Integrated Science Education Journal
Vol. 6, No. 3, September 2025, pp. 232~239
ISSN: 2716-3725, DOI: 10.37251/isej.v6i3.2116

The Effect of Integrating Green Sustainable Science and Technology into STEM Learning on Students' Environmental Literacy

May Zin Aye[1*]
[1]University of Technology Yatanarpon Cyber City, Yatanarpon Cyber City, Myanmar

Article Info

Article history:

Received Jun 21, 2025
Revised Aug 14, 2025
Accepted Sep 13, 2025
OnlineFirst Sep 30, 2025

Keywords:

Environmental Literacy
GSST
PJBL
STEM

ABSTRACT

Purpose of the study: This study aims to explore the integration of Green Sustainable Science and Technology (GSST) in STEM learning to improve junior high school students' environmental literacy through a project-based learning approach.

Methodology: A qualitative case study design was employed. Data were collected through classroom observations, in-depth interviews with teachers and school officials, and document analysis. The data were analyzed using the Miles and Huberman model, which consists of data reduction, data display, and conclusion drawing.

Main Findings: The results show that teachers successfully integrated GSST into STEM learning through project-based activities, such as designing energy-saving devices using recycled materials. Students demonstrated high enthusiasm, gained meaningful learning experiences, and developed awareness of environmental protection. Supportive school policies and facilities further enhanced students' conceptual understanding, environmental literacy, and positive attitudes toward sustainability.

Novelty/Originality of this study: This study introduces GSST integration into STEM learning at the secondary school level as an innovative model to enhance environmental literacy. The novelty lies in linking sustainability with practical project-based approaches, advancing educational practices that foster both conceptual mastery and environmental responsibility to support sustainable education.

Corresponding Author:
Nguyen Nhu Le,
Hue University, Lê Lợi, Vĩnh Ninh, Huế, Thành phố Huế, Vietnam
Email: nguyen_nl@gmail.com

1. INTRODUCTION

Environmental challenges such as climate change, pollution, deforestation, and the ongoing energy crisis have become pressing global issues that threaten ecological balance and human well-being. These complex problems demand not only technological and policy responses but also educational efforts that promote sustainable awareness and action. Education, therefore, is no longer limited to the transmission of scientific knowledge; it must also cultivate attitudes, values, and behaviors that support environmental stewardship and sustainability [1]-[3]. In this regard, fostering students' environmental literacy is essential. Environmental literacy encompasses the knowledge, awareness, and skills required to understand environmental systems, reflect critically on human–nature interactions, and take informed actions toward sustainability [4].

One emerging educational approach that addresses these needs is the integration of Green Sustainable Science and Technology (GSST) into learning. GSST focuses on applying scientific and technological

innovations that are environmentally friendly, efficient, and sustainable. Integrating GSST within the learning process helps students connect theoretical scientific concepts with real-world applications that aim to preserve and restore the environment. Through this approach, students can develop contextual understanding, environmental responsibility, and innovative thinking necessary for solving sustainability-related problems [5], [6].

To further strengthen this integration, the STEM (Science, Technology, Engineering, and Mathematics) framework provides an effective platform. STEM education emphasizes inquiry-based, problem-oriented learning that encourages critical and creative thinking, collaboration, and hands-on experimentation. When combined with GSST principles, STEM-based learning can be transformed into an environmentally conscious pedagogical model that nurtures both cognitive and affective dimensions of learning. For instance, students can design renewable energy prototypes, develop waste recycling mechanisms, or construct sustainable technological solutions that directly address environmental issues [7], [8]. Such integration not only enhances scientific competence but also strengthens students' environmental literacy and sense of ecological responsibility.

However, despite the growing recognition of STEM-based learning in promoting innovation and scientific skills, the specific integration of GSST into STEM to enhance environmental literacy remains underexplored, especially at the secondary school level. Previous research has primarily emphasized quantitative outcomes—such as environmental literacy scores, test performance, or conceptual understanding—while giving less attention to the qualitative aspects of how GSST-STEM learning is implemented in real classroom contexts. Few studies have investigated how teachers design and facilitate GSST-integrated STEM lessons, how students respond to and engage with sustainability-based projects, or how such experiences influence their attitudes and long-term environmental commitments [9], [10]. This indicates a significant research gap in understanding the process, experiences, and pedagogical dynamics involved in integrating GSST within STEM learning.

