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SDGs-Based STEM Learning Integration in Elementary School: a Systematic Literature Review

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Abstract. The integration of Sustainable Development Goals (SDGs) in Science, Technology, Engineering, and Mathematics (STEM) learning in Elementary Schools (SD/MI) is an important step to instill sustainability awareness, understanding of climate change, and critical thinking skills from an early age. This study aims to identify integration patterns, learning approaches, obstacles, and learning outcomes in the implementation of STEM-based SDGs in elementary education. The method used is a Systematic Literature Review (SLR) with reference to the PRISMA 2020 protocol. Literature was obtained from Scopus, Web of Science, ERIC, and Google Scholar databases in the period 2015–2025. The results of the study indicate that the integration of SDGs in STEM learning can direct science education not only to mastery of skills, but also the formation of global citizens who care about sustainability. Optimal implementation requires collaborative teacher training, a contextual curriculum, and a holistic formative assessment system.

Keywords: SDGs, STEM, elementary school, SLR, sustainability education.

INTRODUCTION

The United Nations (UN) 2030 Agenda for Sustainable Development, has triggered a massive realignment across various sectors of the global order, with education identified as one of the most transformative pillars (Qablan et al., 2025). Within this global framework, Sustainable Development Goal 4 (SDG 4) which calls for inclusive, equitable, and quality education that promotes lifelong learning opportunities serves not only as a standalone goal but also as a fundamental prerequisite and overarching objective for achieving the other sixteen goals (Durrani et al., 2023). More specifically, SDG 4.7 explicitly emphasizes the obligation of the global education system to ensure that all learners acquire the knowledge and skills necessary to promote sustainable development, adopt sustainable lifestyles, respect human rights, and foster active global citizenship (Stouthart et al., 2025). In this context, education is no longer viewed merely as a means of transmitting static knowledge, but rather as a key instrument for mitigating global existential crises, such as climate change (SDG 13), the clean water crisis (SDG 6), and the degradation of terrestrial ecosystems (SDG 15) (Bascopé & Reiss, 2021; Holley & Park, 2020; Zidny & Eilks, 2022).

In line with these global demands, the pedagogical landscape of Science, Technology, Engineering, and Mathematics (STEM) has undergone a significant philosophical evolution over the past decade. Historically, STEM education has often been conceptualized through a utilitarian and instrumental lens, with its objectives limited to creating an economically competitive workforce to meet the demands of the Fourth Industrial Revolution (Candan Helvaci & Helvaci, 2019; McCance et al., 2021). However, contemporary educational literature indicates a significant paradigm shift toward reconceptualizing STEM as a transdisciplinary framework approach focused on solving real-world “wicked problems” (Kopbossyn et al., 2025; Ku et al., 2025). This transformation has given rise to a conceptual convergence between STEM education and Education for Sustainable Development (ESD), an intersection that shifts the focus of learning from the accumulation of isolated scientific facts toward the engineering of socio-ecological solutions (Aswirna et al., 2022; Littrell et al., 2020; Nida et al., 2021). Through this integration, the analytical skills, engineering design, and mathematical rigor of the STEM disciplines are harnessed to address sustainability goals (Brase et al., 2025).

Although the concept of STEM-ESD has gained significant traction at the secondary and higher education levels, the urgency of its implementation at the elementary school level (SD/MI) is increasingly being recognized by experts in cognitive development and educational scientists (Kim & Kim, 2020; Tuğba Abanoz & Defne Yabaş, 2025). Middle childhood (ages 6 to 12) is widely recognized as a critical period of psychological development, during which ethical values, ecological identity, and an understanding of the universe’s causality begin to take root permanently in a child’s cognitive framework (Tuğba Abanoz & Defne Yabaş, 2025). Children in this concrete operational stage possess innate curiosity and a tremendous capacity for empathy. Integrating sustainability principles into STEM education at this age prevents the development of "eco-anxiety," which often paralyzes the younger generation, and instead empowers them with behavioral agency. (Ellington & Prado, 2024; Kang & Tolppanen, 2024). Hands-on learning at the elementary level such as building simple renewable energy prototypes or monitoring local water quality bridges the gap between abstract theory and empirical reality, enabling children to see themselves not as victims of future environmental degradation, but as architects of planetary stewardship (Izzah et al., 2023; Jefferson et al., 2020; Kopbossyn et al., 2025).

