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Developing Sustainability Thinking among Students through Strengthening Science Education in Schools: A Systematic Literature Review (SLR)

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Abstract

The education sector plays a pivotal role in advancing sustainable development, particularly through the integration of Education for Sustainable Development (ESD) in science education. However, students' sustainability knowledge and awareness remain at moderate to low levels despite various interventions. This study aims to synthesise the key issues and challenges, review existing interventions and propose improvement strategies to foster students' sustainability thinking. A Systematic Literature Review (SLR) guided by the PRISMA framework was conducted. A total of 18 articles were selected from the Web of Science (WoS), Scopus and Education Resources Information Centre (ERIC) databases. Relevant data were systematically retrieved and analysed thematically. The findings reveal that students' sustainability thinking is influenced by predominantly traditional teaching approaches, the complexity of sustainability-related issues and limitations in teachers' competencies in integrating ESD into science classrooms. Interventions such as inquiry-based and problem-based learning, school-based programmes and the use of technology show significant potential in promoting sustainability thinking among students. Furthermore, the proposed improvement strategies emphasise diverse, real-world-oriented pedagogical approaches, effective technology integration and the strengthening of teachers' competencies through continuous professional development. In conclusion, sustainability-oriented science education requires a holistic approach, with greater emphasis on teacher empowerment and curriculum development to support ESD integration.

Keywords: Sustainability Thinking, Science Education, Education for Sustainable Development (ESD), Science Teaching and Learning, Pedagogical Interventions

Introduction

The Sustainable Development Goals (SDGs) were introduced by the United Nations in 2015 as a global agenda aimed at promoting human well-being while ensuring the protection of the planet (United Nations Development Programme, n.d.). Malaysia has adopted the 2030 Agenda for Sustainable Development (Ministry of Economy, 2021), which encompasses 17 SDGs and 169 targets aimed at promoting holistic sustainable development across social, economic, and environmental dimensions by 2030 (United Nations Development Programme, n.d.). However, the pursuit of sustainable development continues to face considerable environmental challenges. Among the key issues identified are seawater intrusion into paddy fields and irresponsible waste disposal, both of which threaten local ecosystems (Orloff, 2025; Budget Waste, 2024) and adversely affect rice yields as well as the livelihoods of farmers and fishing communities. This is supported by Solaymani (2023) who highlights that the agricultural sector is highly susceptible to climate conditions, noting that rising temperatures associated with climate change pose a significant threat to rice production in Malaysia.

In addition, the education sector plays a crucial role in developing public knowledge and awareness of environmental challenges. For example, schools can serve as key platforms for environmental education by implementing programmes that engage local communities (Husin et al., 2025). This is consistent with the findings of Letchumanan and Rosniza (2021), who emphasise that schools play a vital role in disseminating environmental knowledge, fostering values, awareness and pro-environmental attitudes, as well as cultivating a sense of responsibility towards sustainability, particularly among students. Within the school context, science education is closely aligned with the SDGs (Guo et al., 2024). Therefore, Education for Sustainable Development (ESD) should be integrated into science education as a foundation for enabling students to connect scientific concepts with real-world sustainability issues.

Furthermore, the implementation of ESD in science education has been shown to enhance students' awareness of sustainability issues and promote critical thinking skills (Ekamilasari et al., 2021). Moreover, the integration of ESD content can strengthen teachers' pedagogical competencies and enable them to design and implement sustainability-oriented science education (Guo et al., 2024). Hence, interdisciplinary and project-based interventions in science education are essential for addressing sustainability issues and fostering environmental awareness among students, in line with the aspirations of the SDGs (Utamirohmahsari et al., 2025).

Despite these efforts, the implementation of ESD in schools remains relatively limited, even though various interventions have been introduced to promote sustainable behaviour (Husin et al., 2025). Moreover, students' levels of sustainability knowledge and awareness are still generally moderate to low (Ekamilasari et al., 2021; Ridha et al., 2020). This may be attributed to students' difficulties in relating sustainability issues to real-life contexts. In addition, although some studies report high levels of awareness among students, such awareness does not necessarily translate into sustainable practices or behaviours (Parayiwa & Shabalala, 2025; Abdul Hair et al., 2021). This is further supported by Khirun et al. (2024), who found that while students demonstrate good levels of environmental knowledge and awareness, their sustainable behaviour and level of engagement in addressing environmental issues remain low.

Moreover, Zulkarnaen et al. (2023) reported that although students exhibit high awareness of environmental sustainability, some still show a lack of concern towards environmental issues. This gap between knowledge, awareness and behaviour suggests that students' sustainability thinking remains underdeveloped and may be attributed to the limited emphasis on sustainability within the school education system. Additionally, Al-Barakat et al. (2025) further emphasise that science education plays a critical role in deepening understanding and shaping sustainable behaviour among students.

Therefore, despite the recognised importance of science education, several gaps remain in the existing literature. In particular, there is limited synthesis explaining how science education contributes to students' sustainability thinking or identifying the challenges, effective interventions and future directions for strengthening sustainability-oriented science education.

In light of this, the review offers a novel contribution by synthesising recent evidence published between 2021 and 2025 on sustainability thinking specifically from the perspective of science education. By synthesising evidence on the relationships between educational practices, teacher competencies and students' sustainability thinking, this review contributes to the social sciences by advancing understanding of how education shapes sustainability-related values, attitudes and behaviours. Accordingly, this study aims to achieve the following objectives:

1. To identify the key issues and challenges influencing students' sustainability thinking.
2. To examine the interventions used to promote sustainability thinking among students.
3. To propose improvement strategies for fostering sustainability awareness and sustainable actions among students through science teaching and learning.

Based on these objectives, the study seeks to address the following research questions:

1. What are the key issues and challenges affecting students' sustainability thinking in schools?
2. To what extent do interventions in science education promote the development of students' sustainability thinking?
3. What science teaching and learning strategies are the most effective in fostering sustainability awareness and sustainable actions among students?

Methodology

This Systematic Literature Review (SLR) adopts a qualitative approach to systematically synthesise findings from previous studies. The review is guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, which serves as the protocol for conducting the literature review.

