea Research Institute https://orcid.org/0009-0002-7601-3097

Miftahul Jannah

Alinea Research Institute https://orcid.org/0009-0000-4632-0569

Asna Rahma Auliya

Alinea Research Institute https://orcid.org/0009-0001-2832-1784

Systematic Review

Keywords: STEM education, Social-Emotional Learning (SEL), educational inclusivity

Posted Date: July 23rd, 2026

DOI: https://doi.org/10.21203/rs.3.rs-10446424/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License. Read Full License

Additional Declarations: The authors declare no competing interests.

Abstract

High attrition rates in global Science, Technology, Engineering, and Mathematics (STEM) education highlight a systemic limitation of traditional curricula that focus exclusively on technical cognition while providing insufficient affective support. This study aimed to map the evolution of the conceptual architecture and evaluate the empirical effectiveness of integrating Social-Emotional Learning (SEL) into STEM education. A sequential mixed-methods design was employed. A bibliometric analysis was conducted on 1,132 documents retrieved from the Scopus database, covering publications from 2017 to mid-2026, to identify global research trends and thematic structures. A Systematic Literature Review (SLR), guided by the PRISMA protocol, identified 15 core empirical studies, which were subsequently analyzed qualitatively using the Population, Intervention, Comparison, and Outcome (PICO) framework. The bibliometric findings confirmed exponential growth in publications, indicating an urgent shift toward a holistic science education paradigm. The SLR demonstrated that inclusive pedagogical interventions, such as culturally responsive robotics and makerspaces, simultaneously enhanced technical literacy and the core competencies defined by the Collaborative for Academic, Social, and Emotional Learning (CASEL). A critical evaluation revealed an operational contradiction: SEL integration within formal school hours often failed to produce significant affective outcomes because of systemic pressures to meet curriculum coverage targets, in contrast to the consistent success of out-of-school programs. Psychological well-being emerged as a structural prerequisite for STEM cognition. These findings underscore the need to develop more sensitive evaluation methodologies for formal classroom settings and to conduct longitudinal research that validates the long-term impact of SEL on STEM career retention at the professional level.

1. Introduction

Global knowledge development depends heavily on Science, Technology, Engineering, and Mathematics (STEM) education as the primary driver of innovation and societal advancement (Blanco et al., 2025; Gutiérrez et al., 2024). However, despite substantial structural investment, the global STEM education ecosystem is facing a critical paradox (Man et al., 2026; Olaifa et al., 2026). Demographic reports indicate that attrition rates in STEM programs remain alarmingly high, ranging from 30% to 32%, highlighting attrition as a persistent and major challenge in STEM education (Liu & Kringos, 2025; Salzman et al., 2026). This systemic failure stems from inherent limitations in traditional curriculum design, which prioritizes excessive cognitive demands while neglecting learners' affective development and psychological well-being (Lee & Grapin, 2025; Mahiri, 2026).

These high failure rates do not indicate deficits in students' analytical intelligence; rather, they represent a direct manifestation of a resilience crisis (Bonner et al., 2024; Zorwick et al., 2024), academic anxiety (Rozgonjuk et al., 2024; Wadi et al., 2024), and social isolation within the classroom (Dost, 2024; Narla et al., 2025). In response to this reality, integrating Social-Emotional Learning (SEL) into STEM education can no longer be regarded as an optional peripheral intervention. Instead, integrating technical competencies with emotional intelligence has become an urgent necessity to prevent the future loss of innovative talent (Hiwatig et al., 2024; E. K. Kim et al., 2024).

A critical review of previous research reveals a pronounced conceptual polarization regarding the integration of Social-Emotional Learning (SEL) into STEM education. The conservative paradigm seeks to preserve the disciplinary purity of STEM by excluding affective variables under the premise of maintaining the rigor and objectivity of science (Halawa et al., 2024; Toma et al., 2024). However, the case for holistic education is gaining strong empirical support. Large-scale quantitative evidence from Allen et al (2019) and experimental intervention studies conducted by Puslednik & Brennan (2026) conclusively demonstrated that the integration of Social-Emotional Learning (SEL) acts as a causal catalyst for improving academic achievement and career retention. Furthermore, several equity-oriented

studies have positioned emotional well-being as a strategic mechanism for addressing systemic exclusion among multilingual minority populations (Lee & Grapin, 2025) and neurodivergent populations (Taylor & Glavey, 2024). In response to this debate, this study is firmly grounded in Social Constructivist Theory and is guided by the competency framework established by CASEL (Belay & Dejene, 2024; Swisher & Doyle, 2024). The selection of this framework deliberately rejects the pedagogical dualism that separates cognition from emotion. This study argues that the effective acquisition of advanced computational knowledge is fundamentally unattainable without a strong foundation of self-regulation and relational skills (Luo & Zhou, 2024; Ulrich & Bregulla, 2024).

From both geographical and temporal perspectives, research in this field has accelerated following the global health crisis, as many countries have begun mandating curricula centered on student well-being (Chen et al., 2024; Ersozlu & Barkatsas, 2024). However, this policy transition gives rise to a critical empirical contradiction in practice. Although out-of-school programs consistently demonstrate high levels of success (Cipriano et al., 2024; Levine & Viano, 2025), SEL interventions integrated into the formal school curriculum consistently fail to produce significant improvements in students' affective well-being (Perry et al., 2025). This operational failure is further exacerbated by the findings of Manchanda et al (2025) who documented how educators' intentions to provide sustained emotional support are consistently undermined by systemic pressures and the rigidity of technical curriculum coverage requirements.

This contradiction in practice exposes a clear research gap. The existing literature remains highly fragmented, with most studies limited to small-scale, isolated qualitative observations (Gutierrez et al., 2025), or consists primarily of conceptual advocacy without systematic evaluation. There is currently a critical lack of synthesis research capable of integrating a macro-level mapping of the evolution of the field's global conceptual architecture with a micro-level investigation of pedagogical failures in formal classroom settings (Alemdar, 2025; Cipriano et al., 2024; Pal et al., 2026). Addressing this gap is a scientific imperative. Without a comprehensive structural mapping of the field, educational institutions will continue to invest resources in SEL intervention designs that are theoretically sound but practically incompatible with the realities of formal school ecosystems.

In response to this urgent need, this study aims to critically map the evolution of the global conceptual architecture and evaluate the empirical effectiveness of integrating Social-Emotional Learning (SEL) into STEM education over the 2017–2026 period. This overarching objective is addressed through three research questions.

1. How have publication trends and the global geographic epicenter of research on STEM education and Social-Emotional Learning (SEL) evolved over time?;
2. Based on the conceptual structure mapping, what thematic foundations construct the bridge between analytical competence and affective intelligence?;
3. How effective are Social-Emotional Learning (SEL) interventions in improving students' academic retention, and what systemic barriers hinder their implementation within formal school ecosystems?

This study makes two primary contributions. Theoretically, it deconstructs the traditional paradigm of science education by demonstrating that affective well-being is a structural prerequisite for effective STEM cognition. Practically, it provides an evidence-based blueprint for developing equitable educational policies. The innovative integration of macro-level bibliometric mapping with micro-level PICO framework extraction ensures robust data triangulation and analytical rigor. The complete methodological framework is described in detail in the following Methodology section.

2. Method

2.1 Research Design

This study employed a sequential mixed-methods design that began with a bibliometric analysis and was followed by a Systematic Literature Review (SLR). The first-phase bibliometric analysis was conducted to quantitatively map the global conceptual structure, thematic evolution, and publication trends at the macro level. Building on these macro-level findings, the second-phase SLR was performed to qualitatively extract, critically evaluate, and synthesize the operational empirical evidence from the most relevant literature. The sequential integration of these two methods ensured robust data triangulation, thereby minimizing subjective bias.

2.2 Data Search Strategy

The initial data extraction process was conducted using the Scopus database. Scopus was selected because of its reputation as the largest multidisciplinary peer-reviewed literature database, providing high-quality metadata suitable for bibliometric mapping. The literature search was performed using a combination of specific keywords formulated as a Boolean search string and applied to the Title, Abstract, and Keywords fields (TITLE-ABS-KEY). The search query was carefully designed to capture the intersection between the fields of Science, Technology, Engineering, and Mathematics (STEM) and Social-Emotional Learning (SEL). The complete search string used in the database is presented below:

TITLE-ABS-KEY (("STEM education" OR "STEAM education" OR "integrated STEM" OR "STEM learning" OR "STEAM learning" OR "STEM approach" OR "STEM curriculum" OR "STEM integration" OR "STEM program*" OR "STEM student*" OR "STEM teacher*" OR "STEM class*" OR "STEM disciplin*" OR "STEM field*" OR "STEM subject*" OR "science, technology, engineering, and math*" OR "science, technology, engineering and math*") AND ("social-emotional*" OR "socio-emotional*" OR "social and emotional*" OR "SEL" OR "affective" OR "social skill*" OR "emotional skill*" OR "emotional intelligence" OR "empathy" OR "self-awareness" OR "self-management" OR "social awareness" OR "relationship skill*" OR "responsible decision-making" OR "resilience" OR "well-being" OR "wellbeing" OR "growth mindset" OR "emotional regulation" OR "character education" OR "non-cognitive" OR "noncognitive"))

2.3 Bibliometric Analysis

The search parameters were limited to publications published between 2017 and mid-2026 to ensure the relevance of the research discourse. The initial screening, which restricted the search to English-language publications and document types including journal articles, conference papers, and review articles, yielded a dataset of 1,225 documents. The resulting bibliographic records were then exported in BibTeX format. This format was intentionally selected because the R environment exhibited superior metadata sensitivity and compatibility when processing BibTeX files. The BibTeX dataset was subsequently imported into the R environment using the bibliometrix interface (Biblioshiny).