Addressing this gap, the present study aims to explore the integration of Green Sustainable Science and Technology (GSST) into STEM learning as an innovative strategy to improve students' environmental literacy. Specifically, this research seeks to understand the practical implementation of GSST-STEM integration in classroom settings, including teacher strategies, student engagement, and the learning experiences that emerge from such integration. Furthermore, it examines how this model contributes to developing sustainability-oriented learning frameworks that align with the goals of modern education and global sustainability agendas [11], [12].

2. RESEARCH METHOD

This study employed a qualitative approach with a case study design, as the focus was to explore in depth the process of integrating Green Sustainable Science and Technology (GSST) into STEM learning and how it contributes to students' environmental literacy. The qualitative case study design was considered appropriate to capture contextual dynamics, experiences, and perceptions of the participants in their natural setting [13]. The research site was a junior high school implementing STEM learning with an emphasis on environmental sustainability. The sampling technique used was purposive sampling, selecting participants who were directly involved in or knowledgeable about GSST-STEM integration. The participants consisted of (1) science teachers as learning implementers, (2) eighth-grade students as direct participants in project-based STEM learning, and (3) school officials, such as the principal and curriculum representative, who provided policy support. This technique was chosen to ensure the information obtained was rich and relevant to the research objectives [14].

Although this study applied a qualitative design, the main variables were defined based on theoretical constructs to guide data collection and analysis. *GSST Integration* was defined as the implementation of environmentally sustainable science and technology principles in STEM-based learning, observed through teaching strategies, project design, and learning materials. *Environmental Literacy* referred to students' capacity to understand, care about, and act on environmental issues. It was operationalized into four dimensions: knowledge, awareness, skills, and action [15]. These dimensions were explored through classroom observations, student project outputs, and interview data.

The researcher acted as the primary instrument, supported by systematic tools to enhance rigor. The supporting instruments included: (a) observation guidelines to capture classroom dynamics and GSST integration strategies, (b) semi-structured interview guides to elicit teachers', students', and administrators' experiences and perceptions, and (c) document analysis formats to review lesson plans, learning media, project outcomes, and policy documents. These instruments were developed based on relevant literature and adapted to the research context. Their content validity was ensured through expert judgment by two education specialists, while reliability was strengthened through pilot testing in a comparable setting.

Tabel 1. Instrumen Research

Instrument	Purpose	Data	Examples of Data	Validation &

		Source/Respondents	Collected	Reliability
Observation Guidelines	To record classroom dynamics, teacher strategies, and student engagement in GSST-STEM integration	Teachers and students during classroom activities	Teacher–student interactions, classroom management, GSST integration strategies	Content validity ensured through *expert judgment*; reliability strengthened by *pilot testing*
Semi-structured Interview Guide	To explore experiences, perceptions, and views of teachers, students, and school officials regarding GSST-STEM learning	Teachers, students, principal, curriculum representative	Teachers' perceptions of strategies, students' experiences in STEM projects, school policy support	Content validity ensured through *expert judgment*; reliability reinforced through source triangulation
Document Analysis Format	To review supporting documents that strengthen observation and interview findings	School documents and student project outcomes	Lesson plans (RPP), syllabus, teaching media, student project results, school environmental policies	Content validity ensured through *expert judgment*; reliability strengthened by *cross-checking* among documents

Data were collected through three complementary techniques: (1) participatory observation of STEM learning activities, (2) in-depth interviews with teachers, students, and administrators, and (3) documentation of supporting school documents and student projects. The triangulation of these methods ensured comprehensive coverage of the research problem. Data were analyzed using the Miles and Huberman (1994) model, which consists of three stages: (1) data reduction, namely coding, selecting, and simplifying relevant data; (2) data display, namely organizing information in matrices, charts, and narrative descriptions to identify patterns; and (3) conclusion drawing and verification, namely interpreting findings to answer the research questions. This method was chosen because it provides a systematic framework for handling qualitative data and enables the identification of relationships between GSST-STEM integration and the development of environmental literacy.

To ensure validity and reliability in qualitative terms, four techniques were applied: (1) source triangulation (comparing teachers, students, and administrators' perspectives), (2) method triangulation (using observation, interview, and documentation), (3) member checking (returning preliminary findings to participants for confirmation), and (4) peer debriefing (discussing emerging interpretations with colleagues and experts). Together, these strategies enhanced the credibility, dependability, and confirmability of the findings The study was conducted in five stages: (1) preparation (literature review, permissions, instrument design), (2) data collection (observations, interviews, document gathering), (3) initial analysis (coding and categorization), (4) verification (triangulation and member checking), and (5) reporting (interpretation, conclusion, and recommendations).