Prisma

The PRISMA approach consists of four main stages, which are *identification*, *screening, eligibility and included* (Moher et al., 2009). The databases selected and utilised in this study are *Web of Science* (WoS), Scopus and *Education Resources Information Centre* (ERIC). The PRISMA flow diagram is illustrated in Figure 1.

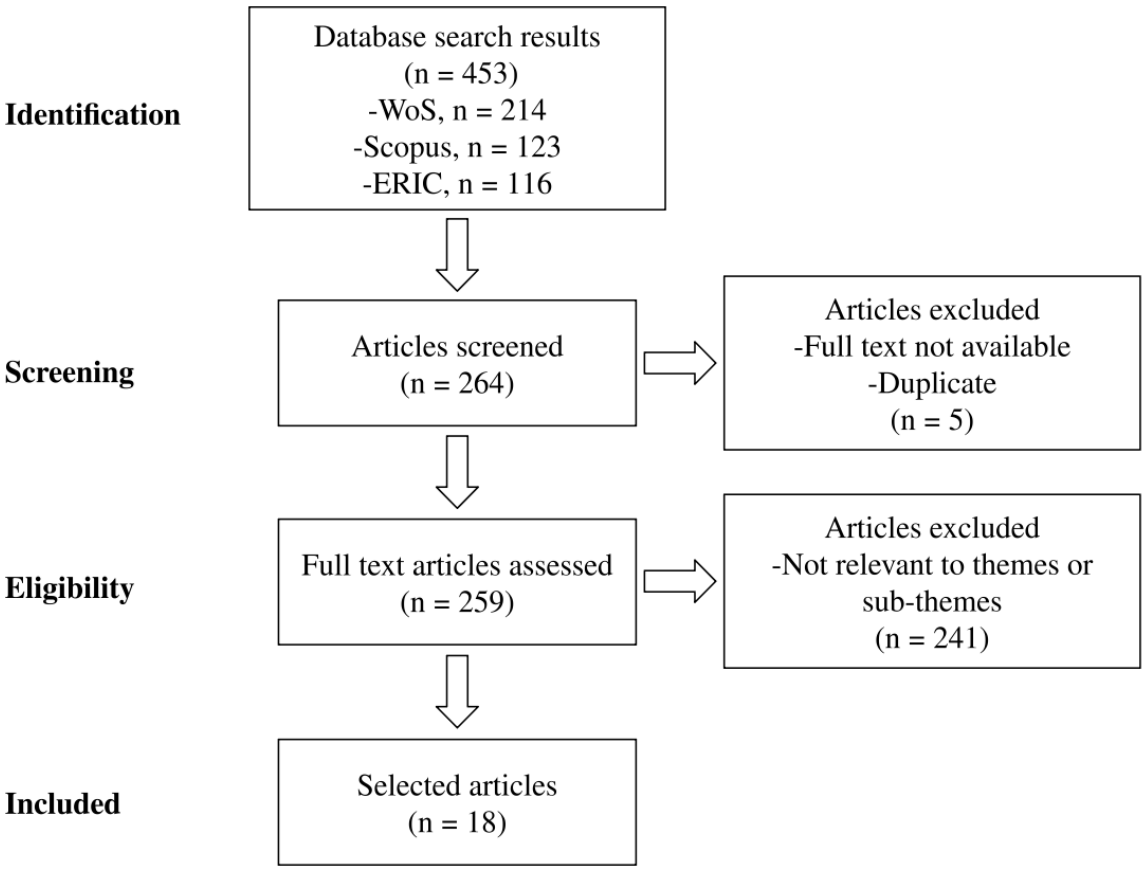

Figure 1. PRISMA flow diagram

The first stage of PRISMA is identification, which involves the process of locating relevant articles through a systematic search across the three selected databases (WoS, Scopus and ERIC). This search process was conducted using a set of predefined keywords (see Table 1), aligned with the objectives of the study. As shown in Figure 1, a total of 453 articles were identified through the search across these databases.

Table 1
Keywords and Search Strategies Used Across Databases

Database	Keywords and Search Strategies
Web of Science (WoS)	Search query 1: (ALL= (“sustainability thinking” OR "sustainability awareness” OR “sustainability” AND “science education” AND “students”)) Search query 2: (ALL= (“education for sustainable development (ESD)” AND “science education” OR “science teaching” OR “science learning" AND “secondary students” OR “high school students” OR “school”)) Filters applied: • Document type: Article or Proceeding Paper • Year: 2020 - 2025 • Language: English and Malay
Scopus	Search query: TITLE-ABS-KEY “sustainability” AND “science education” AND “secondary students” OR “high school students” OR “school” Filters applied: • Document type: Article or Conference Paper • Year: 2020-2025 • Language: English
Education Resources Information Centre (ERIC)	Search query: (ALL= (“sustainability” AND “science education” AND “secondary students” OR “high school students” OR “school”)) Filters applied: • Publication period: Since 2022 (last 5 years)

Table 1 presents the keywords and search strategies employed to facilitate the article retrieval process. Furthermore, the second stage of the PRISMA method involves the screening process, in which the researcher filters articles based on their relevance to the study objectives. A total of 264 articles were screened and five articles were excluded due to the lack of full-text access and the presence of duplicate records (Figure 1).

Subsequently, the eligibility stage resulted in 259 full-text articles being assessed. At this stage, articles that were not directly related to the themes and sub-themes of the study were excluded based on specific criteria. As a result, 241 articles were removed. Finally, the process proceeded to the inclusion stage of PRISMA, where only 18 articles met all the required criteria and were selected for analysis in this SLR study.

Findings

The findings of this study present a synthesis of 18 articles published between 2021 and 2025, focusing on the development of students’ sustainability thinking through the strengthening of science education in schools. The selected articles encompass a range of research designs, issues, and interventions that contribute to addressing the research objectives.

This section discusses the distribution of the selected articles based on year of publication, country and research methodology in order to identify patterns and trends in studies related to strengthening students' sustainability thinking through science education. In addition, the findings highlight the main themes synthesised from the 18 selected articles. The contributions of previous studies in addressing the three research questions are also outlined. Finally, a summary of each article is presented in a matrix table.