The system's automated data-cleaning process consolidated the dataset into a final corpus of 1,132 documents for analysis. The software was used to compute annual publication performance metrics, geographic distribution, and source impact, as well as to visualize the scientific landscape through keyword co-occurrence network analysis and thematic map construction. The results of the quality assessment are presented in Table 1.

<<**Table 1.** The automated data-cleaning process>>

2.4 Systematic Literature Review Procedure (PRISMA)

The second-stage literature selection was conducted in strict accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. As illustrated in Fig. 1, the selection process was

designed to identify the most relevant studies through four sequential stages: identification, screening, eligibility assessment, and final inclusion. During the initial identification stage, a total of 1,555 records were retrieved from the database. Following this comprehensive screening and selection process, 15 core empirical studies met all inclusion criteria and were selected for data extraction.

<<Figure 1. PRISMA Flow Diagram>>

2.5 Data Extraction and Synthesis Framework (PICO)

The final set of 15 studies that met the PRISMA inclusion criteria was subjected to an in-depth analysis. To ensure the consistency and objectivity of data extraction, the qualitative synthesis employed the PICO (Population, Intervention, Comparison, and Outcomes) analytical framework. This framework was systematically applied to examine participants' demographic characteristics, the specific pedagogical interventions implemented, the presence of comparison parameters or control groups, and the intervention outcomes in terms of improvements in students' cognitive performance and affective well-being.

3. Result

3.1 Publication Growth and Global Geographic Distribution

Based on the final dataset of 1,132 documents, the analysis of annual scientific output from 2017 to mid-2026 revealed an exponential growth trajectory. At the beginning of the observation period in 2017, only 31 publications addressed the intersection of STEM education and Social-Emotional Learning (SEL). The volume of publications increased steadily over time, with a slight fluctuation observed in 2020 (61 documents), before rising progressively to 170 publications in 2024. Scientific output reached its peak in 2025, with a total of 280 publications.

The apparent decline recorded in 2026 (156 documents) did not represent a decrease in research interest but rather reflected the partial nature of data collection, as the year had not yet concluded when the data extraction was performed. To visualize this exponential growth trajectory and the slight fluctuations observed during the study period, the detailed annual scientific production trend is illustrated in Fig. 2.

<<Figure 2. Annual Scientific Production Trend of STEM Education and SEL Research (2017–2026)>>

The exponential increase after 2020 was particularly significant. This finding indicated a global paradigm shift driven by educational disruptions caused by the pandemic. The academic community increasingly recognized that cognitive skills within STEM disciplines could not function independently without support from students' social competencies, emotional resilience, and self-regulation. From a geographic distribution perspective, scientific production in this domain demonstrated strong centralization, with several countries emerging as major contributors. The Countries' Scientific Production analysis presented in Fig. 3 revealed that the United States (USA) dominated this discourse, with a total occurrence frequency of 1,267. The frequency value exceeding the total number of documents represented the high intensity of inter-author collaboration among researchers from various institutions across the United States in these publications.

<<Figure 3. Countries' Scientific Production>>

The position of the United States was followed by China (121) in second place and Indonesia (80) in third place, with a considerable gap. The dominance of the United States could be attributed to its well-established national education policies, including the explicit integration of SEL frameworks into the Next Generation Science Standards

(NGSS). The presence of China and Indonesia among the top three global contributors provided important new insights, indicating that the urgency of integrating human-centered and emotionally responsive STEM education was no longer an exclusive agenda of advanced Western countries but had become a strategic educational priority in developing countries undergoing curriculum transformation.

3.2 Core Sources and Influential Authors

This study also identified the primary publication outlets that facilitated discourse on STEM education and Social-Emotional Learning (SEL). The analysis of publication sources was conducted using Bradford's Law of Scattering. The mapping results in the core zone (Zone 1) revealed that the majority of the literature was concentrated in several highly productive primary sources. The mapping results within the core zone (Zone 1), which detail the highly productive primary journals and conference proceedings disseminating research on this intersection, are summarized in Table 2.

<<Table 2. Most Relevant Publication Sources Based on Bradford's Law Core Zone>>

The ASEE Annual Conference and Exposition proceedings ranked as the most productive source, publishing 113 documents. This was followed by the prestigious journal Education Sciences with 41 documents and Frontiers in Education with 36 documents. The presence of engineering conference proceedings alongside specialized education journals provided an important academic signal. This finding indicated that SEL integration was not only examined conceptually by education scholars but was also actively discussed and practically implemented by the engineering education community in practice. Meanwhile, the Authors' Local Impact metric was used to identify researchers with the most significant influence within the dataset. Meanwhile, the Authors' Local Impact metric was evaluated to identify researchers with the most significant influence within the dataset. The leading authors, ranked by their citation counts, h-index, and publication initiation years, are presented in Table 3.

<<Table 3. Top Influential Authors Based on Local Impact Metrics>>

Murphy M.C. emerged as the most influential author, with a total of 931 citations from six publications recorded since 2019. This position was closely followed by Canning E.A., with 855 citations, and Muenks K., with 787 citations. An interesting pattern was observed in the publication initiation years of these leading authors; nearly all highly influential researchers began publishing their core works intensively between 2019 and 2022. This finding confirmed that the modern theoretical foundation underlying the integration of STEM education and SEL represented a relatively emerging research area that was currently undergoing a phase of rapid expansion.

3.3 Thematic Mapping and Keyword Co-occurrence

The Keyword Co-occurrence Network and word frequency analyses were conducted to understand the conceptual architecture of this research domain. These analyses served as a crucial analytical bridge to guide the thematic exploration in the subsequent Systematic Literature Review (SLR) stage. Based on the extraction of the most frequently occurring terms, the keywords "students" (302 occurrences), "technology" (258 occurrences), and "engineering education" (222 occurrences) dominated the literature. The high frequency of these keywords explicitly positioned students and technology as central components of learning interventions. The co-occurrence network visualization divided the research landscape into two closely interconnected primary clusters. This classification mapped the integration of STEM education and SEL into two fundamental dimensions. The co-occurrence network visualization divided the research landscape into two closely interconnected primary clusters. As illustrated in Fig. 4, this classification clearly maps the integration of STEM education and SEL into two fundamental conceptual dimensions.

<<Figure 4. Keyword Co-occurrence Network Analysis in STEM and SEL Literature>>

The first cluster (blue) represented the STEM pedagogy and curriculum dimension. This cluster centered on the structural aspects and implementation of instruction. The largest nodes within this network included engineering education, technology, curriculum, and teaching. The blue cluster represented the institutional and pedagogical approaches involved in designing comprehensive STEM programs. The second cluster (red) represented the psychological and social-emotional dimension. Serving as a balance to the technical aspects of the blue cluster, the red cluster mapped the essential cognitive and affective domains within SEL. The strongly interconnected nodes included psychology, problem solving, empathy, motivation, cognition, and mental health. Notably, this cluster also explicitly incorporated demographic variables, such as gender (male and female) and developmental stage (adolescent). These findings indicated that SEL research within STEM contexts placed substantial emphasis on inclusivity, gender equity, and adolescents' psychological well-being.

The highly dense connectivity between the blue and red clusters visualized the central argument of this study. Technical competencies in STEM education were demonstrated to be inseparable from psychological well-being support, including empathy, motivation, and mental health, in creating holistic and adaptive learning environments. These macro-level network findings were subsequently examined in greater depth through the qualitative literature review presented in the following section.

3.4 Thematic Findings from the Systematic Review

A systematic literature review of the 15 core studies was conducted to validate and deepen the findings obtained from the preceding bibliometric mapping. Data from these studies were comprehensively extracted using the Population, Intervention, Comparison, and Outcomes (PICO) framework. A comprehensive summary of the extracted data, systematically outlining the methodological characteristics, interventions, and thematic categorizations of the 15 core studies based on the PICO framework, is presented in Table 4.