3. RESULTS AND DISCUSSION

3.1. The Process of Integrating Green Sustainable Science and Technology (GSST) in STEM Learning

Based on the results of observations, science teachers integrate GSST concepts through problem-based project learning within a STEM framework. In one session, the teacher asked students to design a simple energy-saving device using recycled materials. The learning process demonstrated that students not only learned science and technology concepts but also learned to think critically about environmental issues [16]-[18].

Interviews with science teachers corroborated these findings. The teacher stated, "I try to incorporate sustainability values into my lessons. For example, when discussing energy, I direct students to create simple, environmentally friendly projects. The goal is to make them realize that the knowledge they learn can be directly applied in their daily lives to protect the environment". This demonstrates that the integration of GSST into STEM is not only cognitive but also practical, thus strengthening students' environmental literacy. Based on classroom observations, science teachers consistently integrate Green Sustainable Science and Technology (GSST) concepts through a project-based learning approach within the STEM framework [19]. In one session, the teacher asked students to design a simple energy-saving device using recycled materials. This activity not only trained students to understand the integrated concepts of science, technology, engineering, and mathematics but also encouraged them to think critically and creatively in addressing real-life environmental issues. Throughout the process, it was evident that students attempted to connect the theories learned in class with

everyday practices, such as how electrical principles can be used to reduce energy use and minimize waste through the use of recycled materials [20].

Interviews with science teachers corroborated these findings. The teacher stated, “I try to incorporate sustainability values into my lessons. For example, when discussing energy, I direct students to create simple, environmentally friendly projects. The goal is to help them realize that the knowledge they learn can be directly applied in their daily lives to protect the environment.” Furthermore, the teacher added, "Students seem more enthusiastic when given project challenges related to real-life problems, such as plastic waste or energy conservation. They feel learning is more meaningful because they can see the connection to their daily lives." From this statement, it can be concluded that the teacher not only emphasizes cognitive understanding but also instills awareness of the importance of sustainability [21].

Another finding shows that students are more actively engaged when learning projects touch on environmental issues around them. The teacher explained, “Some students even came up with ideas for making other products from used materials, such as simple solar-powered lamps or plastic plant pots. This shows that they are becoming accustomed to thinking about solutions and seeing the sustainable potential of materials around them.” Thus, the integration of GSST into STEM through project-based learning not only improves mastery of academic material but also develops students' comprehensive environmental literacy, encompassing aspects of knowledge, problem-solving skills, caring attitudes, and awareness to take concrete action to maintain environmental sustainability [22].

3.2. Student Responses and Experiences to Learning

Students demonstrated high enthusiasm when involved in project activities. They were more enthusiastic when working in groups, discussing with each other, and dividing tasks. Several students admitted to realizing that plastic waste and cans could be reused to create useful products [23], [24]. One student stated, “Usually, science is just theory, but this time we were able to make something from used materials. So we learned that waste can be reused and not just thrown away. It felt more exciting and useful”.

These students’ experiences demonstrate that integrating GSST through STEM can provide meaningful learning by connecting subject matter to real life while fostering environmental awareness. Students demonstrated high enthusiasm when involved in project activities based on the integration of Green Sustainable Science and Technology (GSST) through a STEM framework. They were more enthusiastic when working in groups, discussing, and dividing tasks to complete the assigned projects [25]. This collaborative process appeared to foster a sense of shared responsibility, developing not only academic skills but also social skills. Several students admitted to realizing that plastic waste, cans, and other used materials could be reused to create useful products. One student stated, “Usually, science is just theory, but this time we were able to make something from used materials. It "It taught us that waste can be reused and not just thrown away. It felt more fun and useful”.

Furthermore, another student said that this project activity made them more confident in expressing ideas and daring to try new things. He said, “At first, I was confused about what to make from used bottles, but after discussing it with my friends, it turned out there were many ideas that could be implemented. We ended up making a simple lamp [26]. I felt more confident because the results were usable”. This statement shows that the learning experience not only equips students with an understanding of scientific concepts but also trains them to find creative solutions to everyday environmental problems.