Distribution of Articles by Year of Publication

The distribution of articles by year of publication, as shown in Figure 2 indicates an inconsistent publication trend between 2021 and 2025.

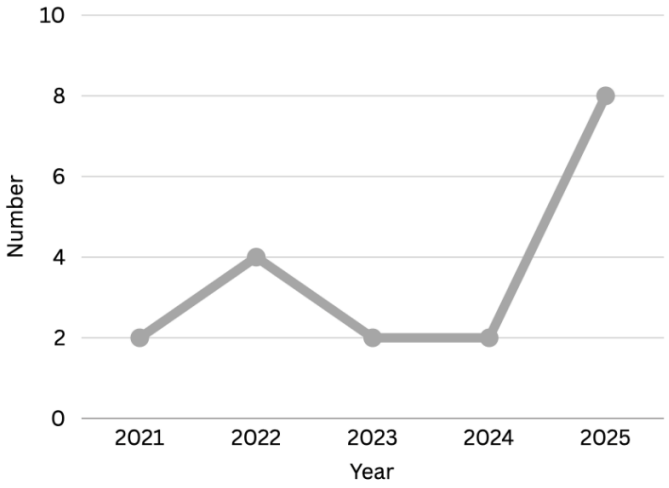

Figure 2. Distribution of Articles by Year of Publication.

Based on Figure 2, the highest number of articles related to the selected theme were published in 2025 with a total of eight articles (44.44%), followed by 2022 with four articles (22.22%). In contrast, the years 2021, 2023, and 2024 recorded lower and relatively similar numbers of publications. This pattern likely reflects evolving research priorities across years. Notably, the increase in publications in 2025 suggests growing scholarly attention to fostering students' sustainability thinking through science education.

Distribution of Articles by Country

This section presents the distribution of articles by country to identify the geographical context of the 18 selected studies.

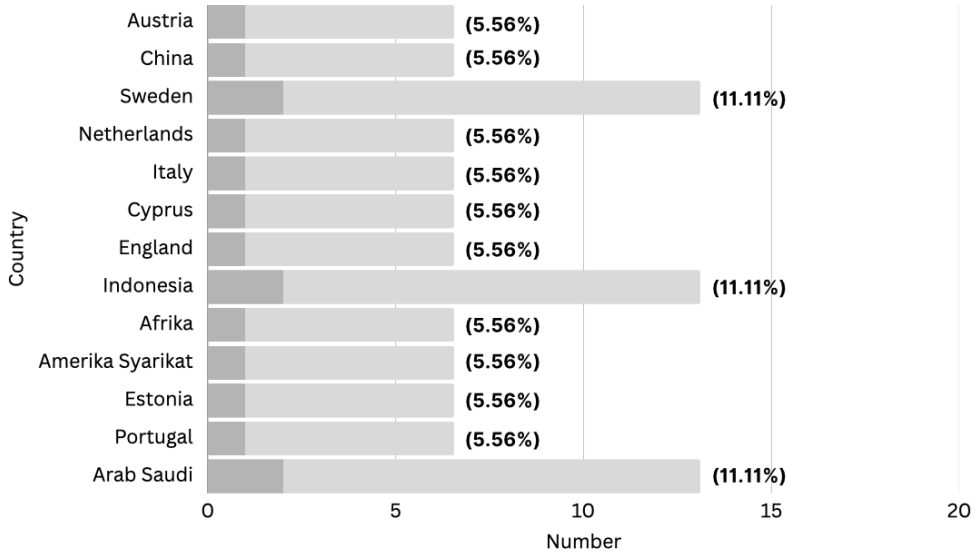

Figure 3. Distribution of Articles by Country

Based on Figure 3, the selected articles represent 13 different countries. The findings show that most studies were conducted in Saudi Arabia (n = 2), Indonesia (n = 2) and Sweden (n = 2). Meanwhile, only one study was reported for each of the following countries, namely Portugal, Estonia, the United States, Africa, England, Cyprus, Italy, the Netherlands, China and Austria. In addition, one study in the form of a Systematic Literature Review (SLR) and one conceptual study were not confined to a specific national context and were therefore categorised as not applicable (N/A).

Distribution of Articles by Research Methodology

Figure 4 illustrates the distribution of articles based on the research methodologies employed in previous studies.

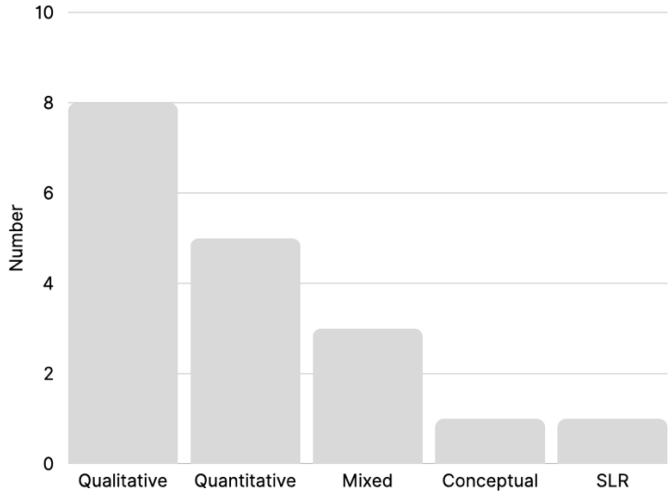

Figure 4. Distribution of Articles by Research Methodology

The findings indicate that 8 out of 18 articles (44.44%) employed qualitative approaches, while 5 out of 18 articles (27.78%) utilised quantitative methods. The qualitative studies were

conducted using interviews, descriptive data analysis and analysis of task outputs. Meanwhile, the quantitative studies primarily focused on the use of questionnaires, experimental and quasi-experimental designs, as well as evaluation-based research (quantitative evaluative studies). In addition, three articles adopted mixed-method approaches, integrating both qualitative and quantitative methods. Furthermore, two articles were non-empirical, consisting of one conceptual study and one review (SLR).

Main Themes from Previous Studies

Five main themes (Table 2) related to students' sustainability thinking through science education were identified through the synthesis of the selected studies.

