Macrothink Institute™

International Journal of Social Science Research
ISSN 2327-5510
2025, Vol. 13, No. 1

Incorporating Environmental Elements in Learning STEM: A Systematic Literature Review

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Received: July 20, 2024 Accepted: September 28, 2024 Published: October 30, 2024

doi:10.5296/ijssr.v12i2.22353 URL: https://doi.org/10.5296/ijssr.v12i2.22353

Abstract

Incorporating environmental elements in STEM learning can foster a deeper understanding of living world issues and promote sustainable solutions. The study's inclusion criteria consisted of empirical articles in English aligned with research questions published in a scholarly journal between 2007 and 2023. Participants included students and pre-service teachers. After quality assessment using PRISMA procedures, 18 eligible studies were identified in this systematic review. Thematic analysis was used to find themes within the STEM program data findings connected with environmental elements. The framework can be organised into three categories: problem-based learning, inquiry-based learning, and project-based learning. Practice recommendations include a quality curriculum that aligns with environmental education.

Keywords: STEM, environmental education, teaching, project-based learning, inquiry-based learning

1. Introduction

STEM education is a multidisciplinary approach that integrates Science (S), Technology (T), Engineering (E), and Mathematics (M) in teaching and learning. The strategy aims to integrate these subjects to provide students with a holistic understanding of how they relate to each other in the real world. In STEM education, active learning is focused, and activities emphasise developing students' 5C skills and knowledge areas that are highly relevant in today's rapidly changing world. For instance, through STEM learning, students' problem-solving skills can be enhanced (Parno et al., 2020; Priantari et al., 2020). Besides, collaborative work with teachers enabled students to grasp the intricacies of STEM career paths (Birney et al., 2023). It fosters a supportive learning environment, encourages hands-on experiences, and provides students with the guidance and resources needed to succeed in STEM fields. According to student surveys, it is evident that students gained a deeper understanding through active engagement and hands-on learning (Birney et al., 2023). This underscores the importance of real-world learning, as it empowers students to comprehend their work, tackle problems, and engage in critical thinking, ultimately fostering a mindset and skills akin to those of scientists and mathematicians.

World environmental issues have become an ever-increasing threat to all humans, living beings, and the natural balance (Alagoz & Akman, 2016); this element should be incorporated to foster a deeper understanding and promote sustainable solutions. For instance, students often need help to fully understand ecology because they need help connecting ecological concepts with other areas of biology (Elif & Muhlis, 2015). It encourages society to recognise the importance of young voices and perspectives in shaping a more sustainable and equitable world for future generations. Protecting the environment is so crucial that setting stringent requirements and elevated standards is imperative, and continuing environmental improvements must be undeterred by any associated costs (Boca & Saracli, 2019). Research has demonstrated that exposure to nature, especially during childhood and adolescence, fosters environmental awareness and encourages pro-environmental conservation behaviours (Araya & Collanqui, 2021; Bascopé & Reiss, 2021; Birney et al., 2023; Chien et al., 2021). By incorporating environmental elements into these STEM disciplines, students can see the real-world applications of their learning to solve environmental issues (Chapman et al., 2022).

Also, environmental elements can provide opportunities for active student engagement, and educators can inspire and empower students to become environmentally conscious citizens and future STEM professionals who contribute to sustainable solutions. Likewise, exposure to nature can enhance cognitive development, including creativity and problem-solving skills, leading to more informed and pro-environmental decision-making (Gallay et al., 2021). These mental benefits can be applied to understanding and addressing environmental challenges. Therefore, the growing prevalence of childhood nature deprivation can elucidate the waning environmental awareness among young people (Bascopé & Reiss, 2021).

Thus, in this study, we systematically review and synthesize empirical research that incorporates environmental elements in STEM programs. The following questions guide the research:

a) What learning activities focus on environmental elements in the STEM program?

b) What teaching approach incorporates environmental elements in the STEM program?