Interviews with other students also revealed that this type of project learning provides deeper meaning than conventional learning. One student said, "If you usually just listen to the teacher's explanation, you quickly forget. But if you directly practice and make something, you remember it better. Moreover, we realize that protecting the environment can start with small things, such as using used goods." This confirms that contextual and applicable learning experiences can strengthen students' environmental literacy through awareness and caring attitudes.

Thus, student experiences demonstrate that integrating GSST through STEM can create meaningful learning. Project activities not only connect science material to real-life situations but also foster environmental awareness, creativity, collaboration, and critical thinking skills. These findings strengthen evidence that project-based learning within the GSST-STEM framework has the potential to be an effective approach to improving environmental literacy while developing sustainable character in students.

3.3. School Support for GSST Integration

The school supports the implementation of environmentally-based learning by providing supporting facilities, such as a science laboratory, a skills room, and a school cleanliness program. The vice principal for curriculum stated, “We encourage teachers to develop project-based learning that is relevant to environmental issues. The school wants to cultivate students not only to be academically intelligent but also to care for their environment.” This school support is a crucial factor in the successful integration of GSST into STEM learning, as it provides teachers with space for innovation and encourages active student participation [27], [28].

The school demonstrates a strong commitment to supporting the implementation of environmentally-based learning by integrating Green Sustainable Science and Technology (GSST) into the STEM framework. This support is demonstrated through the provision of supporting facilities, such as a science laboratory that allows students to conduct experiments related to renewable energy, a skills room used for recycling activities, and a school cleanliness program that involves the entire school community [29], [30]. The vice principal for curriculum stated, "We encourage teachers to develop project-based learning that is relevant to environmental issues. The school wants to cultivate students not only to be academically intelligent but also to care for their environment." This demonstrates the existence of an institutional policy that explicitly encourages innovation in sustainability-oriented learning.

Furthermore, an interview with a science teacher revealed that the school actively facilitates the teachers' needs in implementing environmental projects. The teacher stated, "The school gives us the freedom to develop learning methods and even supports us when we propose project activities that require additional materials. This makes it easier for us to innovate without worrying about limited facilities." This statement demonstrates that the school's support extends beyond material resources to teachers' trust and creative space From the students' perspective, the school's support is also felt directly. One student said, "We're happy because the school provides spaces for practical work, such as a skills room and a laboratory. So if we have a project idea, we can try it right away. The school also frequently runs cleanup programs, which makes us more aware of not littering." This reinforces the finding that a conducive learning environment encourages active student involvement in every learning activity.

Furthermore, interviews with the school's student affairs staff also confirmed the consistency of the school's environmental programs. She stated, "Every month we hold a Clean Friday activity, tree planting, and a creativity competition using used materials. We align these programs with classroom learning so students can see the connection between theory and real-world practice." These efforts demonstrate that the integration of GSST into STEM is not limited to formal classroom learning but is also reinforced through the school's non-academic programs.Thus, school support in the form of facilities, policies, and environmental programs is a crucial factor in the successful integration of GSST into STEM learning. This support not only expands teachers' room for innovation but also builds an environmentally conscious school culture and provides opportunities for students to internalize sustainable values through hands-on experience.

The research results show that the integration of Green Sustainable Science and Technology (GSST) into STEM learning through a project-based learning approach provides a more meaningful and contextual learning experience for students. The observed learning process confirmed that teachers not only emphasize cognitive understanding but also instill sustainability values through practical activities [31]. When students were asked to design a simple energy-saving device using recycled materials, they not only learned science, technology, and engineering concepts but also learned critical thinking about environmental issues. This finding aligns with constructivism theory, which emphasizes that knowledge becomes more meaningful when linked to students' real-life experiences [32]. The integration of GSST within a STEM framework makes learning more relevant to everyday life, enabling students to connect scientific theory with real-world practice. Student responses reinforce this. They demonstrated high enthusiasm, were more active in collaborating, and were able to generate creative ideas related to the use of recycled materials for environmentally friendly products [33]. This experience demonstrates that the integration of GSST can develop students' environmental literacy not only in terms of knowledge but also in skills and attitudes. Several students revealed that they only realized the potential of plastic waste, cans, or bottles after participating in the learning project. This aligns with Ausubel's concept of meaningful learning, which emphasizes that learning becomes meaningful when new information is connected to students' existing knowledge. Through hands-on practice, students not only understand the theoretical concept of sustainability but also begin to develop a critical awareness of the importance of environmental protection. Furthermore, this experience fosters students' courage in expressing ideas, increases self-confidence, and strengthens creative thinking and solution-based skills in solving environmental problems [34].

