CINEFORUM
ISSN: 0009-7039
Vol. 66. No. S2, 2026 (Special Issue 2)

Innovative Traits and Sustainable Development Practices among STEM Learners

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Abstract
Innovation and sustainable development constitute indispensable pillars in cultivating competent and socially accountable STEM learners capable of addressing contemporary global challenges. This study examined the innovative dispositions and sustainable development practices demonstrated by STEM learners within the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering. Employing an exploratory qualitative research design, the study involved 20 undergraduate STEM learners from selected higher education institutions in the Philippines. Empirical data were obtained through semi-structured interviews and subsequently analyzed using Reflexive Thematic Analysis. The findings revealed that the participants exhibited innovative dispositions through systematic problem-solving, analytical reasoning, adaptive planning, interdisciplinary integration, and sustainability-oriented decision-making. Moreover, the participants emphasized the practical implementation of innovation through modular system architecture, mathematical modeling, resource-efficient methodologies, and environmentally conscientious solutions to address sustainability-related concerns. The study further demonstrated that STEM learners perceive innovation as inherently associated with long-term sustainability, ethical responsibility, and collaborative problem-solving. Collectively, the findings suggest that experiential learning opportunities, interdisciplinary collaboration, and sustainability-centered educational practices substantially foster the development of innovation-driven and socially responsible STEM learners...
Keywords STEM Learners, Innovative Traits, Sustainable Development Practices, Sustainability-Oriented Innovation, STEM Education

Introduction

The escalating magnitude of worldwide environmental, economic, and societal concerns has amplified the imperative of sustainable development throughout educational institutions across the globe. The United Nations Sustainable Development Goals (SDGs) underscore the indispensable function of education in equipping learners to confront multifaceted sustainability concerns through innovation, critical reasoning, and ethically grounded decision-making (United Nations, 2022). Within Science, Technology, Engineering, and Mathematics (STEM) education, learners are anticipated not only to acquire technical proficiency but also to cultivate innovative dispositions that foster sustainable and socially accountable solutions (Cordaro et al., 2025).

Innovation has emerged as a fundamental dimension of STEM education because contemporary sustainability concerns necessitate interdisciplinary problem resolution, adaptability, creativity, and systems-oriented cognition. Amabile (2020) asserted that innovation encompasses the capacity to formulate original and purposeful solutions that respond to practical and societal demands. In a similar vein, Dyer et al. (2019) emphasized that innovative individuals exhibit critical reasoning, experimentation, observation, and collaborative problem-solving competencies that facilitate the creation of transformative solutions. Across STEM disciplines, these innovative characteristics are progressively associated with learners' capability to address concerns involving resource optimization, environmental sustainability, technological progression, and ethical accountability (Bai et al., 2021). Consequently, educational institutions assume a pivotal responsibility in fostering innovation-oriented learning environments that inspire learners to utilize acquired knowledge in creative and ethically responsible ways. Grancharova (2024) emphasized that STEM education advances sustainable development when learners participate in interdisciplinary instruction, experiential learning opportunities, and authentic problem-solving experiences. Correspondingly, Beers et al. (2020) explained that collaborative and experiential educational settings reinforce learners' capacity to formulate innovative responses to sustainability-related concerns. Collectively, these scholarly perspectives accentuate the necessity of embedding sustainability-oriented perspectives within STEM education to prepare learners for emerging global exigencies.