<<Table 4. Summary of Data Extraction and Thematic Categorization using the PICO Framework>>

3.4.1 SEL as a Catalyst for STEM Achievement and Retention

The reviewed literature consistently demonstrated that social-emotional competencies were not merely complementary skills but fundamental drivers of cognitive and academic achievement in STEM education. The quantitative study conducted by Puslednik & Brennan (2026) demonstrated that social mentoring interventions had substantial potential to serve as catalysts for improving science achievement, particularly among students in rural and remote areas. The mentoring program produced marked improvements in science knowledge and problem-solving skills, with effect sizes ranging from 0.81 to 1.57, which were supported by significant gains in students' communication skills.

This causal effect was further reinforced at a large population scale by Allen et al (2019). Through an evaluation of 1,599 students across 158 STEM-based programs, their analysis quantified the direct relationship between the quality of SEL integration and STEM career retention. The findings showed that 65% to 85% of students reported increased engagement, career interest, and persistence in STEM, all of which were strongly correlated with critical thinking and interpersonal competencies. These findings confirmed that interventions aimed at enhancing students' psychological well-being directly contributed to their long-term persistence within the STEM academic ecosystem.

3.4.2 Pedagogical Strategies for Integrating SEL into STEM Curricula

The second dominant theme explored practical mechanisms for integrating Social-Emotional Learning (SEL) into classroom practice. Bawaneh et al (2026) the findings further emphasized the need for precise alignment between STEM instruction and the Collaborative for Academic, Social, and Emotional Learning (CASEL) competency framework, particularly given that teachers consistently demonstrated a high level of awareness regarding the importance of this pedagogical approach. Moreover, at the early childhood and preschool levels, the most prominent instructional approach involved the use of robotics through play-based learning pedagogy. Penelitian Mahiri (2026); Mahiri et al (2026) demonstrated compellingly that robotics-based interventions, such as LEGO Robotics integrated with culturally responsive pedagogy, enabled children aged 4 to 5 years to acquire foundational computational and structural assembly skills. Simultaneously, this instructional approach successfully fostered the comprehensive development of all five CASEL core competencies within the classroom. Interdisciplinary curriculum integration was also demonstrated to be effective. A study conducted by Garner et al (2018) found that a module integrating the arts, science, and social-emotional skills within a summer program successfully fostered empathy while simultaneously enhancing students' appreciation of real-world scientific applications.

Beyond curricular interventions, the reviewed literature also highlighted the importance of the physical learning environment and educators' capacity in supporting the effective integration of SEL into STEM education. Mercan et al (2024) revealed that thoughtfully designed physical learning environments, such as STEAM makerspaces, functioned as effective pedagogical tools for facilitating practical cognitive development while simultaneously fostering students' sense of belonging and self-confidence. A study conducted by Fields & Kafai (2023) also highlighted that the successful implementation of innovative curricula, such as e-textiles, depended heavily on addressing teachers' emotional needs through support from communities of practice, ultimately resulting in high levels of STEAM program retention within participating schools.

3.4.3 Demographic Disparities and Inclusive STEM Education

The intersection of STEM education and Social-Emotional Learning (SEL) provided a crucial framework for addressing issues of equity, demographic disparities, and educational justice. Lee and Grapin (2025) proposed a justice-centered STEM education approach for multilingual learners, in which students' emotional well-being was validated as a cross-cultural asset for designing scientific solutions to global challenges. This emphasis on inclusivity was also demonstrated to be adaptable to neurodivergent learners. Taylor and Glavey (2024) demonstrated that integrating robotics into inclusive classrooms successfully supported students with disabilities and autism. This approach not only enhanced coding literacy but also promoted students' independence and social-emotional engagement.

The fulfillment of students' physical and emotional sense of safety was emphasized across diverse demographic groups. A study of early childhood learners conducted by Silvis et al. (2026) highlighted the importance of creating computing classrooms that prioritize dignity and physical comfort through embodied belonging. In rural settings, Gutierrez et al. (2025) found that interactive, family-based independent experimentation activities stimulated positive emotional expression and teamwork among secondary school students. Furthermore, Bonner et al. (2024) demonstrated that a holistic curriculum integrating nutrition, physical fitness, and STEM significantly improved the Positive Youth Development (PYD) index.

Despite its substantial conceptual benefits, the integration of SEL into mainstream educational settings encountered significant implementation challenges. Perry et al. (2025) reported that evaluations of integrated curriculum programs delivered during regular school hours frequently failed to demonstrate significant improvements in SEL survey indicators, in contrast to the positive outcomes observed in after-school programs. This finding was consistent with the phenomenon documented by Manchanda et al. (2025) among preservice STEM teachers.

Although educators regarded Transformative Social-Emotional Learning (T-SEL) as an essential component for promoting classroom equity, its practical implementation was often constrained by systemic time pressures and the demands of covering technical curriculum content. This tension between the demands of the formal academic system and the provision of meaningful social-emotional support emerged as a critical challenge for future research.

4. Discussion

4.1 Synthesis of the Main Findings, Theoretical Relevance, and Critical Analysis

With reference to the original objectives of this study, the principal findings from the bibliometric analysis and the systematic literature review confirmed that the integration of Social-Emotional Learning (SEL) into STEM education had experienced exponential growth. This discourse has evolved from a peripheral concept into a fundamental catalyst for the development of technical cognitive competencies (Corcoran et al., 2018; Ha et al., 2025; Nalipay et al., 2024).

The synthesized findings directly aligned with and reinforced the contemporary literature advocating a transition toward a holistic educational approach. Earlier studies had largely treated STEM disciplines as rigid fields characterized by an exclusive emphasis on objectivity and the transfer of technical skills (Cech, 2014; Faulkner, 2007; Imad et al., 2023). However, the findings of the present study directly challenged and deconstructed this traditional paradigm. Large-scale empirical evidence from Allen et al. (2019) and intervention-based findings reported by Puslednik and Brennan (2026) demonstrated that social-emotional competencies, including resilience, communication, and relational capacity, constitute the primary driving forces underlying sustained academic persistence and long-term STEM career retention.

The most significant contribution of this study to the global literature is the critical demonstration that Social-Emotional Learning (SEL) should no longer be regarded merely as a complementary instrument for enhancing classroom comfort. Based on the critical analysis of the available evidence, social-emotional competencies emerge as a structural foundation for educational equity (Jones et al., 2020; Mahoney et al., 2021). The implications of these findings are highly significant, as neglecting psychological dimensions in the design of STEM curricula perpetuates systemic exclusion among underrepresented populations. The literature supports this conclusion, demonstrating that approaches grounded in emotional justice represent an effective means of promoting the participation of multilingual learners (Lee & Grapin, 2025) while fostering the autonomy of neurodivergent students in inclusive classrooms (Taylor & Glavey, 2024).

These findings necessitate an expansion of the classical cognitivist framework traditionally applied in science classrooms (Pintrich et al., 1993; Sinatra, 2005). A critical evaluation of these dynamics indicates that modern theories of science learning must inherently incorporate affective variables. From a practical perspective, the significance of these findings calls for institutional-level reform. Given the substantial influence of psychosocial factors on academic success (Bonner et al., 2024), future STEM programs will be unlikely to cultivate the next generation of innovators if educational institutions focus solely on computational intelligence without systematically fostering students' mental resilience and collaborative capacity.

4.2 Pedagogical Dynamics and Practical Contradictions

Previous studies have frequently positioned science mastery and developmental psychology as two parallel yet separate curricular pathways (Eylon & Linn, 1988; Linn et al., 2016). The findings of this systematic literature review substantially extended and deconstructed the limitations of this conventional perspective. Our review confirmed that well-designed pedagogical interventions not only bridged these two domains but also successfully integrated them into a unified cognitive-affective framework. For example, the combination of culturally responsive pedagogy with hands-on instructional tools was shown to enable young children to develop foundational computational skills (Mahiri, 2026) while simultaneously fostering all five CASEL core competencies (Mahiri et al., 2026). These findings provide compelling empirical support for Social Constructivist Theory, suggesting that the acquisition of technical competencies is most effectively constructed through meaningful social interaction (Jeong et al., 2019; Lyu et al., 2023).

Nevertheless, when the analytical lens was directed specifically toward real-world implementation, this study identified a striking empirical contradiction. A substantial disparity emerged in the effectiveness of social-emotional competency development across different learning ecosystems. Evaluations of integrated science curricula implemented during regular school hours unexpectedly failed to detect significant improvements in students' psychological well-being indicators (Perry et al., 2025). This unexpected finding stands in sharp contrast to the consistently positive outcomes reported in out-of-school learning environments, including after-school programs (Allen et al., 2019) and summer curriculum interventions (Garner et al., 2018).