Table 2
Main Themes

Theme	Key Focus Areas in Previous Studies	Citation
1. Students' Sustainability Awareness, Understanding, and Behaviour through Science Education	-Fostering students' awareness and sense of responsibility towards environmental sustainability. -Encouraging positive changes in students' attitudes and sustainable behaviours. -Developing students' understanding of sustainability concepts and issues, for example by linking scientific literacy with sustainability	-AlAli et al. (2025) -Jackson et al. (2023) -Georgiou & Kyza (2023) -Pada et al. (2025) -Miani et al. (2025) -Tuba Stouthart et al. (2025) -Oliveira & Lanceros (2021)
2. Students' Interest, Motivation and Active Engagement	-Enhancing students' interest, motivation, and active engagement in sustainability issues through science education.	-AlAli et al. (2025) -Baptista et al. (2025) -MacIntosh & Asghar (2025) -Hsiao & Su (2021) -Haim & Aschauer (2024) -Oliveira & Lanceros (2021) -Gelmez & Reiss (2024)
3. Diverse Pedagogical Approaches in Sustainability-Oriented Science Education	-Inquiry-based and problem-based approaches. -Approaches based on instructional materials and technology - Value- and ethics-based pedagogical models. -Programme- and course-based sustainability interventions. -School-based and reflective approaches.	-AlAli et al. (2025) -Baptista et al. (2025) -MacIntosh & Asghar (2025) -Väljataga & Mettis (2022) -Jackson et al. (2023) -Oliveira & Lanceros (2021) -Rahmawati et al. (2022)

		-Gelmez & Reiss (2024) -Georgiou & Kyza (2023) -Pada et al. (2025) -Miani et al. (2025) -Hsiao & Su (2021) -Haim & Aschauer (2024) -Van Der Leij et al. (2022)
4. Issues and Challenges in Fostering Students' Sustainability Thinking through Science Education	-Science education continues to rely on traditional teaching and learning approaches. -Issues and challenges related to socio-economic, social, ethical, and socioscientific aspects of sustainability, including the need to integrate Education for Sustainable Development (ESD) into science education at schools. -Environmental and future-oriented issues such as climate change -Issues related to students' awareness, behaviour, and sense of responsibility towards environmental sustainability in science education	-AlAli et al. (2025) -Baptista et al. (2025) -Al-Barakat et al. (2025) -MacIntosh & Asghar (2025) -Väljataga & Mettis (2022) -Jackson et al. (2023) -Oliveira & Lanceros (2021) -Rahmawati et al. (2022) -Gelmez & Reiss (2024) -Georgiou & Kyza (2023) -Pada et al. (2025) -Haim & Aschauer (2024)
5. Teachers' Role in Science Teaching and Learning	-Teachers' roles in supporting students' sustainability thinking, for example through pedagogical choices (didactical choices) in science teaching and learning. -The use of teachers' reflective tools such as Content Representation (CoRe) to support students' understanding of sustainability issues.	-Al-Barakat et al. (2025) -MacIntosh & Asghar (2025) -Forsler et al. (2022) -Haim & Aschauer (2024) -Bronmmesson et al. (2025)

Contributions of Previous Studies

The objective of this Systematic Literature Review (SLR) are to identify the key issues and challenges influencing students' sustainability thinking, examine interventions that promote such thinking and propose improvement strategies to foster sustainability awareness and action through science teaching and learning. Hence, this section addresses the three research questions based on the five main themes that have been identified.

Research Question 1: What are the key issues and challenges affecting students' sustainability thinking in schools?

To address the first research question, Table 3 synthesises findings from previous studies on the issues and challenges in fostering students' sustainability thinking through science education.

Table 3
Synthesis of Findings from Previous Studies Addressing Research Question 1

Theme	Findings from Previous Studies
4. Issues and Challenges in Fostering Students' Sustainability Thinking through Science Education	- Science education continues to rely on traditional teaching and learning approaches. -Students' sustainability thinking is influenced by the complexity of sustainability issues, encompassing socio-economic, social, ethical and socioscientific aspects. -Students often struggle to understand environmental issues and connect them to future consequences, highlighting the need for deeper critical and systems thinking skills.
5. Teachers' Role in Science Teaching and Learning	Teachers face challenges in enhancing students' sustainability thinking, particularly in terms of their capability, confidence, and knowledge to integrate Education for Sustainable Development (ESD) into science teaching and learning

Based on Table 3, the findings indicate that students' sustainability thinking is influenced by interrelated issues and challenges. These include the continued reliance on traditional approaches in science teaching and learning, the complexity of sustainability-related issues, as well as the constraints related to teachers' roles and competencies in integrating ESD into science education.

Research Question 2: To what extent do interventions in science education promote the development of students' sustainability thinking?

Table 4 presents a synthesis of interventions identified in previous studies in addressing the second research question.

Table 4
Synthesis of Findings from Previous Studies Addressing Research Question 2

Theme	Findings from Previous Studies
2. Students' Interest, Motivation, and Active Engagement	Effective interventions have been shown to enhance students' interest, motivation, and active engagement in sustainability-oriented science learning.
3. Diverse Pedagogical Approaches in Sustainability-Oriented Science Education	A range of pedagogical interventions have been implemented such as inquiry-based learning, problem-based learning (PBL) that aligned with the Sustainable Development Goals (SDGs), socioscientific inquiry-based learning (SSIBL), the implementation of sustainability-related programmes and courses, the use of instructional materials and technologies (e.g science kits and virtual reality-VR), as well as teaching approaches that emphasise values, ethics, and social responsibility
5. Teachers' Role in Science Teaching and Learning	Teachers' roles and instructional practices influence the effectiveness of the interventions.

Based on Table 4, the findings indicate that a wide range of pedagogical interventions have been employed in science education to promote students' sustainability thinking. These include inquiry-based learning, problem-based learning (PBL) that aligned with the Sustainable Development Goals (SDGs), socioscientific inquiry-based learning (SSIBL), as well as the use of instructional materials and technologies such as science kits and virtual reality (VR).

In addition, sustainability-related programmes and courses, along with teaching approaches that emphasise values, ethics, and social responsibility, play a significant role in supporting the development of sustainability thinking. The role of teachers is also critical in ensuring the effective implementation of these interventions.