2. Method

This systematic literature review utilized Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines and flow charts. The PRISMA guidelines consist of a four-phase flow diagram with an 18-item checklist. The flow diagram (Figure 1) describes the phases of SLR, such as identification, screening, eligibility, and inclusion criteria that fall under the scope of a review (Selcuk, 2019). In order to be included in this review, empirical studies need to be peer-reviewed and published in a scholarly journal (trade journals, magazines, and newspapers were excluded) between 2007 and 2023. We considered documents published from 2007 onward because the acronym STEAM was coined that year (Perignat & Katz-Buonincontro, 2019). Eligible studies must also be published in English and focus on students as participants.

We used the federated search service provided by the university library, which includes a variety of established databases, including Scopus and Web of Science (WoS). These databases are the most respected platforms for analyzing peer-reviewed literature. To be thorough, Google Scholar was also used to check and balance all relevant articles that had been found. Google Scholar does not have the same limiting search terms, so it yielded 5,950,000 results sorted by relevance. Haddaway et al. (2015) recommend that searches of article titles focus on the first 200 to 300 results from Google Scholar to find any missing literature, and the abstract of the first 300 articles was examined.

The following terms were used to search each database: (STEM OR STEAM) AND (environment* OR nature OR sustainab* OR forest OR agro OR botany OR eco* OR geopark). All searches were done against article titles, abstracts, and keywords. Search limiters were used to align with the screening criteria. Results of the initial search can be found in Table 1.

Table 1. Results of the Initial Search

Search items	Database	Search limiters	Hits
(STEM OR STEAM) AND (environment* OR nature OR sustainable* OR forest OR agro OR botany OR eco* OR geopark)	Scopus	Scholarly (peer-reviewed) Journals Published: 2007-2023	368
	Web of Science (WOS)	Scholarly (peer-reviewed) Journals Published: 2007-2023	290
	Total with duplicate removed		625