Recent scholarly discourse has likewise underscored that learners' engagement in sustainability-oriented STEM education extends beyond the acquisition of disciplinary knowledge and increasingly encompasses the cultivation of innovation competencies applicable to authentic societal concerns. According to Li (2025), educational systems that integrate sustainability principles within STEM learning foster learners' capacity to formulate context-responsive and ethically informed solutions to complex global challenges. Similarly, Castaño et al.. (2025) emphasized that developing innovation-related competencies, including adaptive reasoning, collaborative inquiry, and responsible decision-making, equips learners with the essential capabilities required to address emerging environmental and technological issues. These perspectives collectively reinforce the significance of examining how STEM learners internalize and operationalize innovative practices within sustainability-oriented contexts, thereby providing a stronger conceptual foundation for understanding their contributions toward sustainable development

Notwithstanding the increasing incorporation of sustainability principles within STEM curricula, a considerable proportion of existing scholarly literature concentrates on instructional models, curricular development, and policy execution rather than the innovative dispositions demonstrated by learners themselves (Bondoc, 2024; Calzada, 2024). Prevailing studies predominantly underscore educational strategies for sustainability while offering limited elucidation of how STEM learners personally conceptualize and operationalize innovation within sustainability-oriented contexts. Furthermore, there remains inadequate scholarly exploration regarding the manner in which learners from the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering exhibit distinctive yet interrelated innovative practices in addressing sustainability-related challenges.

The theoretical underpinning of this study is anchored in Bandura's Social Cognitive Theory, which posits that human behavior is shaped through the reciprocal interaction of personal determinants, environmental conditions, and behavioral experiences (Bandura, 1986). Within STEM educational environments, learners' innovative practices may consequently evolve through sustained engagement with academic activities, collaborative interactions, technological exposure, and sustainability-oriented challenges. This theoretical perspective reinforces the premise that innovation transcends an individual attribute and instead represents a socially and educationally constructed process cultivated through experiential learning and continuous problem-solving engagement.

To bridge the identified scholarly gap, the present study examined the innovative dispositions and sustainable development practices manifested by STEM learners. More specifically, the study explored how learners within the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering demonstrate innovation through creative problem-solving, adaptability, systems-oriented thinking, and sustainability-focused decision-making. Moreover, the study investigated how these innovative practices contribute to sustainability-oriented actions and problem-solving within their respective disciplinary contexts.

An exploratory qualitative research design was employed to examine learners' lived experiences, perspectives, and sustainability-oriented practices across STEM educational settings. The findings of the study may contribute to reinforcing sustainability-oriented STEM education, interdisciplinary innovation, and experiential learning approaches that advance the attainment of the Sustainable Development Goals. Additionally, the study may generate valuable insights into how educational institutions can cultivate innovation-driven and socially responsible learners equipped to contribute meaningfully to sustainable development initiatives.

2. METHODS

2.1 Research Design

This study adopted an exploratory qualitative research design to investigate the innovative dispositions and sustainable development practices demonstrated by STEM learners. An exploratory qualitative approach is particularly appropriate for examining educational phenomena that remain insufficiently examined and for acquiring comprehensive insights into participants' lived experiences, behavioral patterns, and perspectives within specific educational environments (Adalia et al., 2025). Braun and Clarke (2019) posited that qualitative inquiry enables researchers to construct in-depth interpretations of participants' experiences and the processes through which they attribute meaning to those experiences. Specifically, the study examined how learners within the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering manifest innovative dispositions and implement sustainability-oriented practices across academic and problem-solving contexts.

2.2 Participants and Sampling Procedure

The participants comprised 20 undergraduate STEM learners enrolled in the programs of Information and Communication Technology (ICT), Mathematics, Science, and Engineering from selected higher education institutions in the Philippines. Purposive sampling was employed to recruit participants who possessed firsthand involvement in innovation-driven academic endeavors, sustainability-related engagements, and interdisciplinary problem-solving experiences (Mundo et al., 2024).

The criteria for participant inclusion were as follows: (1) current enrollment in Information and Communication Technology (ICT), Mathematics, Science, or Engineering programs; (2) active engagement in academic activities involving problem-solving, experimentation, system development, or design-oriented tasks; and (3) exposure to sustainability-related concepts through coursework, academic projects, or classroom discussions. Participants were intentionally drawn from diverse STEM disciplines to capture a broad spectrum of perspectives concerning innovation and sustainability practices.