Research Question 3: What science teaching and learning strategies are the most effective in fostering sustainability awareness and sustainable actions among students?
Improvement strategies were not directly derived from individual studies, however, they were developed through a synthesis of the overall findings to address the third research question as presented in Table 5.

Table 5
Synthesis of Findings from Previous Studies Addressing Research Question 3

Theme	Findings from Previous Studies
1. Students' Sustainability Awareness, Understanding and Behaviour through Science Education	Science teaching and learning should emphasise the development of students' awareness and understanding of sustainability issues to encourage sustainable action.
2. Students' Interest, Motivation and Active Engagement	Science teaching and learning should be designed to enhance students' motivation, interest, and active engagement, particularly through learning experiences that are relevant to sustainability issues.
3. Diverse Pedagogical Approaches in Sustainability-Oriented Science Education	Pedagogical approaches should be diverse and grounded in real-world contexts to support students in understanding complex sustainability issues.
4. Issues and Challenges in Fostering Students' Sustainability Thinking through Science Education	Strategies should address the complexity of sustainability issues in a holistic manner.
5. Teachers' Role in Science Teaching and Learning	Teachers should be provided with continuous support through professional development and the strengthening of competencies related to Education for Sustainable Development (ESD).

Based on Table 5, the synthesis indicates that effective science teaching and learning should prioritise the development of students' sustainability awareness and understanding, while also fostering motivation, interest, and active engagement. Approaches that are pedagogically diverse and grounded in real-world contexts are essential in helping students to understand about the complexity of sustainability issues. In addition, proposed strategies must account for the multifaceted nature of sustainability challenges and recognise the central role of teachers by ensuring continuous professional support and the development of ESD-related competencies.

Matrix Table

Table 6 sows a synthesis matrix summarising the 18 articles that has been synthesised in this study.

Table 6

Matrix Table

Author (s) / Year	Topic	Country	Research Design	Sample	Objectives	Contributions
AlAli, R., Al-Barakat, A., Alrosaa, T., Alotaibi, S., Abdullatif, A., & Almughyirah, S. 2025.	Science Education and Environmental Identity: An Integrative Approach to Fostering Sustainability Practices in Primary School Students.	Saudi Arabia	Qualitative (semi-structured interviews)	60 science teachers.	1. To examine how science education fosters sustainable behaviour as well as appreciation and responsibility toward environment (environmental identity) among students. 2. To explore school-based sustainability practices that promote students' sustainable behaviour.	Addresses objectives 1, 2 and 3
Baptista, M., Pinho, A. S., & Alves, A. R. 2025.	Students' Learning for Action Through Inquiry-Based Science Education on a Local Environmental Problem.	Portugal	Qualitative (interviews)	54 secondary school students.	To explore students' sustainable behaviour in addressing local environmental issues through inquiry-based science education (IBSE).	Addresses objectives 1, 2 and 3

Al-Barakat, A., AlAli, R., Alotaibi, S., Alrashood, J., Abdullatif, A., & Zaher, A. 2025.	Science Education as a Pathway to Sustainable Awareness: Teachers' Perceptions on Fostering Understanding of Humans and the Environment: A Qualitative Study.	Saudi Arabia	Qualitative (semi-structured interviews)	49 science teachers.	To examine how science education promotes sustainability awareness among students, as well as to explore science teacher perceptions of the relationship between humans and the environment.	Addresses objectives 1, 2 and 3
MacIntosh, N., & Asghar, A. 2025.	An Integrated Framework to Motivate Student Engagement in Science Education for Sustainable Development.	N/A	Conceptual Study	N/A	To develop a pedagogical framework based on Self-Determination Theory (SDT), integrating Problem-Based Learning (PBL) and the Sustainable Development Goals (SDGs). This framework is designed to enhance student motivation, interest and engagement in sustainability-oriented science education.	Addresses objectives 1, 2 and 3

Väljataga, T., & Mettis, K. 2022.	Secondary Education Students' Knowledge Gain and Scaffolding Needs in Mobile Outdoor Learning Settings.	Estonia (Tallinn)	Mixed-methods action research	68 students	To examine students' understanding of socio-economic environmental challenges in real world context, through collaborative inquiry-based learning using mobile technologies.	Addresses objectives 1, 2 and 3
Jackson, W. M., Binding, M. K., Grindstaff, K., Hariani, M., & Koo, B. W. 2023.	Addressing Sustainability in the High School Biology Classroom through Socioscientific Issues.	United States (Berkeley, California)	Qualitative descriptive (programme evaluation)	9 teachers where each teacher sends approximately 5 students (student work samples as supporting data).	1. To examine socioscientific issues related to sustainability through Biology subject in school. 2. To enhance students' understanding of scientific concepts in science education and the importance of socioscientific issues.	Addresses objectives 1, 2 and 3
Oliveira, J., Neves, L., & Lanceros-Mendez, S. 2021.	Kit "Energy, Environment and Sustainability": An Educational Strategy for a Sustainable Future. A Case Study	West Africa (Guinea-Bissau)	Mixed-methods (interviews and questionnaires)	30 teachers	To promote sustainability knowledge through science education, focusing on energy, gender equality,	Addresses objectives 1, 2 and 3

	for Guinea-Bissau.				water, poverty and well-being through the development of a science kit named Energy, Environment and Sustainability (KEAS).	
Rahmawati, Y., Taylor, E., Taylor, P. C., Ridwan, A., & Mardiah, A. 2022.	Students' Engagement in Education as Sustainability: Implementing an Ethical Dilemma-STEAM Teaching Model in Chemistry Learning.	Indonesia (Jakarta)	Qualitative (semi-structured interviews)	155 secondary school students.	To examine the potential of Ethical Dilemma STEAM Teaching Model by emphasising the knowledge in Chemistry subject and integrating real world based learning through ethical dilemma story pedagogy (EDSP).	Addresses objectives 1, 2 and 3
Gelmez Burakgazi, S., & Reiss, M. J. 2024.	Perceptions of Sustainability among Children and Teachers: Problems Revealed via the Lenses of Science Communication and Transformative Learning.	England	Qualitative (interviews)	24 students, 2 eco-group leaders, 2 principals and 5 teachers	1. To analyse knowledge and perceptions of sustainability and environmental issues among teachers and students. 2. To examine environment	Addresses objectives 1, 2 and 3