This empirical contradiction represents a significant novel contribution of the present study, as it directly exposes the deeply rooted systemic constraints embedded within mainstream educational institutions. The limited effectiveness of SEL implementation during regular school hours is likely attributable to the rigidity of academic performance targets and the widespread curricular emphasis on standardized testing (Araúz-Ledezma et al., 2022; Levatino et al., 2024). This interpretation is supported by the observations of Manchanda et al. (2025), who found that preservice STEM educators faced a substantial dilemma: their intention to provide transformative social-emotional support was consistently undermined by systemic time constraints and the pressure to complete extensive technical curriculum content.

This contradictory implementation landscape carries profound theoretical and practical implications. From a theoretical perspective, future pedagogical integration frameworks can no longer place the responsibility for social-emotional demands solely on students' adaptive capacities. Instead, these frameworks must be expanded to explicitly encompass educators' well-being (Dreer, 2023; Jennings & Greenberg, 2009; Madigan & Kim, 2021). From a practical perspective, the success of an innovative curriculum was shown to depend largely on the extent to which educational institutions supported teachers' emotional well-being through communities of practice (Fields & Kafai, 2023) the success of such curricula also depended on the instructional clarity of their pedagogical frameworks (Bawaneh et al., 2026). Although the interpretation of these systemic barriers should be viewed with caution because several studies relied on small-scale qualitative descriptive designs (Gutierrez et al., 2025), the triangulated evidence consistently pointed to the same underlying structural constraints.

The identification of future research directions calls for the development of more sensitive methodological evaluation frameworks capable of capturing gains in social-emotional competencies within the constraints of regular school schedules (Perry et al., 2025). Extending this perspective to its broader significance, our findings suggest that meaningful reform in STEM education cannot be achieved solely through revisions to curricular content or instructional materials. Instead, the creation of a truly holistic educational ecosystem requires a fundamental redesign of the learning architecture, encompassing both the transformation of physical learning environments to

promote students' dignity and embodied comfort (Silvis et al., 2026) and the establishment of collaborative innovation spaces that foster creativity and active engagement (Mercan et al., 2024).

4.3 Framework and Contextual Significance

The findings of this study hold substantial significance because they fundamentally redefine the benchmarks of success in modern science education. Historically, the effectiveness of STEM curricula has been evaluated through a narrow lens, primarily emphasizing students' mastery of mathematical formulas and mechanical technological literacy (Arikan et al., 2022; Gao et al., 2020; Sussman & Wilson, 2019). However, the interpretive framework developed through this review positions psychological well-being not as a secondary outcome, but as a fundamental prerequisite for the development of technical cognition.

Comparing these findings with the existing literature places the discourse on STEM education within a much broader sociocultural context. Contemporary science education does not operate in isolation (Firdaus & Nurohman, 2025). Justice-centered educational approaches designed to accommodate the transnational experiences of multilingual learners (Lee & Grapin, 2025), together with curricular interventions integrating physical fitness and holistic health (Bonner et al., 2024), demonstrate that STEM education serves as a powerful instrument for social transformation. The significance of this discourse underscores that preparing the next generation of innovators requires curricula that holistically recognize and affirm students' cultural identities and physical well-being (Donnelly et al., 2016; Eitel et al., 2024; Smith et al., 2022). This contextualization reinforces the central argument that mastery of twenty-first-century technologies can generate meaningful and sustainable societal benefits only when guided by individuals who possess well-developed emotional regulation and collaborative empathy.

4.4 Critical Methodological Analysis and Future Research Directions

An objective evaluation of the mixed-methods approach employed in this study revealed several strengths and limitations that influenced the interpretation of the findings. The primary strength of this research lies in its triangulation capacity, whereby quantitative bibliometric mapping established the foundation for identifying global trends, which were subsequently validated through in-depth qualitative analysis using a systematic literature review.

Several methodological limitations should be transparently acknowledged. In the bibliometric phase, the absence of comprehensive citation reference metadata limited the capacity of the analysis to algorithmically map the historical evolution of theoretical lineages. In the systematic literature review phase, the primary limitation originated from the characteristics of the samples reported in several extracted studies. Some innovative investigations remained heavily dependent on small-scale qualitative observations or descriptive designs, such as family-based interventions in rural settings (Gutierrez et al., 2025) and phenomenological research involving eight preservice educators (Manchanda et al., 2025). These sample size limitations constrained the generalizability of the findings to mainstream populations without prior structural adjustments (Carminati, 2018; Hennink & Kaiser, 2022; Malterud et al., 2016).

A critical analysis of the unexpected findings revealed an underlying irony within the academic ecosystem. The evidence indicating that formal school hours failed to produce significant improvements in students' social-emotional learning survey outcomes (Perry et al., 2025) carries substantial evaluative implications. This reality highlights the limitations of conventional educational systems that remain overly rigid and constrained by standardized technical assessment frameworks (Cho & Chan, 2020; Polesel et al., 2014; von der Embse et al., 2016). The logical implication of this finding is that social-emotional competencies cannot simply be inserted as

supplementary modules; rather, they require a fundamental restructuring of assessment systems and instructional time allocation.

Based on the identified gaps and limitations, this study recommends several strategic directions for future research agendas. The first critical step involves developing more sensitive classroom-based evaluation methodologies for formal school settings, including the reformulation of measurement instruments and research approaches capable of effectively detecting changes in students' affective outcomes within the constraints of regular school hours (Perry et al., 2025). Furthermore, to address the persistent dominance of small sample sizes in the existing literature, future research should examine the effectiveness of intervention instruments, such as robotics-based learning and innovative maker spaces, through large-scale longitudinal studies. This long-term approach is essential because it will enable researchers to precisely track the actual impact of such integration on STEM career retention through to the professional level (M. H. Kim & Beier, 2020; Le & Robbins, 2016; Rocker Yoel et al., 2020; Stefani, 2024). Finally, scholars should direct greater attention toward optimizing instructional design by developing standardized pedagogical guidelines at the early education level. This standardization effort should include the systematic alignment of activity difficulty progression (Garner et al., 2018), ensuring that designed curricular interventions can be effectively adopted and adapted to support a substantially broader range of learner demographics (Gutiérrez et al., 2025).

Extending this discourse toward broader global significance, the integration of technical competencies and social-emotional intelligence ultimately represents a roadmap for sustaining an innovation-driven civilization. The success of future STEM education will not be measured solely by the technological sophistication produced by its graduates. Rather, it will be determined by the extent to which educational institutions can preserve learners' humanity, dignity, and psychological resilience while preparing them to navigate increasingly complex global challenges.

5. Conclusion

This study achieved its primary objective of mapping global trends and thematic structures at the intersection of STEM education and Social-Emotional Learning (SEL). The study confirmed that the discourse on SEL integration has experienced exponential growth and has transformed into a fundamental catalyst for career retention and academic achievement in science. In addressing the initial research questions, the literature extraction results demonstrated that innovative, culturally responsive pedagogical strategies not only enhanced technical literacy but also successfully fostered social-emotional competencies simultaneously. The primary scientific contribution of this study lies in its deconstruction of the rigid paradigm of traditional science education. This research advances theoretical understanding by demonstrating that affective variables and psychological well-being constitute structural prerequisites, rather than supplementary elements, for establishing an inclusive STEM ecosystem that supports both minority learners and neurodivergent populations.

Practically, these findings urge policymakers to redesign curricula holistically and provide systematic psychological support for educational communities in the field. Although this study offers a transformative framework, critical evaluation of the literature revealed methodological limitations, particularly the inability of current instruments to detect significant changes in students' affective outcomes during regular school hours. Future research should prioritize the development of more sensitive evaluation methodologies for formal classroom settings and the implementation of large-scale longitudinal studies to validate the effectiveness of SEL interventions through the professional level. The global significance of this study underscores that the future of innovative civilizations will not be measured solely by the sophistication of mechanical technologies. Rather, the true success of STEM education

will be determined by the extent to which our academic ecosystems can cultivate resilience and empathy while preserving the human dignity of future generations of innovators amid increasingly complex global challenges.