2.3 Research Instrument

A semi-structured interview guide served as the principal instrument for data collection in this study. The interview protocol was formulated to examine learners' innovative dispositions, approaches to problem-solving, sustainability-oriented practices, and experiences in addressing sustainability-related challenges within STEM learning environments.

The interview guide underwent expert validation by specialists in STEM education, sustainability studies, and qualitative research to ascertain its content relevance, clarity, and congruence with the objectives of the study. Furthermore, pilot testing was undertaken to refine the wording, organization, and sequence of the interview questions before the commencement of data collection (Chavez et al., 2024). The interview questions centered on: (1) innovative strategies employed in resolving complex academic and practical tasks; (2) experiences in generating original outputs and sustainability-oriented solutions; and (3) the implementation of innovative practices in addressing sustainability-related challenges across the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering.

2.4 Data Collection Procedure

Before initiating the data collection process, formal authorization to conduct the study was obtained from the respective higher education institutions. Participants were comprehensively informed regarding the objectives of the study, measures implemented to ensure confidentiality, the voluntary nature of their participation, and their right to discontinue participation at any point without incurring any form of penalty.

Empirical data were collected through individual semi-structured interviews conducted either in person or via secure online platforms, depending on the participants' availability and preferred mode of participation. Each interview was conducted for approximately 30 to 45 minutes, providing participants with the opportunity to articulate their experiences, practices, and perspectives concerning innovation and sustainability within their respective disciplines. Upon obtaining participants' consent, all interviews were audio-recorded to preserve accuracy during transcription and subsequent analysis. In addition, field notes and reflective observations were systematically documented throughout the data collection process to facilitate richer contextual interpretation of the findings.

2.5 Data Analysis

The qualitative data obtained from the interviews were examined through Reflexive Thematic Analysis in accordance with the analytical framework proposed by Braun and Clarke (2019). Reflexive thematic analysis constitutes a systematic qualitative analytical approach designed to identify recurrent themes, patterns, and underlying meanings across narrative datasets.

The analytical procedure encompassed six sequential phases: (1) familiarization with the data, (2) generation of initial codes, (3) searching for themes, (4) reviewing themes, (5) defining and naming themes, and (6) producing the final report. An inductive analytical strategy was adopted to enable themes to emerge organically from participants' narratives and lived experiences rather than being derived from predetermined assumptions. To reinforce the trustworthiness and credibility of the analysis, peer debriefing and reflective memoing were undertaken throughout the analytical process. Moreover, iterative comparisons across participants' narratives and disciplinary contexts were conducted to ensure the consistency, coherence, and rigor of the resulting interpretations.

2.6 Ethical Considerations

The study strictly complied with established ethical principles governing qualitative educational research. Informed consent was obtained from all participants before the commencement of data collection. Participants' identities, institutional affiliations, and responses were safeguarded through stringent measures ensuring confidentiality and anonymity. All information collected was utilized exclusively for academic and research purposes, and participants were explicitly informed of their right to withdraw from the study at any stage of the research process without any adverse consequences.

3. RESULTS

Research Objective 1. To determine the innovative dispositions demonstrated by STEM learners in relation to sustainable development practices.

Interview Question 1. What distinctive approaches do you usually adopt when facing complex tasks in ICT, Mathematics, Science, or Engineering?

1.1 Strategic Modular Task Management

Nine (9) participants articulated the utilization of strategic and modular approaches when addressing complex academic and technical tasks. They emphasized the importance of decomposing intricate problems into smaller, manageable components to alleviate complexity, enhance organizational efficiency, and maintain motivation throughout the problem-solving process. The findings indicate that STEM learners exhibit strategic planning, systematic task organization, and adaptive problem-solving capabilities when confronted with multifaceted disciplinary challenges.

"When I face a complicated programming task, I break it down into smaller modules so it doesn't feel too overwhelming."
"I use comments or to-do notes in my code and sometimes separate the functions into different files just to stay organized."