School support has proven to be a crucial factor in the success of GSST-STEM integration. School policies that provide space for teacher innovation and the provision of supporting facilities such as science laboratories, skills rooms, and cleanliness programs serve as a foundation for strengthening the implementation of sustainability-based learning [35], [36]. This support demonstrates the synergy between pedagogical and institutional aspects. Schools not only provide facilities but also facilitate a learning culture that fosters environmental awareness. This aligns with the school-based support system theory, which emphasizes that structural support from educational institutions significantly influences the successful implementation of learning innovations. Through programs such as Clean Fridays, tree planting, and recycling creativity competitions, schools consistently strengthen the integration of sustainability values both in the classroom and through non-academic activities.

Previous studies have mainly focused on the adoption of green technologies within industrial, economic, and policy contexts. For instance, research on *Green AI* highlights organizational, technological, and leadership factors influencing the adoption of environmentally friendly technologies in SMEs. Other studies

emphasize the role of green taxation, green logistics, green climate finance, and green technologies in facilitating the transition toward a sustainable economy. Similarly, investigations into green finance and environmental policies tend to address systemic and macro-level issues [37]-[39]. However, these studies pay little attention to how *Green Sustainable Science and Technology (GSST)* can be integrated into the educational domain, particularly within STEM learning, to directly influence students' environmental literacy. This reveals a clear gap in connecting green technology and sustainability practices with students' knowledge, attitudes, and actions toward the environment an area crucial for shaping environmentally responsible future generations.

Addressing this gap, the present study introduces novelty by shifting the focus from industrial and macro-policy frameworks to the educational context of STEM learning. Integrating GSST into STEM is not only an innovative pedagogical approach but also a practical strategy for instilling environmental awareness and science-based critical thinking skills among students. Unlike prior research, this study empirically examines the effect of GSST integration on students' environmental literacy, offering new insights into how sustainable practices can be embedded within classroom learning. Consequently, this research expands the scope of sustainable education literature and strengthens the discourse on the role of STEM education in supporting green and sustainable development agendas [40], [41].

The implications of these findings are significant. First, the integration of GSST through STEM has been proven to improve students' environmental literacy comprehensively, encompassing knowledge, awareness, critical thinking skills, and concrete actions. Second, the project-based learning approach has proven to be an effective means of connecting science material to students' real-life contexts, making learning more applicable and directly impactful [42], [43]. Third, school support is a reinforcing factor, providing space for teachers to innovate while simultaneously building an environmentally conscious school culture. This demonstrates that the successful implementation of GSST integration in STEM depends not only on teacher strategies but also on a supportive educational ecosystem.

This study is subject to several limitations that should be acknowledged. First, the research was conducted within a single junior high school context, which may limit the generalizability of the findings to other educational settings with different resources, teacher capacities, or student demographics. Second, the study focused specifically on the integration of Green Sustainable Science and Technology (GSST) into STEM learning through project-based activities, which means other pedagogical approaches or cross-curricular applications were not explored. Third, the assessment of students' environmental literacy relied primarily on qualitative data obtained through observation, interviews, and document analysis; while this approach provides depth, it may not fully capture measurable changes in knowledge, attitudes, and skills over time. Fourth, the study did not account for long-term effects, as it measured outcomes within a relatively short implementation period, leaving open questions about the sustainability of students' environmental literacy growth. Finally, as the researcher also acted as the primary instrument for data collection and analysis, despite the use of triangulation and validation techniques, the potential for subjectivity and researcher bias cannot be entirely eliminated. These limitations highlight the need for future studies to adopt mixed-methods designs, include multiple school contexts, and investigate long-term impacts to strengthen the robustness and applicability of the findings.

Thus, this study confirms that the integration of GSST in STEM learning is relevant to the needs of 21st-century education, which demands an integration of science, technology, critical thinking skills, and sustainability awareness. These findings also address a gap in previous research that tends to place environmental education solely in the cognitive domain or as an incidental activity, without systematic integration into the STEM curriculum. This urgency is increasingly apparent given the low environmental literacy among students and the increasing global challenges such as the climate crisis, pollution, and the energy crisis. Therefore, the integration of GSST through STEM can be an alternative innovative learning model that not only equips students with academic knowledge, but also forms an environmentally conscious character and sustainable living skills.