Objectives and Research Question (RQ)

This systematic literature review was designed to analyze, evaluate, and synthesize the global body of empirical literature on the implementation of SDG-based STEM education at the elementary school level over the past decade (2015–2025). Specifically, this study was designed to address the following two core research questions:

RQ1: How are the Sustainable Development Goals (SDGs) integrated into the STEM education ecosystem in elementary schools and Islamic elementary schools, as reflected in global literature published between 2015 and 2025?

RQ2: What pedagogical approaches were employed, what instructional and institutional barriers were encountered, and what specific learning outcomes were reported as a result of these integration efforts?

The answers to these questions are expected not only to enrich the theoretical foundation of the discourse on sustainability education, but also to provide actionable operational parameters for practitioners, curriculum developers, and education policymakers.

METHODS

This study was designed and conducted using the Systematic Literature Review (SLR) method. This methodology was chosen for its academically recognized ability to identify, critically evaluate, and synthesize findings from all relevant, high-quality primary studies to provide an unbiased overview of the phenomenon under investigation. The design of this review protocol strictly adheres to the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) international reporting guidelines, which ensure absolute transparency, comprehensiveness, and replicability in every phase of the screening process (Kopbossyn et al., 2025; Lestari et al., 2025; Nida et al., 2021).

To ensure that the collected literature is globally representative, spans various disciplines, and possesses the highest scientific credibility, the information search strategy was conducted across four reputable academic databases: Scopus, Web of Science (WoS), ERIC (Education Resources Information Center), and Google Scholar. Scopus and WoS were used as the primary anchors to capture international peer-reviewed literature with high impact factors. ERIC was specifically included due to its depth in educational research and practical pedagogy. Meanwhile, Google Scholar is utilized precisely to capture primary studies and highly indexed regional publications (such as SINTA-accredited journals in Indonesia) that might otherwise be overlooked by centralized databases but offer rich empirical insights from developing countries (Cole et al., 2024; Ku et al., 2025; Lestari et al., 2025).

The search was limited to publications from January 1, 2015, through early 2025. This timeframe was strategically chosen to coincide with the United Nations' official adoption of the 2030 Agenda and the SDGs in late 2015, which marked the beginning of a massive shift in global ESD research (Liu et al., 2024; Qablan et al., 2025; Zidny & Eilks, 2022).

Search keywords are formulated into complex Boolean string structures to ensure the sensitivity and specificity of document retrieval. The basic search strings adapted across the database interface are as follows: ("SDGs" OR "Sustainable Development Goals" OR "sustainability" OR "sustainability education" OR "ESD") AND ("STEM" OR 'STEAM' OR "integrated STEM") AND ("elementary school" OR "primary school" OR "sekolah dasar" OR "SD/MI" OR "elementary education") (Kopbossyn et al., 2025; Lestari et al., 2025; Qablan et al., 2025).

The literature screening process was based on a set of inclusion and exclusion criteria formulated to precisely address the research questions. The inclusion criteria required that (1) the research subjects focus exclusively on the elementary school level (SD/MI) or students aged 6 to 12 years, (2) the reported instructional design or materials must explicitly integrate at least one target of the Sustainable Development Goals into STEM education, and (3) the article must be an empirical study published in an academic journal through a peer-review process. Conversely, literature was excluded from the review if the study included a mixed population without clear data separation for elementary school students, was conducted at the secondary or higher education levels, or consisted of grey literature or non-peer-reviewed documents such as unindexed conference proceedings (Besalti & Smith, 2024; Kopbossyn et al., 2025; Lestari et al., 2025).

The final stage of the methodology relies on thematic synthesis and narrative synthesis techniques. Following textual analysis guidelines, the coding process was conducted inductively on a line-by-line basis for the results and discussion sections of each article. These descriptive codes were then recategorized, cross-checked, and combined into higher-order themes specifically designed to dissect patterns, pedagogical approaches, outcomes, and barriers that directly align with the formulation of RQ1 and RQ2 (Kopbossyn et al., 2025; Liu et al., 2024).