1.2 Analytical Experimental Reasoning

Another prominent theme emerging from the findings was analytical experimental reasoning. Thirteen (13) participants highlighted the importance of systematically evaluating procedures, examining variables, and utilizing reflective trial-and-adjustment strategies when resolving scientific and technical concerns. The findings suggest that learners exhibit analytical judgment, reflective experimentation, and evidence-guided problem-solving practices within STEM educational settings.

"If an experiment does not produce the expected outcome, I review my previous steps, repeat the procedure, and modify only one variable so I can accurately determine what influenced the result."
"I complete experiments sequentially because understanding the purpose behind every procedure is more valuable than simply following instructions."

1.3 Visual Planning Strategies

Ten (10) participants likewise emphasized the significance of visual planning in developing innovative and sustainable solutions. They explained that preparing sketches, diagrams, and preliminary layouts before implementation enables them to refine ideas more effectively. The findings reveal that visualization and adaptive planning strengthen learners' creativity, flexibility, and sustainability-oriented design capabilities.
"I prefer creating an initial sketch or layout because it allows me to visualize the complete concept and identify possible problems before implementation."
"Preparing visual drafts helps me revise specific components immediately whenever I recognize that an approach may not function effectively."

Interview Question 2. In what situations have your approaches resulted in original or innovative outputs?

2.1 Cross-Disciplinary Creative Integration
Eight (8) participants explained that innovative outputs frequently resulted from integrating concepts across multiple disciplines, exploring unconventional alternatives, and applying creative problem-solving approaches. The findings demonstrate that interdisciplinary integration and creative exploration substantially contribute to the production of innovative outputs within STEM disciplines.

"I integrated ideas from architecture, physics, and technology to develop a solution that was both practical and more innovative."
"Exploring different mathematical strategies instead of relying on only one method has strengthened both my creativity and adaptability."

2.2 Functional User-Centered Innovation
Another significant theme identified from the findings was functional user-centered innovation. Eleven (11) participants emphasized enhancing system performance, usability, and overall efficiency by incorporating additional features and refining design components. The findings indicate that learners apply innovation through improvements in functionality, adaptability, and user experience across technological and engineering environments.

"Once I completed the required features, I incorporated additional user-friendly functions and visual enhancements to make the system more effective."
"I developed the project as though it were an actual software application by organizing the program logic, interface design, and user interaction into separate components."

Interview Question 3. How do your approaches relate to sustainability practices within your discipline?

3.1 Sustainable Resource Optimization
Seven (7) participants associated their innovative practices with sustainability by emphasizing efficient resource utilization, minimizing unnecessary waste, and adopting environmentally responsible approaches during problem-solving. The findings indicate that learners associate innovation with environmental stewardship and sustainable resource optimization.

"Organizing problems into smaller modules minimizes unnecessary time, effort, and resources while improving the overall efficiency of the system."
"Designing systems that consume fewer resources helps reduce energy usage while minimizing negative environmental effects."

3.2 Sustainable Systems Perspective
Another important theme that emerged from the findings was sustainable systems perspective. Ten (10) participants emphasized evaluating future implications, sustainability outcomes, and long-term system functionality throughout planning and decision-making processes. The findings suggest that learners demonstrate sustainability-oriented thinking by integrating long-range planning and systems awareness into their approaches to problem-solving.

"Examining recurring patterns enables me to anticipate future consequences and make more informed decisions."
"For me, sustainability means managing today's resources responsibly while ensuring that future generations can still benefit from them."

Research Objective 2. To examine how STEM learners operationalize innovative dispositions in addressing sustainability-related challenges.

Interview Question 4. What sustainability-related challenges have you encountered in your field?

4.1 Sustainable Performance Resource Balance
Eleven (11) participants described encountering challenges associated with reconciling operational efficiency, functional performance, economic feasibility, and sustainability within their respective disciplines. The findings indicate that STEM learners recognize the practical and financial constraints involved in implementing sustainability-oriented solutions across diverse professional contexts.