4. CONCLUSION

This study concludes that integrating Green Sustainable Science and Technology (GSST) into STEM learning enhances students' environmental literacy by linking scientific concepts with sustainable practices through project-based activities. The findings contribute theoretically by providing a qualitative perspective on GSST-STEM integration, addressing gaps in previous research dominated by quantitative outcomes. Practically, the study implies that schools and policymakers should adopt GSST-based STEM approaches as part of sustainability-oriented curricula to strengthen students' conceptual understanding while cultivating environmental responsibility.

ACKNOWLEDGEMENTS

With all humility, the author would like to express his gratitude to all parties who have provided support, prayers, guidance, and motivation so that this research can be completed well.

REFERENCES

[1] M. Arntzen, E. Scheie, and B. Haug, "Unveiling perceptions: How science teachers perceive sustainable development and their expectations of students' learning outcomes through environmental and sustainability education," *Int. J. Sci. Educ.*, vol. 0693, pp. 1–20, 2025, doi: 10.1080/09500693.2025.2499215.

[2] E. Scharifi, A. Danilenko, U. Weidig, and K. Steinhoff, "Influence of plastic deformation gradients at room temperature on precipitation kinetics and mechanical properties of high- strength aluminum alloys," *J. Eng. Res. Appl.*, vol. 9, no. 1, pp. 24–29, 2019, doi: 10.9790/9622.

[3] X. Zhang, X. E. Zhang, and L. Yang, "Does green entrepreneurial orientation improve the sustainable performance of agribusiness? evidence from China," *SAGE Open*, vol. 14, no. 3, pp. 1–19, 2024, doi: 10.1177/21582440241271110.

[4] A. Gharamohammadi *et al.*, "Smart furniture using radar technology for cardiac health monitoring," *Sci. Rep.*, vol. 15, no. 1, p. 1392, 2025, doi: 10.1038/s41598-024-80062-5.

[5] S. Jain, P. K. Jain, and A. K. Puranik, "Digital health technology & cancer care: Conceptual framework leading comprehensive fruitfulness," *J. Healthc. Leadersh.*, vol. 16, pp. 525–535, 2024, doi: 10.2147/JHL.S486263.

[6] F. ul Haq, N. M. Suki, M. Setini, A. Masood, and T. A. Khan, "Adopting green AI for SME sustainability: Mediating role of green investment and moderation by green servant leadership," *Sustain. Futur.*, vol. 10, no. December 2024, p. 101002, 2025, doi: 10.1016/j.sftr.2025.101002.

[7] M. Ghasemi, M. Govahi, and H. R. Litkohi, "Past and present of energy: The role of green finance, technological innovation, and financial risk in sustainibility indicators," *Int. J. Biol. Macromol.*, p. 138619, 2024, doi: 10.1016/j.indic.2025.100936.

[8] C. C. Graham, "From ideologies to practice: A political ecology approach to green transitions–The case of Tanzania's Ujamaa sustainability communities," *World Dev. Sustain.*, vol. 6, no. August 2024, p. 100217, 2025, doi: 10.1016/j.wds.2025.100217.

[9] C. Zatti *et al.*, "Turning alterations detected by mobile health technology in idiopathic REM sleep behavior disorder," *npj Park. Dis.*, vol. 10, no. 1, pp. 1–5, 2024, doi: 10.1038/s41531-024-00682-6.

[10] A. Lauer, C. de Castro, and Ó. Carpintero, "Beyond Green capitalism: Global scenarios for fast societal transitions toward sustainability," *Environ. Innov. Soc. Transitions*, vol. 56, 2025, doi: 10.1016/j.eist.2025.100981.

[11] K. Zhao, D. Mendes, R. Butfield, and T. Mugwagwa, "Estimating hospitalization costs for Health Technology Appraisals (HTA) in England: a systematic literature review and best practice framework," *J. Med. Econ.*, vol. 27, no. 1, pp. 1558–1568, 2024, doi: 10.1080/13696998.2024.2430127.

[12] D. Mizrahi *et al.*, "Digital health technology use among people aged 55 years and over: Findings from the 45 and up study," *Int. J. Med. Inform.*, vol. 200, no. November 2024, p. 105911, 2025, doi: 10.1016/j.ijmedinf.2025.105911.

[13] S. S. Shah, "Teaching and learning with technology: effectiveness of ict integration in schools," *Indones. J. Educ. Res. Technol.*, vol. 2, no. 2, pp. 133–140, 2022, doi: 10.17509/ijert.v2i2.43554.