PRISMA Selection Results

The systematic implementation of the search strategy yielded a measurable screening record, which was visualized using the PRISMA 2020 reporting guidelines. Literature extraction during the identification phase from four databases (Scopus, Web of Science, ERIC, Google Scholar) yielded a total of 1,227 potential records relevant to the keywords “SDG integration” and “STEM.” The first crucial step involved using state-of-the-art reference management software to perform data cleaning (deduplication), which detected and removed 403 cross-database duplicates, leaving 824 unique articles for the initial screening phase.

During the title- and abstract-based screening phase, a critical review was conducted to ensure demographic and thematic alignment. A total of 638 records were excluded from the analysis because they explicitly focused on higher education students, high school students, or merely mentioned the term “sustainability” as an afterthought without methodological treatment within the STEM education framework. This process resulted in a sharp narrowing down to 186 articles retrieved in full text for comprehensive feasibility evaluation.

The full-text review phase is the most rigorous stage of the screening process. A total of 137 articles were excluded for various reasons: failure to meet the threshold score on the MMAT/CASP quality assessment (due to biased experimental design or the absence of empirical instrument validation), the use of mixed-population samples without the ability to isolate specific analytical data for the elementary school subgroup, or being brief conference proceedings reports without full peer review. The final outcome of this screening process yielded 49 high-quality empirical studies that met all inclusion criteria and were submitted for thematic extraction and synthesis.

The following flowchart adapts the PRISMA 2020 reporting guidelines (Page et al., 2021) to visualize the entire flow of article exclusion and inclusion from the initial literature search stage through to final data extraction.

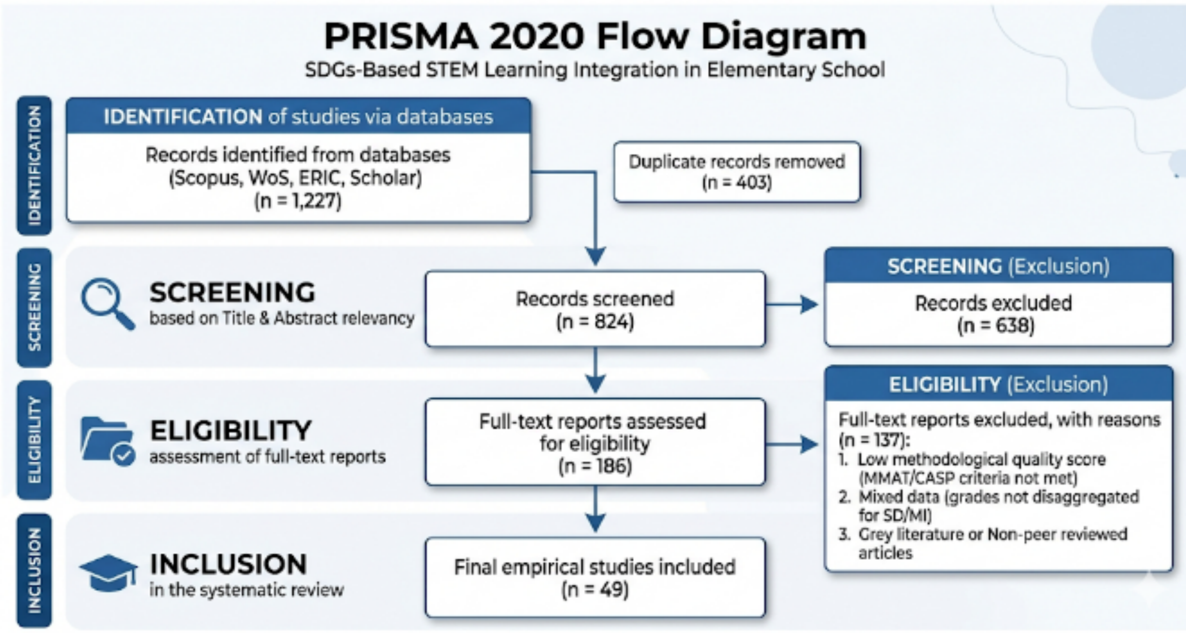

Figure 1. PRISMA 2020 Flowchart for the Study Selection Process

RESULTS AND DISCUSION

Characteristics of the Study

Based on the 49 synthesized studies, which represent a wealth of geographical diversity, it is evident that the integration of the SDGs into basic STEM education is a cross-border phenomenon, although its adoption is shaped by local contexts. The highest concentration of research originates from Asia (particularly Indonesia, China, and Vietnam, which are accelerating 21st Century Skills curriculum reforms), the United States, and Western Europe (such as Spain, Germany, and the United Kingdom). Methodologically, the dominance of mixed-methods and qualitative case study designs indicates a current global academic focus that emphasizes the process of internalizing an understanding of sustainability, rather than merely high-stakes testing scores.