"Developing systems that consume less energy while maintaining optimal performance is challenging because greater efficiency often demands additional resources."
"Environmentally sustainable structures generally require higher initial investments, making it difficult to persuade stakeholders to appreciate their long-term advantages."

Interview Question 5. How did you respond to sustainability-related challenges through your experiences?

5.1 Sustainable Innovative Decision Practices
Nine (9) Participants explained that they responded to sustainability-related challenges by adopting modular system architecture, evidence-informed decision-making, sustainability-focused planning, and advocacy for enduring environmental benefits. The findings suggest that learners demonstrate sustainability-oriented innovation through practical problem resolution and ethically responsible decision-making.

"I prioritize modular system designs because they allow individual components to be upgraded instead of replacing the entire system."
"I advocate for sustainable alternatives by emphasizing their long-term value, even when the initial investment is considerably higher."

Interview Question 6. What features of your actions demonstrate your contribution to sustainability practices within your field?

6.1 Responsible Sustainable Systems Innovation
Thirteen (13) participants emphasized that their contributions to sustainability are reflected through the development of adaptable systems, the minimization of unnecessary waste, the application of evidence-informed decision-making, and the prioritization of long-term environmental stewardship. The findings indicate that STEM learners demonstrate responsible, future-oriented innovative practices that advance sustainable development across the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering.

"I develop systems using modular architectures so individual components can be enhanced without replacing the entire structure."
"I apply mathematical modeling to anticipate future scenarios and formulate strategies that promote greater sustainability."

4. DISCUSSION
The findings of the study disclosed that STEM learners exhibit innovative dispositions through strategic problem resolution, analytical reasoning, adaptive planning, interdisciplinary synthesis, and sustainability-centered decision-making. Participants characterized innovation as a dynamic process encompassing creativity, adaptability, experimentation, and long-range thinking when responding to both academic and authentic real-world challenges. These findings corroborate the assertions of Amabile (2020), who emphasized that innovation entails the generation of meaningful and practical solutions through creative and analytical processes. In a similar manner, Dyer et al. (2019) explained that innovative individuals demonstrate experimentation, observation, adaptability, and problem-solving behaviors that facilitate transformative and socially consequential solutions.
The findings further demonstrated that STEM learners consistently employ modular and systematic approaches when managing complex tasks across the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering. Participants described decomposing intricate tasks into manageable segments, organizing procedural workflows strategically, and employing reflective experimentation throughout problem-solving activities. These findings are congruent with Kolodner et al. (2019), who emphasized that problem-based and experiential learning environments reinforce learners' analytical reasoning, adaptability, and innovative practices. Likewise, Pinar et al. (2025) explained that scientific problem-solving approaches cultivate learners' creativity, experimental competencies, and reflective thinking within STEM educational contexts.
Another noteworthy finding of the study pertains to the contribution of visualization and adaptive planning in reinforcing innovation and sustainability-oriented practices. Participants underscored the value of sketches, diagrams, prototypes, and design planning in anticipating potential challenges and refining solutions before implementation. These findings substantiate the perspective of Grancharova (2024), who explained that STEM learning environments emphasizing experiential and design-oriented activities enhance learners' innovative thinking and sustainability consciousness. Similarly, Beers et al. (2020) observed that collaborative and experiential learning practices strengthen learners' capacity to formulate creative and adaptive solutions for sustainability-related challenges.

The findings likewise revealed that learners closely associate innovation with sustainability-oriented thinking and environmental stewardship. Participants emphasized optimizing resource utilization, enhancing system efficiency, minimizing ecological impact, and developing enduring solutions within their respective disciplines. These findings are consistent with Bai et al. (2021), who emphasized that innovation within technological and scientific domains should promote sustainable resource utilization, responsible technological advancement, and environmental sustainability. Likewise, Cordaro et al. (2025) explained that STEM education contributes to sustainable development when learners incorporate ethical consciousness, systems-oriented thinking, and long-term sustainability considerations into their problem-solving practices.