References

1. Alemdar M (2025) Mapping the Evolution of Social and Emotional Learning Research in Primary Education Contexts: A Bibliometric and Thematic Analysis. J Intell 13(9):123. https://doi.org/10.3390/jintelligence13090123
2. Araúz-Ledezma AB, Massar K, Kok G (2022) Implementation of a school-based Social Emotional Learning Program in Panama: Experiences of adolescents, teachers, and parents. Int J Educational Res 115:101997. https://doi.org/10.1016/j.ijer.2022.101997
3. Arikan S, Erktin E, Pesen M (2022) Development and Validation of a STEM Competencies Assessment Framework. Int J Sci Math Educ 20(1):1–24. https://doi.org/10.1007/s10763-020-10132-3
4. Belay S, Dejene W (2024) Testing and validating the collaborative for academic, social, and emotional learning (CASEL) model in the context of Ethiopian secondary schools: Factorial analysis. Social Sci Humanit Open 10:101128. https://doi.org/10.1016/j.ssaho.2024.101128
5. Blanco PA, Guisasola J, Zuza K (2025) Integrated STEM education: addressing theoretical ambiguities and practical applications. *Frontiers in Education*, *10*. https://doi.org/10.3389/feduc.2025.1568885
6. Bonner J, Xiong W, Velasquez C, Nienhuis N, Wallace B, Friedman A, Lee D, Perry A (2024) A Novel Summer Camp Integrating Physical, Psychological, and Educational Health in Youth: The THINK Program. Nutrients 16(12):1838. https://doi.org/10.3390/nu16121838
7. Carminati L (2018) Generalizability in Qualitative Research: A Tale of Two Traditions. Qual Health Res 28(13):2094–2101. https://doi.org/10.1177/1049732318788379
8. Cech EA (2014) Culture of Disengagement in Engineering Education? Sci Technol Hum Values 39(1):42–72. https://doi.org/10.1177/0162243913504305
9. Chen J, Du X, Guerra A, da Silva FMF, Chaaban Y (2024) Sources contributing to engineering students' academic well-being: An exploration using the Q methodology. J Eng Educ 113(3):576–602. https://doi.org/10.1002/jee.20605
10. Cho EY-N, Chan TMS (2020) Children's wellbeing in a high-stakes testing environment: The case of Hong Kong. Child Youth Serv Rev 109:104694. https://doi.org/10.1016/j.childyouth.2019.104694
11. Cipriano C, Ha C, Wood M, Sehgal K, Ahmad E, McCarthy MF (2024) A systematic review and meta-analysis of the effects of universal school-based SEL programs in the United States: Considerations for marginalized students. Social Emotional Learning: Res Pract Policy 3:100029. https://doi.org/10.1016/j.sel.2024.100029
12. Corcoran RP, Cheung ACK, Kim E, Xie C (2018) Effective universal school-based social and emotional learning programs for improving academic achievement: A systematic review and meta-analysis of 50 years of research. Educational Res Rev 25:56–72. https://doi.org/10.1016/j.edurev.2017.12.001
13. Donnelly JE, Hillman CH, Castelli D, Etnier JL, Lee S, Tomporowski P, Lambourne K, Szabo-Reed AN (2016) Physical Activity, Fitness, Cognitive Function, and Academic Achievement in Children. Med Sci Sports Exerc 48(6):1197–1222. https://doi.org/10.1249/MSS.0000000000000901
14. Dost G (2024) Students' perspectives on the 'STEM belonging' concept at A-level, undergraduate, and postgraduate levels: an examination of gender and ethnicity in student descriptions. Int J STEM Educ 11(1):12. https://doi.org/10.1186/s40594-024-00472-9

15. Dreer B (2023) On the outcomes of teacher wellbeing: a systematic review of research. *Frontiers in Psychology*, *14*. https://doi.org/10.3389/fpsyg.2023.1205179
16. Eitel KB, Wheeler A, Seven K, Pinkham J, Cavazos Cohn T, Uh C, Temple W, Davis E, McFarland M, Eitel J, Carter J, Dixon M, R., Vierling L (2024) Culturally sustaining pedagogy in an outdoor environmental science education program to support high school students' identities as Indigenous people and scientists. J Geosci Educ 72(2):119–133. https://doi.org/10.1080/10899995.2023.2228170
17. Ersozlu Z, Barkatsas T (2024) Editorial: The psychology of STEM education. *Frontiers in Education*, *9*. https://doi.org/10.3389/feduc.2024.1354783
18. Eylon B-S, Linn MC (1988) Learning and Instruction: An Examination of Four Research Perspectives in Science Education. Rev Educ Res 58(3):251–301. https://doi.org/10.3102/00346543058003251
19. Faulkner W (2007) `Nuts and Bolts and People'. Soc Stud Sci 37(3):331–356. https://doi.org/10.1177/0306312706072175
20. Firdaus T, Nurohman S (2025), September The Role of Artificial Intelligence in Science Education: Enhancing Student Engagement and Preparing the Foundations for Future Education through Digital Literacy. In 2025 *International Workshop on Artificial Intelligence and Education (WAIE)* (pp. 181–185). IEEE. https://doi.org/10.1109/WAIE67422.2025.11381299
21. Gao X, Li P, Shen J, Sun H (2020) Reviewing assessment of student learning in interdisciplinary STEM education. Int J STEM Educ 7(1):24. https://doi.org/10.1186/s40594-020-00225-4
22. Gutiérrez VF, Suero LC, del Bermea C, Flores DHA, Fraustro MLP, Castillo MD, Velasco OMF, M. J. F., Bustamante AMM (2024) The axiological foundations of innovation in STEM education A systematic review and ethical meta-analysis. Heliyon 10(12):e32381. https://doi.org/10.1016/j.heliyon.2024.e32381
23. Ha C, McCarthy MF, Strambler MJ, Cipriano C (2025) Disentangling the Effects of Social and Emotional Learning Programs on Student Academic Achievement Across Grades 1–12: A Systematic Review and Meta-analysis. Rev Educ Res. https://doi.org/10.3102/00346543251367769
24. Halawa S, Lin T-C, Hsu Y-S (2024) Exploring instructional design in K-12 STEM education: a systematic literature review. Int J STEM Educ 11(1):43. https://doi.org/10.1186/s40594-024-00503-5
25. Hennink M, Kaiser BN (2022) Sample sizes for saturation in qualitative research: A systematic review of empirical tests. Soc Sci Med 292:114523. https://doi.org/10.1016/j.socscimed.2021.114523
26. Hiwatig BMR, Roehrig GH, Rouleau MD (2024) Unpacking the nuances: an exploratory multilevel analysis on the operationalization of integrated STEM education and student attitudinal change. Disciplinary Interdisciplinary Sci Educ Res 6(1):18. https://doi.org/10.1186/s43031-024-00108-6
27. Imad M, Reder M, Rose M (2023) Recasting the agreements to re-humanize STEM education. *Frontiers in Education*, *8*. https://doi.org/10.3389/feduc.2023.1193477
28. Jennings PA, Greenberg MT (2009) The Prosocial Classroom: Teacher Social and Emotional Competence in Relation to Student and Classroom Outcomes. Rev Educ Res 79(1):491–525. https://doi.org/10.3102/0034654308325693
29. Jeong H, Hmelo-Silver CE, Jo K (2019) Ten years of Computer-Supported Collaborative Learning: A meta-analysis of CSCL in STEM education during 2005–2014. Educational Res Rev 28:100284. https://doi.org/10.1016/j.edurev.2019.100284
30. Jones TM, Fleming C, Williford A (2020) Racial equity in academic success: The role of school climate and social emotional learning. Child Youth Serv Rev 119:105623. https://doi.org/10.1016/j.childyouth.2020.105623