The following table extracts and summarizes the 15 most seminal and representative studies from the final collection, providing a panoramic view of how the SDGs are implemented in elementary school STEM classrooms.

Table 1. The SDGs are implemented in primary school STEM classrooms.

Authors & Year	Country	Methodological Design	SDGs Goals	Key Findings & Supporting Pedagogical Outcomes
Qablan et al., 2025	Uni Emirat Arab	Qualitative / Curriculum Document Analysis	SDG 4, 6, 8, 15	SDG representation is dominated by SDG 4. There is a significant gap; SDG 6 (Water) and 8 (Economy) rarely appear in the primary school curriculum.
Aswirna et al., 2022	Indonesia	Mixed Methods / Quasi-Experimental	SDG 4, 13	The PjBL-based STEM e-module enhances elementary school students' critical thinking skills with a very large effect size.
Littrell et al., 2020	United States	Mixed Methods	SDG 13	Place-Based Environmental Education (PBEE) interventions foster climate awareness and the development of local civic literacy.
Maass et al., 2022	German/English	Qualitative / Exploratory Review	SDG 4, 11	Mathematical modeling in the STEM curriculum is essential for fostering responsible citizenship in the evaluation of sustainability data.
Candan Helvaci & Helvaci, 2019	Turki	Exploratory Qualitative	SDG 12, 15	The E-STEM (Environmental STEM) “Waste Management” project for lower-middle school students fosters a holistic appreciation of the practical applications of science and ecology.
Pramasdyahsari et al., 2024	Indonesia	Mixed Methods	Lintas SDG (Holistik)	The innovative Ethno-STEM program and local wisdom effectively translate abstract macro-ecological issues into concrete conservation actions rooted in cultural identity.

Georgiou & Kyza, 2023	Cyprus	Quantitative / Experimental	Lintas SDG (Holistik)	The Socio-Scientific Inquiry-Based Learning (SSIBL) approach facilitates the development of students' ethical reasoning and pro-environmental chemistry literacy.
Herodotou et al., 2024	English	Qualitative Case Study	SDG 4	The Design Thinking framework has proven to be effective, but it is limited by the lack of instructional technology and the short duration of the learning sessions.
Dung et al., 2023	Vietnam	Research & Development (R&D)	SDG 9, 13	The integration of the engineering design process fosters inventive creativity in developing locally-based low-carbon solutions.
Zhu & He, 2022	China	Quantitative / Quasi	SDG 15	Teaching the Claim-Evidence-Reasoning model specifically in relation to ecological issues strengthens students' cognitive resilience in engaging in rational debate.
Cole et al., 2024	Europe	Review / Qualitative	SDG 4, 13	Modeling social-ecological systems helps students understand the feedback loops between consumer decisions and environmental impacts.
Ellington & Prado, 2024	United State	Case Study / Observational	SDG 15	Outdoor learning in marginalized communities helps bridge the gap in access to science and foster a sense of STEM identity.
Lestari et al., 2025	Indonesia	SLR / Narrative	SDG 13	Problem-Based Learning (PBL-STEM) has been shown to consistently link data-driven analytical thinking with sustainability awareness.
Kim et al., 2023	South Korea	Quantitative / Game Experiment	SDG 7, 11	Game-based technology and digital simulations are effective at improving attention span, but they require strong teacher support to ensure that cognitive depth is not compromised.
Sezen-Barrie et al., 2023	United State	Qualitative / Design-Based	SDG 13	Students' modeling practices and generative questions can reveal gaps in teachers' understanding and prompt iterative improvements in the presentation of environmental content.

Thematic Findings Based on RQ1 & RQ2

An analytical synthesis of the literature reveals multi-layered insights into the pedagogical architecture of STEM-SDG integration in elementary schools. The extraction of these themes is systematically designed to examine patterns, strategies, and practical challenges.