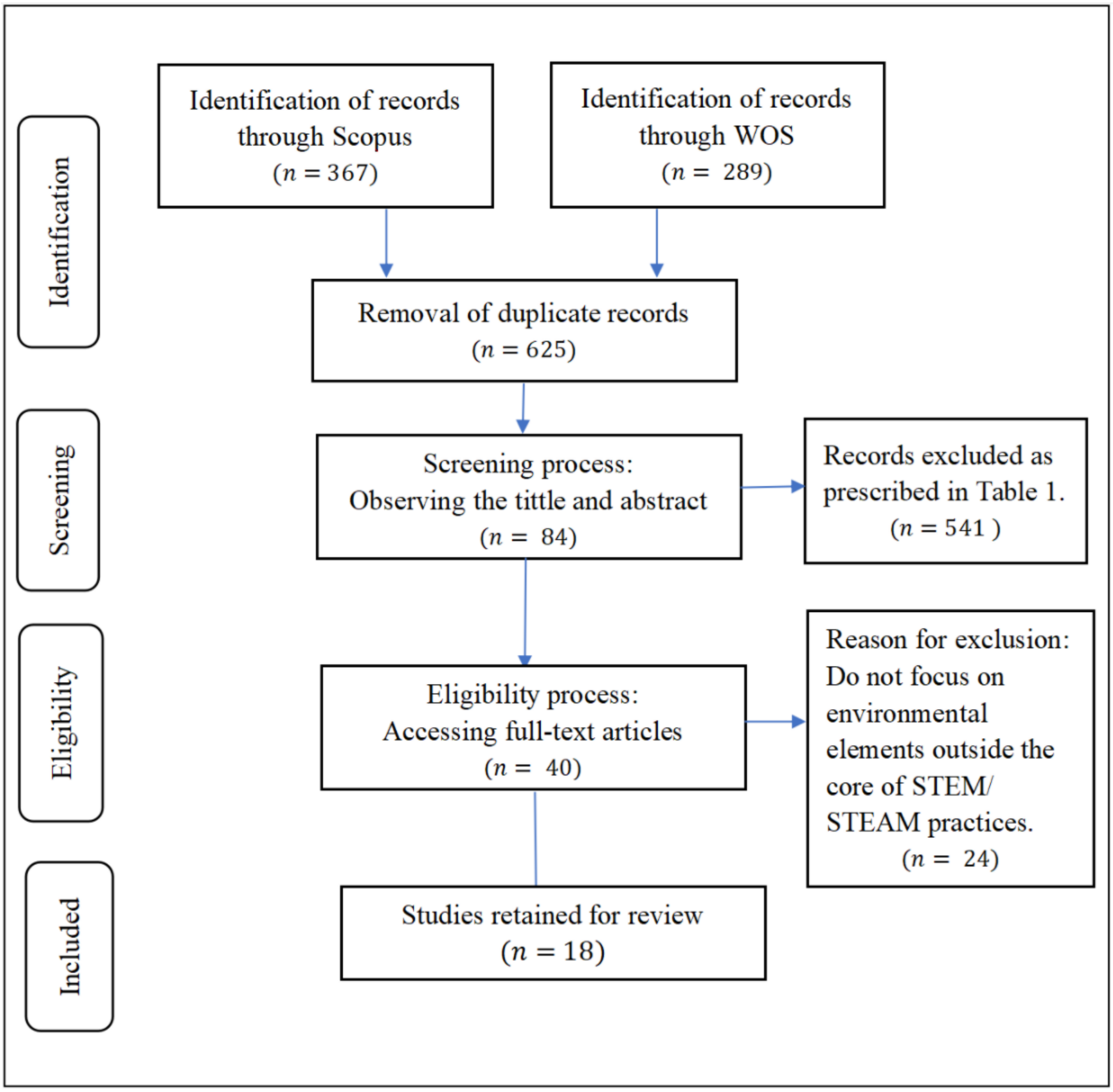

Figure 1. PRISMA flow chart (Xiao & Watson, 2019)

2.1 Study Selection

Figure 1 shows a diagram of the screening process. After screenings, 40 articles were retained. The full texts of 40 articles were studied and examined thoroughly. One rater checked whether the articles met the criteria to evaluate their quality. In case of doubt, papers were discussed with two other raters until a consensus was reached. At the final stage, only 18 articles were included because the remaining did not focus on environmental elements outside the core of STEM or STEAM practices. Themes and sub-themes were appropriately identified by reviewing the abstract and reading the full articles utilizing qualitative content analysis. The authors then organized sub-themes around the central themes established by typology. Reviewers used thematic analysis to identify the findings of previous studies by grouping the findings based on similarities or relevance and categorizing them (Adams et al., 2021).

3. Results and Discussion

An interesting pattern was noted in the retained articles, specifically on the learning activity and teaching approach incorporating environmental elements through STEM education. Based on the year of publication, the earliest article published was in 2014, and then, the number of articles published on the topic area increased, ending with two articles in 2022. A summary of retained articles can be found in Table 2.

Table 2. Summary of the Studies Retained for Review

Author(s) / year	**Learning Activity**	**Teaching Approach**		
		Problem-based learning	Inquiry-based learning	Project-based learning
Araya & Collanqui (2021)	• An interactive cross-border class between Chilean and Peruvian eighth-grade classes. • Students experimented and answered open-ended questions about energy efficiency on an online platform. Some questions were designed to check conceptual understanding, whereas others asked for suggestions on developing their economies while keeping CO_2 air concentration at acceptable levels.	✓	✓	
Bascopé & Reiss (2021)	• STEM4S projects to connect schools with local realities to generate a broad conceptual framework that makes teaching interact with traditional and everyday cultural knowledge. • Local knowledge used to understand the natural environment, climatic phenomena, and physical and chemical processes present in the daily activities of communities surrounding the school. • A comprehensive work with a group of schools and their external communities on in-depth interviews with teachers, traditional educators, families, and Indigenous community leaders.		✓	✓
Birney et al. (2023)	• Engage teachers and students in environmental restoration and experiential learning in New York City, including learning about vital ecology projects related to New York Harbor, such as oyster restoration, which is critical to cleaning pollutants.		✓	✓