					al, social, economic and sustainability education aspects in schools. 3. To explore challenges faced by stakeholders in promoting sustainability in school. 4. To identify key sources used by teachers and students to learn about sustainability issues. 5. To investigate the experiences and perspectives among teachers and students regarding sustainability programmes (e.g. eco-schools).	
Georgiou, Y., & Kyza, E. A. 2023.	Fostering Chemistry Students' Scientific Literacy for Responsible Citizenship through Socio-Scientific Inquiry-Based Learning (SSIBL).	Cyprus	Experimental	93 secondary school students	To analyse the importance of sustainability-oriented learning interventions in science education.	Addresses objectives 1, 2 and 3

Pada, A., Chanunan, S., & Rahmat, I. 2025.	Fostering Environmental Awareness Through Sustainable Development Goal-Oriented Ethno-STEM Approach in Elementary Education.	Indonesia	Kuasi eksperimen	60 students	To examine the effectiveness of an SDG-oriented Ethno-STEM model in enhancing students' awareness regarding environmental issues.	Addresses objectives 1, 2 and 3
Miani, L., De Zuani Cassina, F. & Levrini, O. 2025.	Raising Awareness on the Complexity of Decision-making through Climate Change Education.	Italy	Qualitative (analysis of student work and written reflections)	34 students	To develop a future-oriented climate change course that linking science and society to support students in reasoning about complex sustainability issues and future implications.	Addresses objectives 2 and 3
Tuba Stouthart, Dury Bayram, Jan van der Veen. 2025.	Science teachers' view on student competences in education for sustainable development.	The Netherlands	Mixed methods (Q methodology)	16 secondary school science teachers	To study the ESD competencies required among students based on the teachers' perspectives.	Addresses objectives 2 and 3
Brommesson, S., Jönsson, A., Lundegård, I., &	'Facting or Acting' in sustainable development teaching? Science	Sweden	Quantitative (survey)	155 science teachers	To examine teachers' didactic choices in teaching interdisciplin	Addresses objectives 2 and 3

Einarsson, E. 2025.	Studies teachers' didactical choices in Swedish upper-secondary schools.				ary science studies within the context of sustainable development, with the aim to improve teaching practices and to support student learning.	
Hsiao, P.-W., & Su, C.-H. 2021.	A Study on the Impact of STEAM Education for Sustainable Development Courses and Its Effects on Student Motivation and Learning.	China, Taiwan	Quasi-experimental	303 students	To integrate Education for Sustainable Development (ESD) into STEAM education using virtual reality (VR).	Addresses objectives 2 and 3
Haim, K., & Aschauer, W. 2024.	Innovative FOCUS: A Program to Foster Creativity and Innovation in the Context of Education for Sustainability.	Republic of Austria	Quantitative (programme evaluation)	64 secondary school students	To enhance scientific creativity and promote innovative approaches within Education for Sustainable Development (ESD) context.	Addresses objectives 1, 2 and 3
Forsler, A., Nilsson, P. & Walan, S. 2022.	Collective pedagogical content knowledge for teaching sustainable	Sweden	Qualitative (semi-structured interviews)	12 science teachers	To explore how science teachers develop their knowledge and expertise in	Addresses objectives 2 and 3

	development.				sustainable development using Content Representation (CoRe) as a reflective tool as students' understanding and active engagement in sustainability issues begins with efficient teachers.	
Van Der Leij, T., Avraamidou, L., Wals, A., & Goedhart, M. 2022.	Supporting Secondary Students' Morality Development in Science Education.	N/A	Review Paper	28 studies	To explore moral dimensions of socioscientific issues (SSI) in science education because SSI is seen to be able to promote moral reasoning and decision making processes by considering moral aspects.	Addresses objectives 2 and 3

Discussion

This section critically discusses the main findings by examining the issues and challenges in fostering students' sustainability thinking, while also analysing the interventions employed and proposing effective strategies to promote sustainability thinking, awareness and sustainable behaviour among students through science education.

Issues and Challenges Influencing Students' Sustainability Thinking

Based on the synthesis of previous studies, several key challenges were identified in fostering students' sustainability thinking (Table 3). First, science education continues to rely on traditional teaching and learning approaches. Second, students' sustainability thinking is influenced by complex sustainability-related issues, particularly those involving socio-

economic, social, ethical, and socioscientific dimensions. Third, challenges in fostering sustainability thinking are closely linked to the role, competency, and readiness of science teachers. According to AlAli et al. (2025), science education in schools continues to rely heavily on passive and theory-oriented instructional approaches. Such practices make it difficult for students to connect scientific learning with sustainability issues, as science is often perceived merely as a fact-based subject rather than a discipline that can be applied to environmental contexts and Education for Sustainable Development (ESD). For instance, students may understand the concept of recycling theoretically but fail to relate it to reducing domestic waste and promoting environmental sustainability. This finding is consistent with the study by Maslamany et al. (2025), which reported that science teaching that is overly focused on memorisation and theoretical content is ineffective in promoting sustainability, as ESD requires more student-centred learning approaches. Similarly, Bulut and Elci Oksuzoglu (2025) highlighted that limited integration of ESD within the curriculum, as well as the examination-oriented school systems constrains the meaningful incorporation of sustainability elements into science teaching and learning. Hence, this situation reflects broader limitations within the education system itself (Oliveira & Lanceros, 2021).