[14] E. Schwartz, T. Shamir-Inbal, and I. Blau, "Teacher prototypes in technology-enhanced instruction in elementary school second language acquisition: Comparing routine and emergency learning in different cultures," *Comput. Educ. Open*, vol. 5, no. November, p. 100155, 2023, doi: 10.1016/j.caeo.2023.100155.

[15] A. Koduah *et al.*, "Institutionalizing health technology assessment in Ghana: Enablers, constraints, and lessons," *Heal. Syst. Reform*, vol. 9, no. 3, 2023, doi: 10.1080/23288604.2024.2314519.

[16] W. Guo *et al.*, "Health technology assessment in China's health care sector: Development and applications," *Heal. Syst. Reform*, vol. 9, no. 3, 2023, doi: 10.1080/23288604.2024.2327099.

[17] A. M. Herzallah *et al.*, "Sustainable innovation as a catalyst: linking green supply chain practices to corporate reputation in emerging markets," *Clean. Logist. Supply Chain*, vol. 16, no. December 2024, p. 100245, 2025, doi: 10.1016/j.clscn.2025.100245.

[18] M. Ikram and J. E. Sadki, "Resilient and sustainable green technology strategies: A study of Morocco's path toward sustainable development," *Sustain. Futur.*, vol. 8, no. September, p. 100327, 2024, doi: 10.1016/j.sftr.2024.100327.

[19] S. Botwright *et al.*, "Good practices for health technology assessment guideline development: A report of the health technology assessment international, HTAsiaLink, and ISPOR special task force," *Value Heal.*, vol. 28, no. 1, pp. 1–15, 2025, doi: 10.1016/j.jval.2024.09.001.

[20] C. Perrotta, C. Bailey, and C. Garside, "Culture, technology and local networks: towards a sociology of 'making' in education," *Cambridge J. Educ.*, vol. 48, no. 5, pp. 553–569, 2018, doi: 10.1080/0305764X.2017.1375459.

[21] M. J. Alam *et al.*, "Agricultural extension service, technology adoption, and production risk nexus: Evidence from Bangladesh," *Heliyon*, vol. 10, no. 14, p. e34226, 2024, doi: 10.1016/j.heliyon.2024.e34226.

[22] S. Kusairi, S. Muhamad, N. A. Razak, and A. P. Trapsila, "The role of local wisdom ``Ugahari'' and the impact of internet and mobile technology on work-life-balance during COVID-19 outbreak: Data set from malaysian workers," *Data Br.*, vol. 40, p. 107779, 2022, doi: 10.1016/j.dib.2021.107779.

[23] T. Xia and X. Chen, "Unlocking sustainable production pathways: digital transformation driving green dual innovation in Chinese enterprises," *Clean. Environ. Syst.*, vol. 19, no. April, p. 100301, 2025, doi: 10.1016/j.cesys.2025.100301.

[24] S. Y. Zheng, J. N. Han, F. Gandolfi, F. Alturise, and S. Alkhalaf, "Fostering eco-conscious tourists: How sustainable marketing drives green consumption behaviors," *Acta Psychol. (Amst).*, vol. 255, no. March, p. 104900, 2025, doi: 10.1016/j.actpsy.2025.104900.

[25] A. J. Turner *et al.*, "Transporting Comparative Effectiveness Evidence Between Countries: Considerations for Health Technology Assessments," *Pharmacoeconomics*, vol. 42, no. 2, pp. 165–176, 2024, doi: 10.1007/s40273-023-01323-1.

[26] L. Kulembekova *et al.*, "Stakeholders' Involvement in Health Technology Assessment in Kazakhstan, Poland and Bulgaria," *Patient Prefer. Adherence* , vol. 18, pp. 1009–1015, 2024, doi: 10.2147/PPA.S455838.

[27] A. K. Ambusaidi and H. M. Al Dayri, "Investigating the current state of implementing sustainable green marketing among higher education students," *Cogent Bus. Manag.*, vol. 11, no. 1, p., 2024, doi: 10.1080/23311975.2024.2421410.