Bokor et al. (2014)	• In this module, students utilized 12 flowering plant species to generate morphological and molecular phylogenies using biological techniques and bioinformatics tools. • Students explored diverse topics such as molecular biology, materials engineering, and wetlands ecology, and they were utterly immersed in indoor laboratory and outdoor field experiences.		✓	✓
Chien et al. (2021)	• Hands-on solar energy experiments to enhance students' understanding of physics concepts and to promote students' awareness of renewable energy.		✓	✓
Gallay et al. (2021)	• Projects focus on the natural and built environment and, in some cases, illustrate how environmental and social justice intersect.		✓	✓
Gutiérrez-García et al. (2020)	• The workshop content focused on the significant interculturality in knowledge linked to wild and cultivated plant species of enormous value in botany content.	✓	✓	
Ian et al. (2019)	• The programs were launched in Australia as the Young Australians' Plan Program for the Planet.		✓	✓
Martin et al. (2022).	• Programs were created to learn whether students were still involved in geosciences and document how they used an agency to navigate the marine sciences learning ecosystem.	✓	✓	
Martín-Sánchez et al. (2022)	• Students and the city of Cáceres were fostered to work on preserving its historical values and environmental protection.		✓	✓
Mikhailova et al. (2022)	• A laboratory exercise on soil reaction (pH) with ecosystem services (ES) / ecosystem disservices (ED) in an online introductory soil science course.		✓	✓
Owens et al. (2019)	• Teachers participated in several learning experiences related to environmental issues. • The teachers investigated here read a narrative concerning a problem situation localized in Des Moines, IA, where residents resent having to remove nitrates from their source of drinking water, the Raccoon River.	✓	✓	
Rico et al. (2021)	• Interdisciplinary teaching-learning sequence (TLS) about air quality for pre-service primary teachers using an organic learning garden.	✓	✓	

Rudd et al. (2020)	• The STEAM program is designed to encourage students to reflect on their impact on the environment while appreciating their place within society to bring about positive societal change.	✓	✓	
Sigit et al. (2022)	• The research analyzes the PjBL-STEAM learning model on the improvement of students' concept mastery in ecological concepts.		✓	✓
Sprague et al. (2021)	• This study investigates the STEM capacity, environmental perceptions, and environmental awareness of low-income youth participating in one of two interventions.	✓	✓	
Videla et al. (2021)	• Learners are depicted in the marine museum collaboratively taking part in the virtual reality experience, complementing the knowledge experienced during the snorkelling experience.	✓	✓	
Ward et al. (2014)	• Teaching and reinforcing botanical knowledge, experimental design and analysis, and scientific writing.	✓	✓	

3.1 Learning Activities

Incorporating environmental elements in STEM programs is crucial for fostering awareness of conserving natural resources and protecting global ecosystems. Based on the reviewed articles, the school offers diverse STEM programs focusing on environmental elements. Some students are involved in experiments during their programs. Araya and Collanqui (2021) stated that an experiment can foster a sense of teamwork and camaraderie that extends beyond the classroom and into various aspects of their lives. Most students interested in personal growth and practical use of experimentation started a problem-solving activity during the lab exercise (Mikhailova et al., 2022). Working together improved their learning and helped them build critical social skills. This collaborative environment enriched their academic experiences and helped them develop essential interpersonal skills. In addition, the highest positive feedback was elicited by experimental skills, followed by an attitude toward sustainability (Chien et al., 2021). It demonstrates the significance of technical proficiency and a commitment to environmentally responsible practices.