Theme 1: Models for Integrating the SDGs into the STEM Ecosystem

A review of the literature reveals that the integration of the 17 SDGs into the elementary STEM curriculum is neither symmetrical nor evenly distributed. Rather than embracing all pillars of sustainability (economic, social, and environmental) in a balanced manner, educators and curriculum developers demonstrate a strong methodological tendency to anchor their work on specific pillars that are cognitively more aligned with the concrete reasoning of elementary school students.

The Dominance of the Ecological and Physical Environment Axis (SDGs 13, 15, and 6):

Environmental literacy absolutely dominates the STEM curriculum at the elementary school level. The most extensive instructional designs are anchored in the fulfillment of SDG 13 (Climate Action) and SDG 15 (Terrestrial Ecosystems). The natural affinity between the natural sciences (biology, physical geography, earth science) and ecological conservation themes makes these two SDGs the most logical catalysts in the classroom. The literature indicates that educators often stimulate understanding of pure mathematics and computational STEM through SDG 13, for example by assigning students to analyze trends in school temperature sensor data, which transforms abstract numerical data into a tangible discourse on extreme weather. Similarly, SDG 6 (Access to Clean Water and Sanitation) serves as the primary framework for integrating engineering processes. In empirical studies (e.g., in peatland areas or urban communities), elementary school students no longer learn about pH or the separation of mixtures theoretically, but rather through PjBL projects assembling prototype water filtration systems from natural biomass materials, which combine materials engineering with concern for the real-world clean water crisis.

SDG 4 as a Universal Meta-Goal:

Interestingly, SDG 4 (Quality Education) functions not merely as a target, but as the fundamental conceptual foundation of a meta-goal for the integrative STEM education framework itself. The literature frames many STEM interventions—particularly those that promote digital literacy, address gender bias in girls' participation in science, and prioritize social justice-based learning—as direct manifestations of the mandates of SDGs 4.5 and 4.7. This demonstrates that effective STEM integration is considered inherently sustainable if it expands cognitive equity.

Gaps in the Macroeconomic Dimension (SDGs 8 and 9):

The literature review also highlights a significant blind spot: the lack of representation of the economic dimension of sustainability. Goals such as SDG 8 (Decent Work and Economic Growth), SDG 1 (No Poverty), or SDG 9 (Industry, Innovation, and Infrastructure) are systematically underrepresented or completely overlooked in elementary school curricula. Concepts such as green inflation, technological material supply chain justice, or the circular economy model are viewed by curriculum designers as concepts that are too cognitively abstract or too detached from basic natural sciences, so that this debate only emerges separately at the upper secondary school level.

Theme 2: Pedagogical Learning Approaches

In addressing the multidimensional nature of the sustainability discourse, the literature highlights the shift away from teacher-centered didactic instruction. The four pillars of constructivist pedagogy dominate implementation in elementary schools:

1. **Project-Based Learning (PjBL) and the Engineering Design Cycle**
   PjBL and engineering serve as the backbone of the pedagogical architecture for more than half of the studies analyzed. At the elementary level, STEM transforms into an inventive process. Through the iterative engineering design process (formulating sustainability problems, sketching ideas, testing materials, assembling prototypes, evaluating results), students are positioned as problem-solving engineers. This practice requires students to apply algebra, proportions, and materials science simultaneously. As a prime example, exploring the creation of packaging from biodegradable bioplastics (targeting SDG 12) or designing autonomous agricultural systems (SDGs 2 and 15) allows mathematics and science to be operationalized as tools for ecological defense, fostering strong cognitive

retention due to their significance.

2. **Socio-Scientific Issues (SSI) and Ethics-Based Argumentation**
   The SSI curriculum deliberately introduces real-world dilemmas with no single correct answer into science lessons to foster critical systems thinking. In the context of children aged 6–12, the arguments are simplified yet remain morally thought-provoking. For example, evaluating land-use decisions between the need for local agricultural land versus the conservation of endemic species (SDG 15). This intervention educates students using the Claim-Evidence-Reasoning rubric, compelling them to weigh empirical scientific evidence to justify their environmental moral compass, thereby significantly bridging the gap between technical science and social citizenship.
3. **Place-Based Environmental Education (PBEE) and the Ethno-STEM Paradigm**
   Recognizing children's limited capacity for abstraction, studies in rural, coastal, and multicultural urban settings consistently utilize the school's physical environment as an open-air laboratory. They ground the narrative of global carbon emissions in the practical activities of calculating and planting tree cover along local riverbanks. In line with this, the emergence of Ethno-STEM and indigenous knowledge plays an unparalleled transformational role within specific communities. The integration of cultural wisdom technologies does not merely reflect students' identities, but deconstructs the myth that science is an exclusive Western elite activity, making it a practice of stewardship of nature that is deeply rooted in the sociocultural fabric of their own communities.
4. **System Modeling and Game-Based Learning (Digital Simulation)**
   The use of digital computing ranging from carbon footprint calculators to simulation games for smart urban planning and simple computer-controlled robotics (such as micro:bit sensors or basic Arduino projects) is on the rise. These representational models foster students' computational thinking, enabling young learners to represent climate ecosystems (socio-ecological systems) through algorithmic interactions, thereby revealing microscopic feedback loops that are impossible to observe directly with the naked eye.