31. Kim EK, Allen JP, Jimerson SR (2024) Supporting Student Social Emotional Learning and Development. School Psychol Rev 53(3):201–207. https://doi.org/10.1080/2372966X.2024.2346443
32. Kim MH, Beier ME (2020) The college-to-career transition in STEM: An eleven-year longitudinal study of perceived and objective vocational interest fit. J Vocat Behav 123:103506. https://doi.org/10.1016/j.jvb.2020.103506
33. Le H, Robbins SB (2016) Building the STEM pipeline: Findings of a 9-year longitudinal research project. J Vocat Behav 95–96:21–30. https://doi.org/10.1016/j.jvb.2016.07.002
34. Lee O, Grapin S (2025) Justice-centered < scp>STEM education with multilingual learners to address societal challenges: A conceptual framework. J Res Sci Teach 62(5):1202–1231. https://doi.org/10.1002/tea.21999
35. Levatino A, Verger A, Camphuijsen M, Termes A, Parcerisa L (2024) School Governance Through Performance-Based Accountability: A Comparative Analysis of Its Side Effects Across Different Regulatory Regimes. Rev Res Educ 48(1):248–286. https://doi.org/10.3102/0091732X241270672
36. Levine RS, Viano S (2025) Promising Practices of Out-of-School Time Programs for Low-Income Adolescents: A Systematic Review. J Adolesc 97(5):1145–1160. https://doi.org/10.1002/jad.12506
37. Linn MC, Gerard L, Matuk C, McElhaney KW (2016) Science Education. Rev Res Educ 40(1):529–587. https://doi.org/10.3102/0091732X16680788
38. Liu Z, Kringos N (2025) What prevents STEM universities from widening participation? A systematic literature review on global experiences. Int J STEM Educ 12(1):63. https://doi.org/10.1186/s40594-025-00580-0
39. Luo R, Zhou Y (2024) The effectiveness of self-regulated learning strategies in higher education blended learning: A five years systematic review. J Comput Assist Learn 40(6):3005–3029. https://doi.org/10.1111/jcal.13052
40. Lyu Q, Chen W, Su J, Heng KH (2023) Collaborate like expert designers: An exploratory study of the role of individual preparation activity on students' collaborative learning. Internet High Educ 59:100920. https://doi.org/10.1016/j.iheduc.2023.100920
41. Madigan DJ, Kim LE (2021) Does teacher burnout affect students? A systematic review of its association with academic achievement and student-reported outcomes. Int J Educational Res 105:101714. https://doi.org/10.1016/j.ijer.2020.101714
42. Mahiri J (2026) Difference without deficits: culturally responsive SEL for diverse early learners of STEM. Multicultural Educ Rev 18(1):1–17. https://doi.org/10.1080/2005615X.2026.2618924
43. Mahoney JL, Weissberg RP, Greenberg MT, Dusenbury L, Jagers RJ, Niemi K, Schlinger M, Schlund J, Shriver TP, VanAusdal K, Yoder N (2021) Systemic social and emotional learning: Promoting educational success for all preschool to high school students. Am Psychol 76(7):1128–1142. https://doi.org/10.1037/amp0000701
44. Malterud K, Siersma VD, Guassora AD (2016) Sample Size in Qualitative Interview Studies. Qual Health Res 26(13):1753–1760. https://doi.org/10.1177/1049732315617444
45. Man R, Li J, Tan KM (2026) Educational disparities in STEM during COVID-induced distance learning and a potential strategy to address them. Nat Commun 17(1):3239. https://doi.org/10.1038/s41467-026-69925-9
46. Nalipay MJN, Huang B, Jong MSY, Chai CS, King RB (2024) Promoting STEM learning perseverance through recognizing communal goals: understanding the impact of empathy and citizenship. Int J STEM Educ 11(1):17. https://doi.org/10.1186/s40594-024-00471-w
47. Narla AV, Edwards MM, Bullard E, Petrie KL, Heinrichsen ET (2025) Classroom Interactions Facilitate a Sense of Belonging in Remote STEM Classes: Lessons from a Large-Scale Quantitative Study. J STEM Educ Res 8(3):387–407. https://doi.org/10.1007/s41979-024-00135-y

48. Olaifa KW, Elshikh M, Balgaliyeva A, Sagindykova E, Inegbedion E, Nussipzhanova G (2026) Bridging the AI divide in high school STEM education in developing countries to advance equity and innovation. Discover Educ 5(1):415. https://doi.org/10.1007/s44217-026-01437-6
49. Pal S, Mitra P, Mustak S, Bika SL, Pradhan B (2026) Global research trends in STEAM education: a bibliometric analysis. Discover Educ. https://doi.org/10.1007/s44217-026-01494-x
50. Pintrich PR, Marx RW, Boyle RA (1993) Beyond Cold Conceptual Change: The Role of Motivational Beliefs and Classroom Contextual Factors in the Process of Conceptual Change. Rev Educ Res 63(2):167–199. https://doi.org/10.3102/00346543063002167
51. Polesel J, Rice S, Dulfer N (2014) The impact of high-stakes testing on curriculum and pedagogy: a teacher perspective from Australia. J Educ Policy 29(5):640–657. https://doi.org/10.1080/02680939.2013.865082
52. Rocker Yoel S, Shwartz Asher D, Schohet M, Dori YJ (2020) The Effect of the FIRST Robotics Program on Its Graduates. Robotics 9(4):84. https://doi.org/10.3390/robotics9040084
53. Rozgonjuk D, Täht K, Soobard R, Teppo M, Rannikmäe M (2024) The S in STEM: gender differences in science anxiety and its relations with science test performance-related variables. Int J STEM Educ 11(1):45. https://doi.org/10.1186/s40594-024-00504-4
54. Salzman H, Douglas D, Khudododov K (2026) Reconceptualizing college STEM pathways: is leaving STEM the problem? J STEM Educ Res. https://doi.org/10.1007/s41979-025-00178-9
55. Sinatra GM (2005) The Warming Trend in Conceptual Change Research: The Legacy of Paul R. Pintrich. Educational Psychol 40(2):107–115. https://doi.org/10.1207/s15326985ep4002_5
56. Smith T, Avraamidou L, Adams JD (2022) Culturally relevant/responsive and sustaining pedagogies in science education: theoretical perspectives and curriculum implications. Cult Sci Edu 17(3):637–660. https://doi.org/10.1007/s11422-021-10082-4
57. Stefani A (2024) Parental and peer influence on STEM career persistence: From higher education to first job. Adv Life Course Res 62:100642. https://doi.org/10.1016/j.alcr.2024.100642
58. Sussman J, Wilson MR (2019) The Use and Validity of Standardized Achievement Tests for Evaluating New Curricular Interventions in Mathematics and Science. Am J Evaluation 40(2):190–213. https://doi.org/10.1177/1098214018767313
59. Swisher JL, Doyle LB (2024) The CASEL Framework and Christian Schools: Using a Hermeneutical Tool to Determine Worldview Alignment. J Res Christ Educ 33(1–2):40–57. https://doi.org/10.1080/10656219.2024.2345634
60. Toma RB, Yánez-Pérez I, Meneses-Villagrá JÁ (2024) Towards a Socio-Constructivist Didactic Model for Integrated STEM Education. Interchange 55(1):75–91. https://doi.org/10.1007/s10780-024-09513-2
61. Ulrich DL, Bregulla M (2024) The Relationship Between Self-Regulated Learning and Executive Functions—a Systematic Review. Educational Psychol Rev 36(3):95. https://doi.org/10.1007/s10648-024-09932-8
62. von der Embse NP, Pendergast LL, Segool N, Saeki E, Ryan S (2016) The influence of test-based accountability policies on school climate and teacher stress across four states. Teach Teacher Educ 59:492–502. https://doi.org/10.1016/j.tate.2016.07.013
63. Wadi M, Shorbagi A, Shorbagi S, Taha MH, Bahri Yusoff MS (2024) The impact of the Systematic Assessment for Resilience (SAR) framework on students' resilience, anxiety, depression, burnout, and academic-related stress: a quasi-experimental study. BMC Med Educ 24(1):506. https://doi.org/10.1186/s12909-024-05444-9
64. Zorwick MLW, Kinoshita V, Lassiter-Counts L, Moran M, MacDonald L (2024) Intentional scaffolding of advising, mentoring, and wise intervention programming in the 1st year experience promotes student resilience in the

face of a global pandemic: a case study of STEM student responses to college and COVID-19 stressors. Cult Sci Edu 19(4):647–673. https://doi.org/10.1007/s11422-024-10230-6

Tables

Table 1. The automated data-cleaning process

Metadata	Description	Missing Counts	Missing %	Status
AU	Author	0	0.00	Excellent
DT	Document Type	0	0.00	Excellent
SO	Journal	0	0.00	Excellent
LA	Language	0	0.00	Excellent
PY	Publication Year	0	0.00	Excellent
TI	Title	0	0.00	Excellent
TC	Total Citation	0	0.00	Excellent
AB	Abstract	1	0.09	Good
C1	Affiliation	10	0.88	Good
DI	DOI	146	12.90	Acceptable
DE	Keywords	204	18.02	Acceptable
RP	Corresponding Author	304	26.86	Poor
ID	Keywords Plus	667	58.92	Critical

Table 2. Most Relevant Publication Sources Based on Bradford's Law Core Zone

Sources	Rank	Freq	cumFreq
Asee Annual Conference and Exposition, Conference Proceedings	1	113	113
Education Sciences	2	41	154
Frontiers in Education	3	36	190
International Journal O]of Stem Education	4	26	216
Frontiers in Psychology	5	19	235
Proceedings - Frontiers in Education Conference	6	19	254
Sustainability (Switzerland)	7	17	271
Communications in Computer and Information Science	8	12	283
Cogent Education	9	11	294
International Journal of Technology and Design Education	10	11	305

Table 3. Top Influential Authors Based on Local Impact Metrics

Author	h_index	g_index	m_index	TC	NP	PY_start
Murphy Mc	6	6	0,75	931	6	2019
Canning Ea	5	5	0,625	855	5	2019
Maiorca C	5	5	0,833	144	5	2021
Muenks K	5	5	0,625	787	5	2019
Burton M	4	5	0,8	48	5	2022
Roberts T	4	4	0,667	135	4	2021
Tripp Lo	4	4	0,8	46	4	2022
Chen J	3	3	0,375	53	3	2019
Diekman Ab	3	3	0,375	103	3	2019
Esparza D	3	3	0,375	17	3	2019

Table 4. Summary of Data Extraction and Thematic Categorization using the PICO Framework