Besides, Bokor et al. (2014) believed the practices given an exceptional opportunity to involve students in a genuine experimental sequence with direct practical applications. Nevertheless, Araya and Collanqui (2021) contend that students must still catch up on some critical concepts while conducting the experiments. These gaps in understanding were particularly evident in areas such as data analysis techniques, experimental design, and the interpretation of results. Besides, many students referenced sources instead of pinpointing specific issues and needed to clarify the connection between these sources and the problems at hand (Rico et al., 2021). However, students are still showing a greater interest in or, at the very least, an increased awareness of environmental issues (Ward et al., 2014).

This review found that some students were involved in STEM for Sustainability projects (STEM4S) focused on creating sustainable solutions for local environmental issues. Hands-on projects involving teachers and students showed that experiential learning and real-world STEM engagement can enhance student engagement and interest, deepen teacher knowledge, and foster the development of more effective pedagogical techniques in teaching and learning (Bascopé & Reiss, 2021; Birney et al., 2023). These projects provide a valuable opportunity for students to apply the theoretical knowledge they acquire in the classroom to real-world situations. For instance, Bascopé and Reiss (2021) observed STEM4S projects that transformed green gardens into a natural laboratory for students to understand a wide variety of topics, including seed recognition, food production, growing medicinal herbs, and the production of oils, ointments, infusions, or poultices, depending on the research topic. The STEM4S projects potentially serve as engaging and practical projects, offering numerous resources for conducting educational experiences for students across various topics. Fieldwork and purposeful learning provided a valuable avenue for students facing challenges in traditional classroom settings, allowing them to explore using multiple senses and make meaningful contributions to projects (Bascopé & Reiss, 2021).

Gallay et al. (2021) indicate that young individuals from marginalized backgrounds who continue to face disparities in STEM education become actively involved when provided with chances to apply their knowledge to address local community environmental concerns. Furthermore, regarding attitudinal changes, teachers observed increased motivation among students and identified project-based learning as an effective method to foster active engagement. Teachers reported enhancements in students' self-esteem, enjoyment of learning, teamwork, and skills.

In a study by Gutiérrez-García et al. (2020), they argued that not all students who attended the environmental workshop took part in the practical sessions outside the classroom because these sessions were optional. In the first part, students exhibited a greater degree of passivity. However, their interest noticeably increased during the analysis and discussion of the results obtained from the fieldwork. This observation suggests that the topic was intrinsically appealing to the students. Utilizing training techniques and tools in workshops rooted in active methodologies offers an intriguing avenue for fostering knowledge harmoniously with conventional classroom instruction (Gutiérrez-García et al., 2020). Integrating workshops with environmental elements enriches students' educational journey and prepares them for a successful career. Thus, these educational experiences allow students to collaborate with peers, learn from experienced professionals, and build a strong network within their industry.

In addition, some studies incorporated a module into their STEM program that focused on enhancing students' skills and allowing them to tackle complex real-world problems more effectively. A study by Bokor et al. (2014) investigated the introduction of a plant module among high school students in an informal situated-learning setting, and the module holds significant potential for various educational contexts involving secondary and postsecondary learners. Deliberate instruction in the module could help students construct their comprehension of evolutionary relationships, and using them as mental and physical models assist in their knowledge development. In addition, students would concentrate on exploring problem scenarios associated with ecosystem components. The interactions among these components through activities that indirectly involve analyzing and connecting concepts can enhance their mastery of the critical concepts, as indicated by their understanding (Sigit et al., 2022).

3.2 Teaching Approach

In preparing students for careers that require a solid foundation in STEM subjects, teachers can implement tested and proven models, namely problem-based learning (PBL) and project-based learning (PjBL), which are the specialized approaches under inquiry-based learning (IBL). These distinct educational models highlight active, student-centered, and inquiry-driven approaches to learning.