Theme 3: Learning Outcomes and Institutional Barriers

Transformative Learning Outcomes:

An analysis of the data reveals that this holistic integration yields cognitive and behavioral benefits that go beyond those of a single-discipline curriculum:

1. Expansion of Cognitive Domains: There was a consistent improvement with large statistical effect sizes on standardized science inference tests, the ability to analyze data anomalies, and scientific reasoning. Students demonstrate a transition from passive factual knowledge toward mastery of "Systems Thinking," recognizing the interconnectivity between mechanical actions (technology/industry) and biological consequences (the environment).
2. Affective Revolution and Biospheric Values: Contextualized PjBL learning drastically eliminates math phobia and boredom with science. This instills Utility Value—the students' perception that STEM disciplines are protective instruments for their vulnerable communities, not merely exam theory. This integration has also been shown to build group cohesion and empathy for intergenerational justice.
3. Acceleration of Behavioral Agency: Perhaps the most valuable achievement is this educational framework's ability to mitigate the eco-anxiety crisis. Rather than feeling hopeless about planetary damage, the literature indicates that students develop agency: a psychological conviction, reinforced by methodological capacity, that they are capable of designing concrete technology-based interventions, which transform concern into future-oriented leadership (future thinking).

Barriers and Challenges to Implementation:

Despite its idealistic vision, the path to implementing SDG education at the elementary level is fraught with severe pedagogical and technical challenges:

1. The Crisis in Primary School Teachers' Pedagogical Content Knowledge (PCK): The greatest and most persistent barrier is consistently reported across countries. Elementary school teachers with non-science backgrounds (as generalists) feel intellectually overwhelmed when trying to communicate complex phenomena such as thermodynamic fusion or marine biochemistry, and then weave

them in real time into mathematical modeling and discussions of social justice. This lack of subject matter knowledge often causes teachers to fall back on superficial lectures about "don't litter," undermining the very pillars of engineering and STEM reasoning.
2. Cognitive Overload and digital distractions: Introducing climate literacy through digital simulation systems often presents cognitive challenges. The lack of rigorous scaffolding from instructors leads children to engage with simulation games superficially, focusing on visual aesthetics rather than extracting fundamental epistemic understanding, which ultimately hinders knowledge transfer.
3. Conflict with the Assessment System (High-Stakes Testing): Bureaucratic systems and multiple-choice-based standardized evaluation regimes are completely at odds with the PjBL model or the multidimensional SSI framework. The bureaucracy's failure to adopt portfolio-oriented rubric assessment tools or project iterations forces teachers to halt innovative activities and revert to a mechanical drill-and-practice curriculum as the school exam season approaches.
4. Infrastructure Equity Disparities: Equity in access to essential technologies for sustainable education (access to smart education hardware, microcontrollers, environmental kits, and even stable internet connectivity) remains an acute structural barrier, particularly in low-income or rural community schools in the developing world. Expecting engineering innovation in this climate of scarcity actually jeopardizes the very goal of SDG 4 (educational inclusion) itself.