Authors	Population	Intervention	Comparison	Outcome
(Bawaneh et al., 2026)	114 Public School Teachers (K-12) in Jordan.	Online Questionnaire on STEM Pedagogy Integrated with CASEL Competencies.	Not Applicable (Survey Research/Internal Demographic Comparison).	STEM: Strong alignment of STEM instruction with the cells. SEL: Uniform and high level of teacher awareness (M=4.96/6).
(Gutierrez et al., 2025)	Nine rural junior high school students (and their families).	Interactive STEM Experiment (Tinkering) Activities at Home.	Not Applicable (Descriptive Case Study).	STEM: Stimulation of creativity and freedom of expression. SEL: Enhancement of collaboration, teamwork, and positive emotional expression.
(Manchanda et al., 2025)	8 Prospective STEM Secondary School Teachers in West Asia.	Application of the Transformative Cell (T-Cell) Framework in Teacher Preparation.	Not Applicable (Phenomenological Approach).	STEM: Tension between material delivery targets and emotional support practices. SEL: Considered essential for equity, yet implementation is hindered by time constraints.
(Silvis et al., 2026)	Children from 2 Kindergarten Classes (Tk).	Integrated Floor-Based CS-STEM Curriculum.	Not Applicable (Qualitative Interaction Analysis).	STEM: Active participation in the computing environment. SEL: Creation of a physical/emotional "comfort zone" and a sense of belonging.
(Mahiri, 2026)	11 Diverse Children Aged 4–5 at a Northern California Elementary School.	Lego Robotics After-School Program Featuring Culturally Responsive Pedagogy and SEL.	Not Applicable (Longitudinal Qualitative Research).	STEM: Capable of designing and programming robots at the level of 4th–5th grade students. SEL: Culturally responsive learning is well-established.
(Puslednik & Brennan, 2026)	32 High-Achieving Students (Grade 10) in Rural Australia.	Three-Year Authentic Research Mentor Program (ARMP)	Control Group (Students Without Mentoring Intervention).	STEM: Rapid improvement in scientific knowledge and problem-solving (ES: 0.81–1.57).

Authors	Population	Intervention	Comparison	Outcome
				SEL: Significant development in communication and social skills.
(Mercan et al., 2024)	Teachers and Preschool/Early Childhood Children.	Utilization of STEAM Makerspaces (Creative Spaces).	Not Applicable (Teacher's Qualitative Reflection).	STEM: Enhancement of cognition, imagination, and hands-on creativity. SEL: Development of a sense of belonging and self-confidence.
(Fields & Kafai, 2023)	8 Experienced High School Computer Science (CS) Teachers.	Implementation of an E-Textile-Based STEAM Curriculum.	Not Applicable (Teacher's Qualitative Reflection).	STEM: Successful Advocacy and Retention of the STEAM Program in Schools. SEL: Meeting Teachers' Emotional Needs Through Communities of Practice.
(Lee & Grapin, 2025)	K-12 Minority Groups (Multilingual Learners / MLs).	A Justice-Centered STEM Education Framework Based on Social Challenge Issues (e.g., COVID-19).	Not Applicable (Conceptual/Theoretical Paper).	STEM: Involvement of Data Science/CS in Designing Solutions for Social Issues. SEL: Cross-Language/Cultural Asset Validation and MLS Emotional Well-being.
(Garner et al., 2018)	Preschool/Young Children in After-School Programs.	STEAM-SEL Summer Curriculum (Integrating Art, STEM, and Emotional Skills).	Not Applicable (Qualitative Design Evaluation by Experts).	STEM: Increased appreciation of and interest in the application of science. SEL: Development of empathy (although experts assessed the cell design as lacking integration in terms of STEM).

Authors	Population	Intervention	Comparison	Outcome
(Mahiri et al., 2026)	11 Students (Transitional Kindergarten/Kindergarten, ages 4–5) in Northern California.	Project-Based/Play-Based Pedagogy Using Two Lego Robotics Kits.	Not Applicable (One-Year Academic Qualitative Observation).	STEM: Mastery of basic computing, structural assembly, and technology. SEL: Students fully manifest the five pillars of CASEL skills.
(Taylor & Glavey, 2024)	Students with Disabilities/Autism in Elementary School.	The Use of Robotics and Coding (Project Raise) in Inclusive Classrooms.	Not Applicable (Vignette Study/Practical Research).	STEM: Development of coding literacy, problem-solving, and 21st-century skills. SEL: Enhancement of independence, discussion skills, and socio-emotional engagement.
(Bonner et al., 2024)	108 adolescents (mean age 12 years) in South Miami.	The Think Program (6 Weeks): Integrating Nutrition, Fitness, STEM, and Cells.	Baseline vs. Post-Intervention (Pre-Post Test Design).	STEM: Physical Health Education/Stem Achieved. SEL: Significant Increase in the Positive Youth Development Index (PYDI).
(Allen et al., 2019)	1,599 students (grades 4–12) from 158 after-school programs across 11 U.S. states.	National STEM-Based After-School Program.	High-Quality vs. Low-Quality Program Interventions (Based on Observation).	STEM: 65–85% of students report increased engagement, career interest, and persistence. SEL: Strong correlation between STEM achievement and critical thinking/relational skills (Cell).
(Perry et al., 2025)	81 Junior High School Students in a Formal Classroom Setting (In-School).	Think Integrated Academic Curriculum (Focus on the Whole-Child Approach).	Baseline vs. End of Spring Semester (2019, 2021, 2023).	STEM: Increase in scientific knowledge regarding sports/nutrition and physical fitness. SEL: Cell surveys showed no significant changes during

Authors	Population	Intervention	Comparison	Outcome
				formal school hours.