3.2.1 Inquiry-Based Learning

Several essential aspects of inquiry-based learning (IBL) are mentioned in the reviewed papers. As an educational approach, IBL emphasizes active engagement, critical thinking, problem-solving, and exploration within the context of STEM subjects. Also, IBL encourages students to ask questions, investigate real-world problems, and connect concepts, as the activities are crucial to their understanding (Loizou & Lee, 2020). Hence, IBL aims to foster a deep understanding of STEM concepts through a dynamic and active process rather than passively absorbing information. On the other hand, questioning is an integral part of inquiry-based learning because learning is greatly enhanced by curiosity and motivation (Gutiérrez-García et al., 2020). Inquiry-based learning fosters a deep understanding of the subject matter as students become active participants in their education, sparking a lifelong passion for learning.

Notably, the inquiry process allows students to engage with the material actively. It empowers the students to take ownership of their learning, ultimately leading to a more profound and lasting educational experience. For instance, engaging students through inquiry allows teachers and students to explore environmental issues by embracing complexity, practising perspective-taking, nurturing scepticism, and leveraging insights from scientific and non-scientific sources of knowledge (Owens et al., 2019). However, students' sentiments about their environment varied, encompassing both positive and negative feelings, yet they notably underwent a substantial increase in environmental awareness (Sprague et al., 2021). The positive changes in students' attitudes toward their environment not only ensemble well for the future of our planet but also serve as a reminder that education and community efforts can truly make a difference in shaping a more environmentally responsible world. With this regard, Martin et al. (2022) stated that activism was redefined to encompass a broader range of efforts, such as research and other undertakings to improve society. Hence, it is essential to demonstrate an interest in, or at least increase, students' awareness of their environment (Ward et al., 2014).

3.2.2 Problem-Based Learning

The reviewed papers show that environmental elements in STEM problem-based learning (PBL) empower students to actively cooperate and foster problem-solving skills. Problem-based learning is an instructional approach that encourages students to solve real-world problems actively, often within the context of STEM disciplines. Many researchers found that PBL is an effective way to promote critical thinking, problem-solving skills, and collaboration among students while also connecting classroom learning to practical applications so that students will be active in the learning process (Araya & Collanqui, 2021). The initiative of merging the syllabi marks a pioneering stride in integrating sustainability and STEM education, responding to real-world challenges that demand applying knowledge and skills traditionally confined to separate academic disciplines (Rico et al., 2021). The initiative of breaking down the barriers fosters a more holistic and interconnected approach to education and equips students with the multidisciplinary tools necessary to address complex problems. An ecological model proves valuable when applied to STEM education within integrated teaching and learning settings within and beyond the traditional classroom (Videla et al., 2021). By nurturing this model, the students are equipped with the tools and mindset needed to tackle problems in environmental issues.

The PBL activity enhanced students' grasp of environmental issues and promoted unity and motivation. Gutiérrez-García et al. (2020) stated that motivation was crucial in the outdoor workshop. Motivation inspires students to push their limits, embrace challenges, and explore their full potential. However, some students conveyed unfavourable views when discussing elements in their learning that represented their surroundings (Sprague et al., 2021). They encountered unsupportive peer networks and recounted their sense of isolation among their classmates, leading to imposter syndrome (Martin et al., 2022). Hence, through the amalgamation of this approach, students are immersed in learning, all within the dynamic environment of a classroom setting that fosters group interaction and collaboration in solving the problem (Rudd et al., 2020). For instance, students from different nations could collaborate to find solutions through an interactive cross-border class between Chilean and Peruvian eighth-grade classes (Araya & Collanqui, 2021).

3.2.3 Project-Based Learning

Within the reviewed papers, the PjBL educational approach shows the potential to help secondary-level students grasp complex concepts, as evidenced by improved mastery of ecological principles in their overall learning outcomes (Sigit et al., 2022). This empowers them to excel academically and instils a sense of responsibility for our environment, encouraging them to become environmentally conscious citizens who actively contribute to preserving our planet. Concerning changes in attitudes, students became more motivated and discovered an avenue for active learning through the projects. Teachers noted that engaging in fieldwork and learning with a tangible purpose allowed children who struggled in traditional school settings to develop their skills, enabling them to explore using other senses and make meaningful contributions to the projects (Bascopé & Reiss, 2021). Moreover, teachers reported an elevation in students' self-esteem, enjoyment of learning, and teamwork skills.