In addition, several previous studies emphasised that sustainability issues remain insufficiently integrated into science education (Baptista et al., 2025; Al-Barakat et al., 2025). For example, sustainability issues remain underemphasised in Biology despite the subject's has a great potential to cultivate sustainability knowledge and behaviour among students (Jackson et al., 2023). This finding is supported by Ridha et al. (2020), who reported that there's limited integration of ESD elements in Chemistry subject. Furthermore, the synthesis revealed that students often struggle to connect science learning with environmental contexts because sustainability-related issue like socioscientific issues (SSI) are insufficiently emphasised in schools (MacIntosh & Asghar, 2025; Gelmez & Reiss, 2024; Georgiou & Kyza, 2023). SSI refers to social dilemmas involving complex interactions between scientific, social, and cultural dimensions, including issues such as climate change, vaccination and the COVID-19 pandemic (Herman et al., 2022). Within the context of ESD, SSI encourages students to relate scientific learning to real-world situations, foster critical thinking and make evidence-based scientific judgements (Viehnmann et al., 2024). Consequently, the limited integration of SSI may hinder the relevance of science education and hinder the development of students' scientific literacy, particularly their ability to engage with real-world sustainability challenges critically and meaningfully.

Moreover, Väljataga and Mettis (2022) identified limitations in addressing socio-economic issues within science teaching and learning, particularly through collaborative inquiry-based approaches. Socio-economic issues are inherently complex, involving the intersection of social conditions and economic factors that affect society (Fiveable, 2024). Therefore, developing awareness of socio-economic issues is essential in enabling students to gain a deeper understanding of environmental challenges and make informed, evidence-based decisions (Väljataga & Mettis, 2022). In addition, the findings revealed that social, ethical and cultural dimensions remain underemphasised in science education (Georgiou & Kyza, 2023; Rahmawati et al., 2022; Pada et al., 2025). This is particularly evident in STEM education, where local cultural elements are often insufficiently integrated, limiting students' ability to understand sustainability issues within their own sociocultural contexts (Pada et al., 2025). According to Georgiou and Kyza (2023), fostering responsibility towards

sustainability issues is essential for achieving sustainable development and should therefore be nurtured among students to develop responsible citizenship. Interdisciplinary approaches in science education may offer valuable opportunities to incorporate social and ethical dimensions, including moral dilemmas, more meaningfully into classroom learning (Rahmawati et al., 2022). Hence, these findings collectively suggest that fostering students' sustainability thinking requires a holistic educational approach that integrates multiple dimensions of ESD through science education.

Meanwhile, challenges in fostering students' sustainability thinking are also closely associated with the role, competencies and readiness of science teachers. According to Haim and Aschauer (2024), teachers often face difficulties in integrating ESD into secondary school science syllabi due to limited knowledge of sustainability education. Similarly, Forsler et al. (2022) reported that science teachers demonstrated relatively low self-efficacy in teaching sustainability-related topics, which may indirectly influence students' learning experiences. These findings are consistent with the study by Bulut and Elci Oksuzoglu (2025), which found that teachers encounter challenges in integrating ESD because of their limited understanding of its broad and complex scope. Teachers also perceived that the natural abstract of ESD concepts may make sustainability issues difficult for students to comprehend. Thus, efforts to foster sustainability thinking among students may remain limited if teachers are not adequately prepared and confident in connecting sustainability issues with science education. This is particularly important because teachers' pedagogical practices can significantly influence students' attitudes and motivation in science learning (MacIntosh & Asghar, 2025)

Interventions Employed to Promote Students' Sustainability Thinking

The synthesis of previous studies revealed a wide range of interventions designed to foster students' sustainability thinking through science education (Table 4). One of the prominent approach involves connecting scientific concepts in science education to students' daily lives, while incorporating inquiry-based and collaborative learning, as well as linking science learning to local environmental contexts. These interventions not only strengthen students' understanding of environmental issues, but also encourage active participation through classroom- and school-based activities such as "Clean Your Classroom" activities, environmental awareness programmes, poster-making activities, and green school programmes. Similarly, Gelmez and Reiss (2024) highlighted the effectiveness of interventions such as Eco-School programmes, community-based projects and sustainability-oriented science communication activities in enhancing students' knowledge, awareness and understanding of sustainability and climate change issues. These approaches were also found to encourage sustainable behaviour and strengthen students' critical thinking skills. In addition, emphasis on ESD competencies particularly critical thinking and systems thinking, plays an important role in shaping students' values, attitudes and behavioural change, ultimately contributing to the development of sustainability thinking among students (Tuba Stouthart et al. 2025).

Furthermore, the findings from Table 4 demonstrate that diverse pedagogical approaches constitute a major intervention strategy in fostering students' sustainability thinking. Among the approaches identified were Inquiry-Based Science Education (IBSE) using the 5E instructional model (Engage, Explore, Explain, Elaborate and Evaluate), which

integrates science education with ESD to support the achievement of the Sustainable Development Goals (SDGs) (Baptista et al., 2025). Other approaches include integrated pedagogical models combining Problem-Based Learning (PBL), SDGs, and motivational frameworks such as Self-Determination Theory (SDT) (MacIntosh & Asghar, 2025), as well as Socio-Scientific Inquiry-Based Learning (SSIBL), which connects scientific literacy with sustainability-related issues (Georgiou & Kyza, 2023). Interdisciplinary approaches were also identified, including the Ethical Dilemma STEAM Teaching Model, which incorporates real-world learning into chemistry education (Rahmawati et al., 2022), and the Ethno-STEM model, which contextualises learning through local cultural elements (Pada et al., 2025). In a related study, Van der Leij et al. (2022) found that the Four Component Model (FCM) supports students' sustainability thinking more comprehensively, particularly in relation to moral reasoning and decision-making concerning environmental and socioscientific issues.

Other than that, the sustainability-oriented programmes and courses implemented through science education have been shown to effectively foster students' sustainability thinking. For instance, Miani et al. (2025) introduced a climate change course supported by educational games named the "FyouTURES" board game, which was found to enhance students' awareness and understanding of complex sustainability issues while reinforcing the relevance of science education. Likewise, the Science and Global Issues: Biology (SGI) programme under the Science Education for Public Understanding Program (SEPUP) expanded sustainability-related discussions within secondary school biology education (Jackson et al., 2023). Similarly, Haim and Aschauer (2024) reported that the year-long Innovative FOCUS (InFOCUS) programme, which integrates the domains of Flexibility, Originality, Creative Personality, Unconscious Mind and Strategies, was effective in connecting real-world problems with SDG elements while simultaneously enhancing students' interest and motivation in learning.