Figures

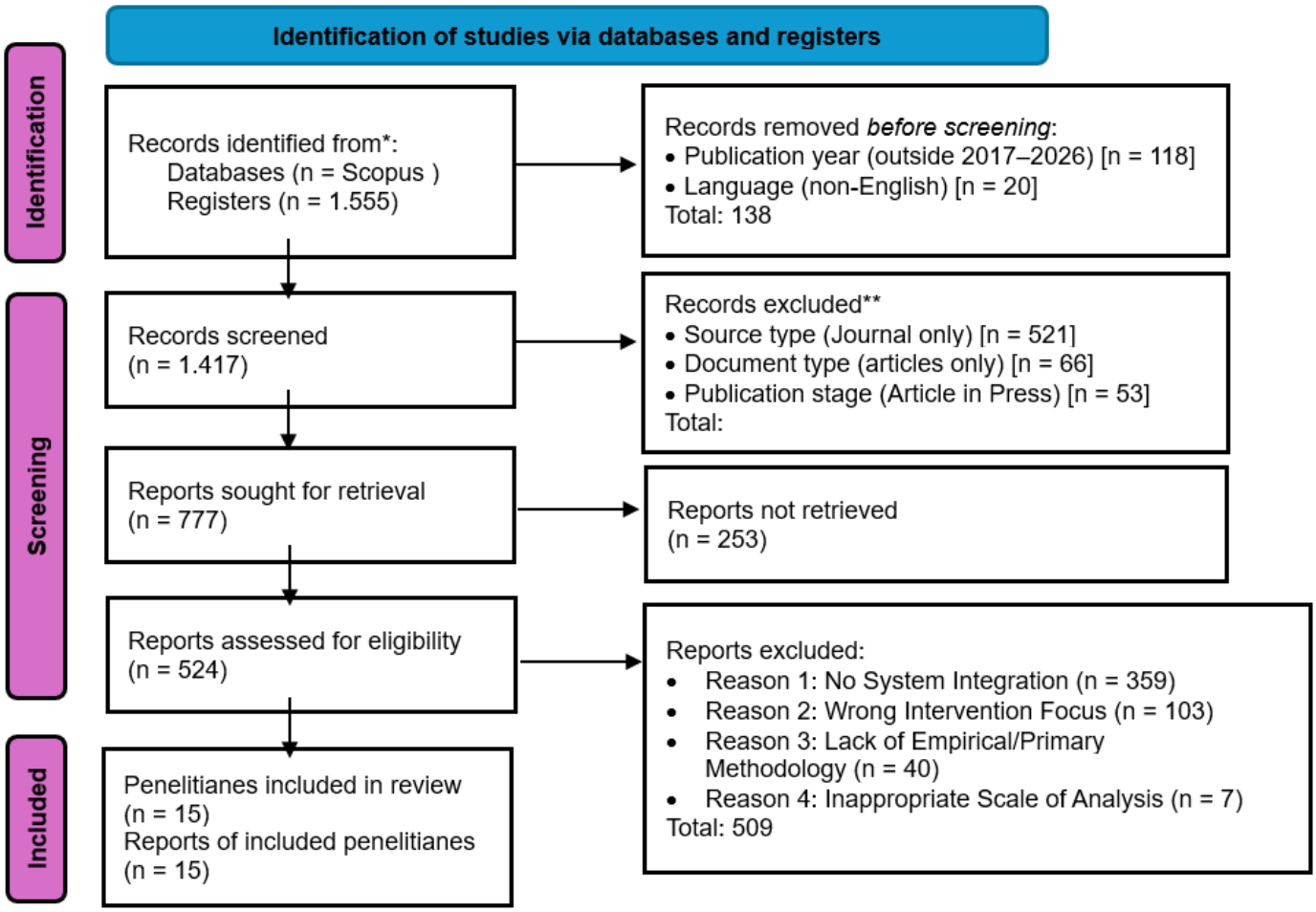


Figure 1

PRISMA Flow Diagram

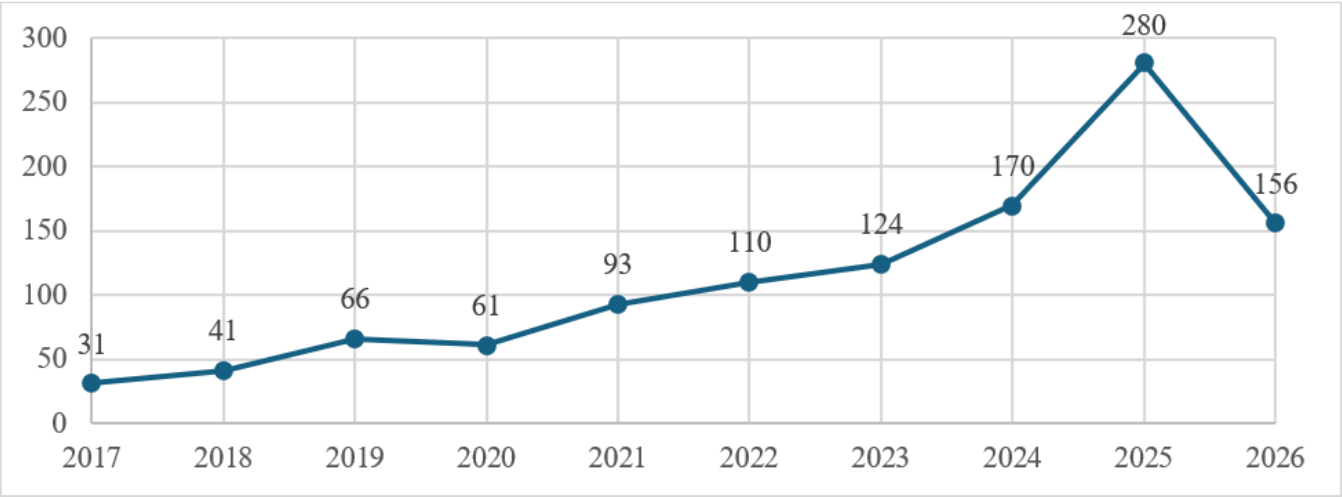


Figure 2

Annual Scientific Production Trend of STEM Education and SEL Research (2017–2026)

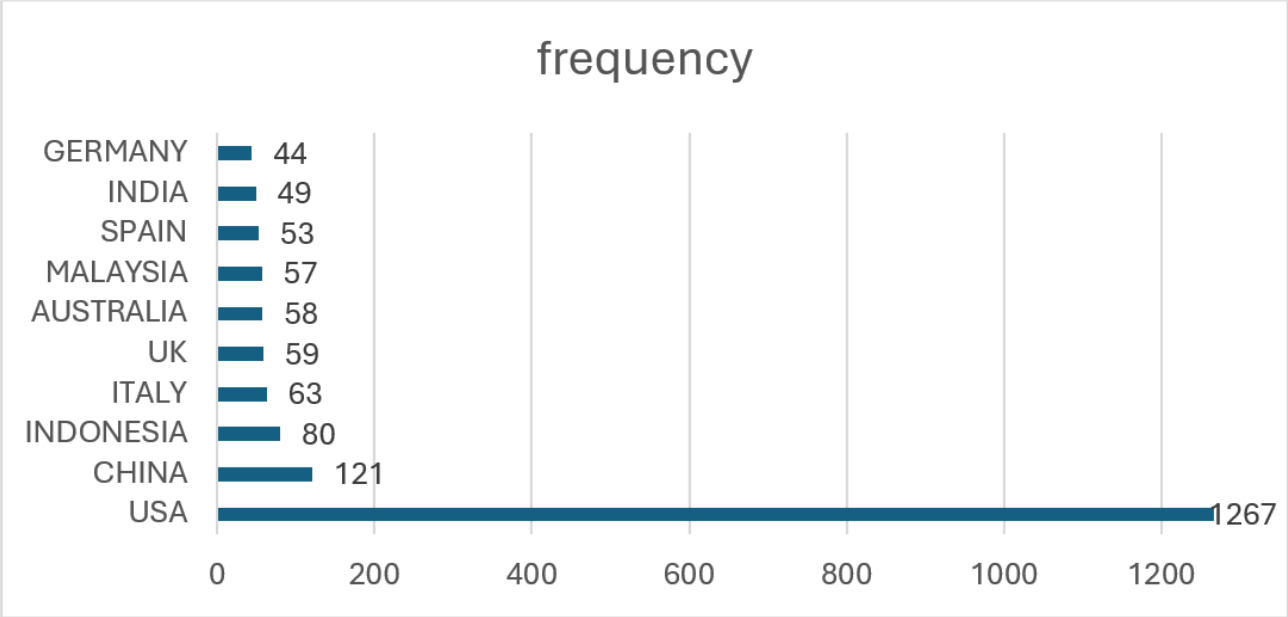


Figure 3

Countries' Scientific Production

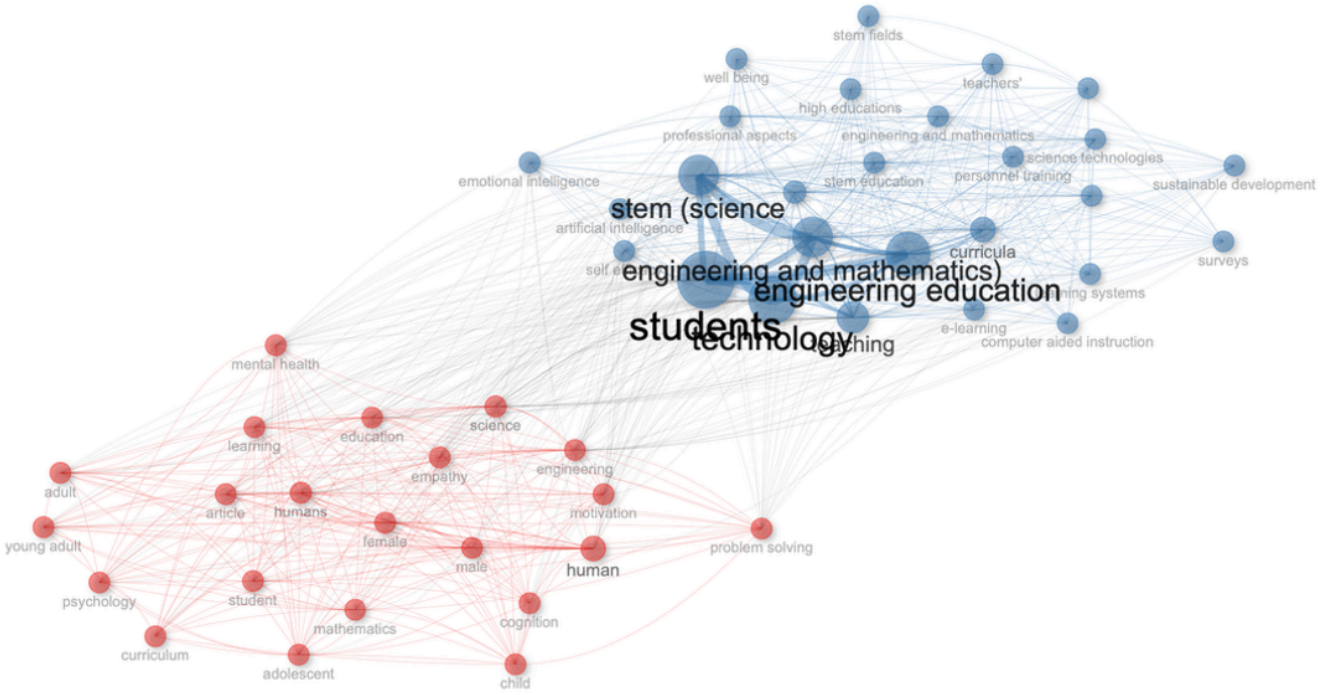


Figure 4

Keyword Co-occurrence Network Analysis in STEM and SEL Literature