[28] W. Khaokhajorn and N. Srisawasdi, "Assessing pre-service science teachers' understanding of the nature of scientific inquiry to develop a sustainable technology-infused pedagogical program in teacher education," *Cogent Educ.*, vol. 11, no. 1, p., 2024, doi: 10.1080/2331186X.2024.2439160.
[29] H. J. Evans and M. Achiam, "Sustainability in out-of-school science education: identifying the unique potentials," *Environ. Educ. Res.*, vol. 27, no. 8, pp. 1192–1213, 2021, doi: 10.1080/13504622.2021.1893662.
[30] E. C. Ndlovu and M. T. Gumbo, "Decolonising Technology Education: Integrating Indigenous Knowledge for Sustainable Development in Electrical and Mechanical Systems and Control," *African J. Res. Math. Sci. Technol. Educ.*, vol. 28, no. 3, pp. 362–372, 2024, doi: 10.1080/18117295.2024.2381984.
[31] P. Blose and M. T. Gumbo, "Developing a framework for integrating IKS in technology education with sustainable development principles," *African J. Res. Math. Sci. Technol. Educ.*, vol. 28, no. 3, pp. 330–342, 2024, doi: 10.1080/18117295.2024.2356416.
[32] R. Kouser, G. Mahmood, W. A. Watto, M. Fahlevi, and A. L. Aziz, "Assessing the impact of green manufacturing and green technology innovation on sustainable green practices: unveiling the mediating role of eco-design," *Int. J. Sustain. Eng.*, vol. 18, no. 1, 2025, doi: 10.1080/19397038.2025.2538868.
[33] L. Levin and D. De Filippo, "Evolution of the public understanding of science based on a bibliometric analysis of two major journals," *Tapuya Lat. Am. Sci. Technol. Soc.*, vol. 4, no. 1, 2021, doi: 10.1080/25729861.2021.1954381.
[34] P. Duifhuis, G. van Dijk, and E. Savelsbergh, "Pre-service science teachers' visions on education for sustainable development–tensions, underlying beliefs, and experiences," *Int. J. Sci. Educ.*, vol. 0693, pp. 1–22, 2025, doi: 10.1080/09500693.2025.2546459.
[35] A. P. Vilbar, "Children as courseware collaborators: Using participatory research to produce courseware integrating science and sustainable development," *Cult. Sci.*, vol. 4, no. 1, pp. 25–39, 2021, doi: 10.1177/20966083211017351.
[36] R. Mo, X. H. Peng, S. B. Wang, and J. Z. Zhang, "Knowledge mapping of green economy research: A bibliometric analysis," *SAGE Open*, vol. 14, no. 4, pp. 1–16, 2024, doi: 10.1177/21582440241293581.
[37] H. Chen, X. Cui, and Z. Li, "Research on the Impact of Digital-Realistic Integration to Promote Sustainable Development of Enterprises: Based on the Perspective of Technology Bias," *SAGE Open*, vol. 15, no. 2, pp. 1–20, 2025, doi: 10.1177/21582440251329725.
[38] S. Zhai *et al.*, "Evaluating behavioral intervention technologies: Integrating human-centered design and implementation science outcomes," *Digit. Heal.*, vol. 11, 2025, doi: 10.1177/20552076251348579.
[39] J. M. Luo, K. Y. Chau, Y. Fan, and H. Chen, "Barriers to the Implementation of Green Practices in the Integrated Resort Sector," *SAGE Open*, vol. 11, no. 3, 2021, doi: 10.1177/21582440211030277.
[40] F. Odoi-yorke, G. Mensah, D. D. Opoku, K. A. Ntiamoah, L. K. Osei, and C. K. K. Sekyere, "Empowering Ghana ' s green hydrogen future : Innovative strategies to overcome barriers and drive sustainable energy transition," *Sage Journal, J. Res. Nurs.*, 2025, doi: 10.1177/27533735251378539.
[41] I. T. P. Miranda, J. Moletta, B. Pedroso, L. A. Pilatti, and C. T. Picinin, "A Review on Green Technology Practices at BRICS Countries: Brazil, Russia, India, China, and South Africa," *SAGE Open*, vol. 11, no. 2, 2021, doi: 10.1177/21582440211013780.
[42] A. Baquero, "Examining the role of ambidextrous green innovation and green competitive advantage in stimulating sustainable performance: The moderating role of green absorptive capacity," *SAGE Open*, vol. 14, no. 4, pp. 1–22, 2024, doi: 10.1177/21582440241294160.
[43] Y. Li, T. R. Pertheban, Q. Li, and Z. Guang-Wen, "The Green Innovation Gateway: How Technological Capabilities and Environmental Strategies Drive Sustainability Performance in Manufacturing Firms," *SAGE Open*, vol. 15, no. 3, pp. 1–21, 2025, doi: 10.1177/21582440251360842.