DISCUSSION

Interpretation of Findings Regarding the RQ and Theoretical Comparison

The convergence of SDG goals within the framework of STEM in elementary education is a tangible manifestation of a radical shift in the ontology of science education. For decades, the epistemology of STEM education has been dominated by a technocratic-reductionist approach; disciplines were taught in a fragmented manner within academic "silos," with the view that technological progress itself is value-neutral and inevitable (Candan Helvaci & Helvaci, 2019; Liu et al., 2024). The results of our review fundamentally refute this historical doctrine. This dismantling of silos is methodologically aligned with Vygotsky's Sociocultural Theory and the framework of Social Constructivism, in which the internalization of laws of mechanics or botany does not occur through one-way transmission, but is constructed dialectically as students strive to give moral justice and concrete utility to these tools. For example, by creating technology for drought survivors or measuring damage to local rivers (Candan Helvaci & Helvaci, 2019; Ku et al., 2025; Zhu & He, 2022).

Cognitively, the implementation of Place-Based Education and experiential design aligns with the processing needs of elementary school students who are in the "concrete operational" stage according to Piaget's framework. The abstraction of the climate is materialized into sensory experiences (soil, water, weather, physical models) that can be directly manipulated both kinesthetically and analytically, creating a direct link between children's motor actions and the consequences of real-world ecological systems (Ellington & Prado, 2024; O'Neill et al., 2024; Tuğba Abanoz & Defne Yabaş, 2025). The absence of the circular economy dimension (SDGs 8 and 9) in the current curriculum clearly indicates that this integration is still in a transitional phase, with a strong focus on the ethics of pure conservation environmentalism. Curriculum experts may view the circular economy as a secondary conceptual burden that can only be fully grasped at higher levels of education (Bascopé & Reiss, 2021; Cole et al., 2024; Zidny & Eilks, 2022).

Theoretical Implications: Contributions to the Body of Knowledge on the SDGs–STEM Nexus

The synthesis of empirical findings in this literature offers a critical intervention in the body of pedagogical knowledge. To date, the discourse on educational pedagogy has relied heavily on the Technological Pedagogical Content Knowledge (TPACK) model in training prospective educators. However, consistent findings regarding persistent instructional barriers among elementary school teachers demonstrate that individual competency autonomy is entirely insufficient when addressing cross-spectrum debates on empirical science, global sustainability, and human ethics. This SLR proposes a shift in theoretical focus toward mastering Collective Pedagogical Content Knowledge for Sustainable Development (C-PCK-SD) (Forsler et al., 2024; Wang et al., 2025). This new lens posits that successful integration does not rely on a "super-teacher," but rather on an ecosystem of group practices (co-teaching and collaborative communities across teachers) that piece together a mosaic of disciplinary knowledge and pedagogical ethics for students (Kopbossyn et al., 2025; Pramasdyahsari et al., 2024).

Furthermore, the findings of this review revitalize the epistemology of Socio-Scientific Issues (SSI). The SSI approach for ages 6–12 has proven to be more than just a means of honing verbal skills or merely discussing moral values. The systematic staging of scientific conflicts functions as a "generator of critical literacy." By directly confronting infrastructure optimization metrics with habitat conservation parameters, students recognize that scientific methodology is always subject to ethical constraints and socio-cultural compromises (Alcaraz-Dominguez & Barajas, 2021; Kopbossyn et al., 2025; Maass et al., 2022). This undermines the doctrine of pure positivism in schools.

Practical Implications: Recommendations for Stakeholders

The challenges and successes identified in the implementation process call for institutional reform at various levels of stakeholders:

1. **Micro Level (Teachers and Education Practitioners):** Elementary school teachers must definitively move away from an authoritarian role in the dissemination of scientific facts. Practitioners are strongly encouraged to adopt a strategy of contextualization, translating global macroecological abstractions into interventions within the immediate local community (PBEE and Ethno-STEM). Global physical phenomena are contextualized through indigenous knowledge or the students' own socio-demographic dynamics (Zhu & He, 2022). In addition, cognitive scaffolding must be firmly integrated when using advanced simulation technology or carbon footprint calculators (low-cost green kits), guiding students' spatial attention toward systemic cause-and-effect patterns rather than visual entertainment (Pramasdyahsari et al., 2024). Student evaluation must also shift to a multidimensional portfolio assessment format and a Claim-Evidence-Reasoning rubric, which legitimizes the trial-and-error process of prototype design (Kopbossyn et al., 2025).
2. **Meso Level (School Administration and Professional Development):** School administrators and principals must redesign mechanistic scheduling models. Sustainable STEM projects that require cycles of ideation, empirical testing, iteration, and outreach campaigns require a flexible block scheduling infrastructure to eliminate the cognitive fragmentation inherent in conventional hour-by-hour class schedules. (Pynes et al., 2025; Wang et al., 2025). Schools must reallocate their budgets to establish periodic professional development (PD) programs based on group reflective analysis, specifically focused on C-PCK and climate change literacy for generalist teachers (Forsler et al., 2024; Wang et al., 2025).
3. **Macro Level (Policy Makers and National Curriculum Development):** Future developers of elementary science curricula must avoid treating the SDGs merely as "add-ons." Instead, sustainability goals should be structured as epistemological anchors around which arithmetic skills, basic algorithms, empirical biological observations, and integrated citizenship are woven to address a common thread of crisis (Ku et al., 2025; Pynes et al., 2025; Wang et al., 2025). It is crucial for the government to bridge the infrastructure gap by ensuring affordable access to low-emission eco-friendly solutions in underserved areas, in order to fulfill the commitment to equity and inclusion under SDG 4 (Kopbossyn et al., 2025). Policymakers should also explore transition models to incorporatethe fundamental principles of the circular economy into the ecological discourse (SDG 8, 9, 12).