In addition, the integration of instructional materials and educational technologies emerged as another significant intervention in promoting sustainability thinking. Examples include the use of the Energy, Environment and Sustainability (KEAS) science kit to promote sustainability knowledge (Oliveira & Lanceros, 2021), mobile learning technologies that support students' understanding of socio-economic environmental challenges (Väljataga & Mettis, 2022) and Virtual Reality (VR) technology, which has been shown to enhance students' motivation, learning experiences and understanding of ESD concepts (Hsiao & Su, 2021). Nevertheless the effectiveness of these interventions is strongly influenced by teachers' pedagogical roles and practices in implementing sustainability-oriented science teaching and learning. According to Bronmmesson et al. (2025), teachers' didactical choices, particularly those grounded in interdisciplinary, for instance integrating action competence teaching approaches can encourage students to solve problems independently and develop competencies necessary for addressing sustainability-related issues, while also enriching learning experiences. Moreover, teachers serve as facilitators in connecting scientific concepts to students' everyday lives and local communities by creating interactive learning environments that enhance the effectiveness of sustainability-oriented interventions (Al-Barakat et al., 2025; MacIntosh & Asghar, 2025).

Improvement Strategies for Fostering Sustainability Awareness and Sustainable Actions among Students through Science Teaching and Learning

Based on Table 5, several improvement strategies were identified as having strong potential to foster sustainability awareness and sustainable actions among students more effectively through science teaching and learning. In Theme 1, the synthesis of previous studies suggests that the development of students' sustainability thinking requires a strong awareness of sustainability-related issues, as such awareness can encourage sustainable actions. Therefore, pedagogical approaches and interventions in science education should emphasise sustainability concepts and issues that are connected to real-world contexts. The findings indicate that interventions in enhancing active student engagement, including Eco-School activities (AlAli et al., 2025; Gelmez & Reiss, 2024), IBSE approaches (Baptista et al., 2025), Ethno-STEM interventions (Pada et al., 2025), as well as the emphasis on ESD competencies (Tuba Stouthart et al. 2025) contribute positively to the development of sustainable behaviour among students.

In addition, improvement strategies in science teaching and learning should be designed to enhance students' interest, motivation and active engagement through diverse pedagogical approaches that are grounded in real-world contexts and capable of addressing the complexity of sustainability-related issues (Themes 2, 3 and 4). This is particularly important as traditional and passive learning approaches have been found to be less effective in cultivating students' sustainability thinking (AlAli et al., 2025). Therefore, pedagogical diversity plays a crucial role in helping students develop a deeper understanding of sustainability issues, particularly through the integration of educational technologies that can enrich learning experiences in science education while simultaneously strengthening sustainability thinking, as demonstrated in the study by Väljataga and Mettis (2022).

Furthermore, the effectiveness of these improvement strategies is closely linked to the support provided to teachers in terms of professional training and the development of ESD competencies (Theme 5). Without adequate support, teachers may encounter difficulties in integrating sustainability elements effectively into science teaching. The findings of this review are consistent with Viehnmann et al. (2024), who reported that science teachers face several constraints in integrating ESD into classroom practice, including limited professional training, resistance to pedagogical change, insufficient knowledge of sustainability issues, as well as ethical challenges. Thus, strengthening teachers' ESD competencies is essential to ensure effective integration of sustainability education within science classrooms (Guo et al., 2024). In this regard, improvement strategies should also prioritise continuous professional development alongside the provision of appropriate teaching and learning resources to support effective intervention implementation, address existing challenges and foster more comprehensive and meaningful sustainability thinking among students.

Conclusion

This Systematic Literature Review (SLR), which synthesised 18 studies published between 2021 and 2025, highlights the significant role of science education in fostering students' sustainability thinking. The findings indicate that the development of sustainability thinking among students is constrained by several interconnected challenges, including the continued reliance on traditional teaching and learning approaches, difficulties in understanding complex sustainability issues encompassing socioscientific, social, ethical, and

socio-economic dimensions, as well as limitations related to teachers' competencies and readiness to integrate Education for Sustainable Development (ESD) into science education. The review further indicates that diverse interventions and pedagogical approaches that connect science learning with real-world sustainability issues have considerable potential to enhance students' scientific understanding, encourage sustainable behaviour, and strengthen sustainability thinking. Nevertheless, the effectiveness of these interventions is strongly influenced by the extent to which they are implemented holistically through effective pedagogical support from teachers.

The findings also suggest that effective improvement strategies should prioritise the development of students' awareness and understanding of sustainability-related issues. Science teaching and learning should therefore be contextualised and designed to enhance students' motivation, interest, and active participation, as these elements may contribute to the development of sustainable behaviour. Within this context, science teachers play a critical role in integrating ESD-related knowledge into classroom practice. However, limitations in teachers' knowledge, confidence and readiness to teach ESD may hinder the comprehensive implementation of sustainability-oriented science education. Therefore, educational stakeholders, particularly school administrators, should ensure continuous support for the development of teachers' ESD competencies, while policymakers are encouraged to review and strengthen the science curriculum to facilitate a more systematic and comprehensive integration of sustainability-oriented education within schools.

In addition, this study carries important implications for science teachers, educational stakeholders and future research. Science teachers are encouraged to diversify their pedagogical approaches by connecting scientific concepts with sustainability-related issues in ways that are interactive, contextual and relevant to students' lived experiences. Such approaches not only enhance students' scientific understanding, but also contribute to the development of values, moral responsibility towards the environment, and sustainable behaviour among students. Furthermore, science teachers should take proactive steps in strengthening their ESD competencies to facilitate more effective integration of sustainability elements within science education. At the institutional and policy levels, school administrators, curriculum developers and education policymakers should provide continuous support through professional training to strengthen teachers' competencies in ESD. Moreover, improvements to the science curriculum are necessary to facilitate more systematic integration of sustainability elements within science education. This review also contributes to the enrichment of existing literature on sustainability-oriented science education by providing a comprehensive synthesis of the challenges, interventions and improvement strategies associated with fostering students' sustainability thinking. The findings may therefore serve as a valuable reference for researchers, educators and policymakers in developing more sustainable and ESD-integrated educational frameworks and curricula.

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