In comparison, PjBL is more structured than PBL, with a clear end product and students being guided through the project's steps. In fact, PjBL is the appropriate model for an engaging and practical approach to education that integrates various scientific disciplines and practical abilities into the real world through hands-on projects (Yudiono et al., 2019). It encourages students to explore and apply their knowledge and skills to solve complex problems, fostering critical thinking, creativity, collaboration, and innovation. As a learner-centred learning approach, PjBL is designed to help students understand and apply concepts more practically and gain a meaningful learning process by developing their knowledge (Yudiono et al., 2019).

Also, PjBL focuses on students applying their knowledge to complete a specific task. Even though students carried out the projects, they proved highly effective in establishing new connections with local actors and organizations that had never previously engaged with schools (Bascopé & Reiss, 2021). This approach allowed them to explore using their other senses and enabled them to make meaningful contributions to various projects. However, engaging students, particularly in sustainability, can be challenging due to the absence of a platform for adolescents to express themselves (Ian et al., 2019). For instance, high school students face challenges in comprehending and engaging with their learning (Bokor et al., 2014). Addressing this issue is crucial for fostering a sense of ownership and responsibility among the younger generation regarding environmental education. Besides, proficiency in conducting projects garnered the most enthusiastic response, with sustainability-minded attitudes coming in a close second (Chien et al., 2021). Hence, emphasizing the importance of location in students' STEM education and demonstrating the connections between their learning and the positive changes they can effect in their community can nurture their understanding of how STEM can benefit themselves and those around them (Gallay et al., 2021).

4. Conclusion

Based on the reviews across multiple studies, the findings could help inform future students' awareness of environmental issues. It should be used to guide schools in incorporating environmental elements through STEM programs. By identifying trends and insights from diverse studies, we can better tailor teaching strategies, design curricula, and implement policies that foster a deeper understanding of environmental issues and sustainable practices among students. This, in turn, will contribute to a more informed and environmentally conscious citizen better equipped to address the complex challenges of our changing world.

Most of the findings from previous studies proved that STEM learning has positive impacts. Addressing environmental issues necessitates implementing robust STEM programs (Arslan & Albay, 2019). Many initiatives are crucial in raising awareness among pupils about environmental issues. However, they are limited to the level of commitment as awareness-raising actions do not lead to actual participation. A significant influence on student engagement often emphasizes the importance of curriculum content being applicable and meaningful to students in their daily experiences outside the educational setting (Attard &

Holmes, 2020). These initiatives are designed to foster an understanding of the natural world, promote sustainability, and empower students to become responsible stewards of the environment. Besides, Ian et al. (2019) did not find any evidence to suggest that the motivational frameworks introduced at the beginning of the environmental program specifically impacted how the students went about their strategic planning. Motivation did not significantly influence how students made their plans and decisions.

Although integrating environmental elements and STEM in schools remains limited, students have displayed enthusiasm and motivation when engaging in hands-on experimental activities and projects encompassing science, technology, engineering, arts, and mathematics. The primary objective is to foster the creation of innovative products (Sigit et al., 2022). This multifaceted approach empowers students to explore the interconnectedness of these subjects, bridging the gap between theoretical knowledge and practical application. Through hands-on projects, they gain a deeper understanding of each discipline and learn how these fields can intersect and complement each other. Besides, this paper provides an essential step toward environmental education in STEM implementation, and future research is needed. Further investigations will be necessary to track students' academic accomplishments and progress in their learning, as well as their ultimate choices of careers (Birney et al., 2023). To bridge this gap, educators and community leaders can explore innovative approaches to empower students and provide them with the necessary tools to express their concerns and ambitions.

Acknowledgement

This research was funded by the University Kebangsaan Malaysia (UKM) under grant numbers GG-2023-004 and GG-2024-001.

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