Limitations of the Systematic Review

The empirical robustness of the PRISMA-based SLR protocol does not obscure the inherent limitations of this literature review, which call for caution in drawing generalizations. First, the threat of publication bias, where the international journal ecosystem has a strong tendency to favor the publication of PjBL- or STEM-ESD-based research reports that demonstrate dramatic improvements in learning outcomes, while pedagogical intervention experiments that fail to stimulate cognitive growth are rarely published (the file drawer problem) (Cole et al., 2024).

Second, limiting the linguistic criteria to publications in English and Indonesian solely to accommodate the local perspectives of the target regions may result in the exclusion of substantial breakthroughs in the academic literature from Germany, Spain, and the Nordic countries (Scandinavia) regions that, notably, hold a legacy of global leadership in research on Outdoor Environmental Education (friluftsliv) (O'Neill et al., 2024; Spencer et al., 2022). Third, from a methodological perspective, the majority of the primary literature reviewed evaluates the effectiveness of the STEM-SDGs approach based on short-term cross-sectional data or one-semester quasi-experimental studies. This limits our ability to confirm the theoretical claim that the commitment to biospheric values instilled in these pre-adolescents persists (longitudinal retention) as they mature (Kang & Tolppanen, 2024).

CONCLUSION

A comprehensive systematic literature review confirms that the integration of the universal framework of the Sustainable Development Goals (SDGs) with the Science, Technology, Engineering, and Mathematics (STEM) framework at the elementary level (elementary school/MI) catalyzes more than just a theoretical fusion of methodologies. It presents an epistemological turning point that reconceptualizes elementary school science from the passive acquisition of mechanistic ecological vocabulary into an instrument for collective planetary rescue and participatory sociopolitical agency.

By extracting empirical realities from a decade of global research, we frame definitive conclusions for two main research questions:

(Answering RQ1): The architecture of SDG integration is uneven, substantially centered on the fulfillment of specific environmental rescue imperatives: mitigation under SDG 13 (Climate), halting degradation under SDG 15 (Land), and optimizing the conservation of essential water engineering resources under SDG 6. SDG 4 (Quality Education) uniquely guides the overarching narrative of this entire movement as the foundation for global equity. Gaps in narrative representation regarding the circularity of economic infrastructure (SDGs 8 and 9) highlight a reluctance to adapt discourse to the complexities of early childhood.

(Answering RQ2): The highest level of conceptual understanding is achieved when conventional dogmatic instruction is replaced with meaningful creation pedagogy. The formulation of PjBL (Project-Based Learning) in design engineering, the confrontation of moral debates through discourse on Socio-Scientific Issues (SSI), and the grounding of observations in the local ecological context specific to children's culture through Place-Based and Ethno-STEM approaches emerge as the most reliable mechanisms. This methodology successfully achieves a quantum leap in students' cognitive outcomes specifically Systems Thinking and epistemic scientific literacy accompanied by the emergence of resilient pro-environmental agency against eco-anxiety. Nevertheless, the momentum of this educational transition is sharply hindered by the lack of teachers' Pedagogical Content Knowledge, the inflexibility of standardized testing within a bureaucratic system that stifles iterative problem-solving, and the discriminatory gap in access to basic technological simulation infrastructure.

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