Another substantial finding of the study was the significance of interdisciplinary integration in generating innovative outputs. Participants described synthesizing concepts from Information and Communication Technology (ICT), Mathematics, Science, and Engineering to develop solutions that are more functional, efficient, and sustainable. These findings reinforce the assertions of Cordaro et al. (2025), who emphasized that interdisciplinary collaboration enhances learners' capacity to address complex sustainability challenges through integrated and innovative approaches. Furthermore, the findings indicate that sustainability-oriented innovation within STEM education extends beyond technical proficiency and encompasses collaborative engagement, reflective practice, and systems-oriented thinking.

The study additionally revealed that STEM learners encounter challenges associated with balancing operational efficiency, sustainability, economic feasibility, and long-term implications within their respective disciplines. Participants described difficulties in developing energy-efficient systems, promoting evidence-informed sustainability decisions, and encouraging support for sustainable innovations despite higher initial investments. These findings support the observations of Bai et al. (2021), who explained that sustainability-oriented innovation frequently involves balancing performance demands, resource utilization, and economic considerations. Similarly, Lai (2023) emphasized that sustainability-focused technological innovation requires harmonizing practicality, operational efficiency, and long-term environmental responsibility.

Despite these challenges, participants demonstrated sustainability-oriented innovation through modular system architecture, mathematical modeling, evidence-informed planning, and advocacy for environmentally responsible solutions. Learners emphasized designing adaptable systems, minimizing unnecessary waste, and advancing long-term sustainability benefits within their respective fields. These findings are aligned with Bandura's Social Cognitive Theory, which posits that innovative and socially responsible behaviors evolve through the reciprocal interaction among individual experiences, environmental influences, and problem-solving engagement (Bandura, 1986). Accordingly, the findings suggest that STEM learning environments substantially influence learners' development of innovation-oriented and sustainability-centered practices.

The findings further imply that higher education institutions assume a pivotal role in reinforcing sustainability-oriented innovation among STEM learners. Educational institutions may derive substantial benefits from integrating experiential learning, interdisciplinary collaboration, project-based instruction, and sustainability-focused problem-solving activities into STEM curricula. Such educational practices may further facilitate the cultivation of innovation-driven learners capable of addressing sustainability-related challenges within technological, scientific, and engineering disciplines.

Notwithstanding the favorable findings of the study, several limitations warrant acknowledgment. The study involved a relatively limited cohort of participants drawn from selected higher education institutions in the Philippines, which may constrain the broader transferability of the findings across diverse educational contexts. Furthermore, the study relied predominantly on learners' self-reported experiences and perceptions concerning innovation and sustainability-oriented practices. Future scholarly endeavors may further investigate sustainability-oriented innovation among STEM learners through longitudinal research designs, classroom-based observations, mixed-methods methodologies, and expanded participant populations representing multiple institutional settings.

5. CONCLUSION

The study concluded that STEM learners exhibit innovative dispositions through strategic problem resolution, analytical reasoning, adaptive planning, interdisciplinary synthesis, and sustainability-centered decision-making across the disciplines of Information and Communication Technology (ICT), Mathematics, Science, and Engineering. Learners actively operationalize these innovative practices in addressing sustainability-related challenges through resource-optimized solutions, modular system architecture, mathematical modeling, and environmentally conscientious planning.

The findings further disclosed that STEM learners conceptualize innovation as intrinsically associated with long-term sustainability, ethical accountability, and collaborative problem-solving. Participants demonstrated a heightened awareness of the significance of mitigating environmental impact, optimizing resource utilization, and formulating adaptable, resilient, and sustainable solutions within their respective disciplinary domains.

The study suggests that higher education institutions may further reinforce sustainability-oriented innovation among STEM learners by incorporating experiential learning opportunities, interdisciplinary collaboration, and project-based sustainability initiatives into STEM curricula. Future scholarly inquiries may further examine the longitudinal cultivation of innovation-driven and sustainability-centered practices among STEM learners across more diverse educational settings and institutional contexts.

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