Innovative Traits and Sustainable Development Practices among STEM Learners

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Abstract: This study explored the innovative traits and sustainable development practices among STEM learners within Information and Communication Technology (ICT), Mathematics, Science, and Engineering contexts. The study employed an exploratory qualitative research design involving 20 undergraduate STEM learners from selected higher education institutions in the Philippines. Data were gathered through semi-structured interviews and analyzed using Reflexive Thematic Analysis. The findings revealed that learners demonstrate innovative traits through strategic problem-solving, analytical thinking, adaptive planning, interdisciplinary integration, and sustainability-oriented decision-making. Participants also emphasized applying innovation through modular system design, mathematical modeling, resource-efficient practices, and environmentally responsible solutions to address sustainability-related challenges. The study further revealed that STEM learners associate innovation with long-term sustainability, ethical responsibility, and collaborative problem-solving. The findings suggest that experiential learning, interdisciplinary collaboration, and sustainability-focused educational practices contribute significantly to 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 growing urgency of global environmental, economic, and social challenges has intensified the importance of sustainable development across educational systems worldwide. The United Nations

Sustainable Development Goals (SDGs) emphasize the critical role of education in preparing learners to address complex sustainability issues through innovation, critical thinking, and responsible decision-making (United Nations, 2022). In Science, Technology, Engineering, and Mathematics (STEM) education, learners are expected not only to develop technical competence but also to cultivate innovative traits that contribute to sustainable and socially responsible solutions (Cordaro et al., 2025).

Innovation has become an essential component of STEM learning because modern sustainability challenges require interdisciplinary problem-solving, adaptability, creativity, and systems-oriented thinking. According to Amabile (2020), innovation involves the ability to generate original and meaningful solutions that address practical and societal concerns. Similarly, Dyer et al. (2019) emphasized that innovative individuals demonstrate critical thinking, experimentation, observation, and collaborative problem-solving skills that support the development of transformative solutions. Within STEM disciplines, these innovative traits are increasingly associated with learners' ability to respond to issues related to resource efficiency, environmental sustainability, technological advancement, and ethical responsibility (Bai et al., 2021).

Educational institutions therefore play a significant role in cultivating innovation-oriented learning environments that encourage learners to apply knowledge creatively and responsibly. Grancharova (2024) emphasized that STEM education supports sustainable development when learners engage in interdisciplinary learning, experiential activities, and real-world problem-solving tasks. Likewise, Beers et al. (2020) explained that collaborative and experiential learning environments strengthen learners' capacity to develop innovative approaches toward sustainability-related challenges. These perspectives highlight the importance of integrating sustainability-oriented thinking within STEM education to prepare learners for future global demands.

Despite the growing integration of sustainability concepts within STEM curricula, much of the existing literature focuses on instructional frameworks, curriculum design, and policy implementation rather than on the innovative traits demonstrated by learners themselves (Bondoc, 2024; Calzada, 2024). Existing studies often emphasize educational strategies for sustainability but provide limited understanding of how STEM learners personally conceptualize and apply innovation within sustainability-related contexts. Moreover, there remains insufficient exploration regarding how learners from ICT, Mathematics, Science, and Engineering disciplines demonstrate distinct yet interconnected innovative practices in addressing sustainability challenges.

Theoretical support for the study is anchored on Bandura's Social Cognitive Theory, which explains that human behavior is influenced by the interaction among personal factors, environmental conditions, and behavioral experiences (Bandura, 1986). Within STEM learning environments, learners' innovative practices may therefore develop through continuous interaction with academic tasks, collaborative experiences, technological exposure, and sustainability-oriented challenges. This framework supports the assumption that innovation is not merely an individual ability but a socially and educationally influenced process shaped through experiential learning and problem-solving engagement.

To address the identified gap, the present study explored the innovative traits and sustainable development practices among STEM learners. Specifically, the study examined how learners in ICT, Mathematics, Science, and Engineering demonstrate innovation through creative problem-solving, adaptability, systems-oriented thinking, and sustainability-oriented decision-making. The study further explored how these innovative practices contribute to sustainability-related actions and problem-solving within their respective disciplines.

The study employed an exploratory qualitative research design to examine learners' experiences, perspectives, and sustainability-oriented practices within STEM education contexts. The findings of the study may contribute to strengthening sustainability-oriented STEM education, interdisciplinary innovation, and experiential learning practices that support the achievement of the Sustainable Development Goals. Furthermore, the study may provide insights into how educational institutions can cultivate innovation-driven and socially responsible learners capable of contributing to sustainable development initiatives.

METHODS

2.1 Research Design

This study employed an exploratory qualitative research design to examine the innovative traits and sustainable development practices among STEM learners. Exploratory qualitative research is appropriate for investigating underexplored educational phenomena and understanding participants' experiences, behaviors, and perspectives within specific learning contexts (Adalia et al., 2025). According to Braun and Clarke (2019), qualitative inquiry allows researchers to generate in-depth interpretations of participants' experiences and meaning-making processes. The study specifically explored how learners in ICT, Mathematics, Science, and Engineering demonstrate innovative traits and apply sustainability-oriented practices within academic and problem-solving contexts.

2.2 Participants and Sampling Procedure

The participants of the study consisted of 20 undergraduate STEM learners enrolled in Information and Communication Technology (ICT), Mathematics, Science, and Engineering programs from selected higher education institutions in the Philippines. Purposive sampling was utilized to select participants who possessed direct experiences related to innovation-oriented academic tasks, sustainability-related activities, and interdisciplinary problem-solving experiences (Mundo et al., 2024).

The inclusion criteria for participant selection were: (1) currently enrolled in ICT, Mathematics, Science, or Engineering programs; (2) active participation in academic activities involving problem-solving, experimentation, system development, or design tasks; and (3) exposure to sustainability-related concepts through coursework, projects, or academic discussions. Participants represented diverse STEM disciplines to capture varying perspectives regarding innovation and sustainability practices.

2.3 Research Instrument

The study utilized a semi-structured interview guide as the primary instrument for data collection. The interview questions were designed to explore learners' innovative traits, approaches to problem-solving, sustainability-oriented practices, and experiences in addressing sustainability-related challenges within STEM contexts.

The interview guide underwent expert validation involving specialists in STEM education, sustainability studies, and qualitative research to ensure content relevance, clarity, and alignment with the objectives of the study. Pilot testing was also conducted to refine the wording and sequencing of interview questions prior to data collection (Chavez et al., 2024).

The interview questions focused on: (1) innovative approaches used in solving complex academic and practical tasks, (2) experiences in producing original outputs and sustainability-oriented solutions, and (3) the application of innovative practices in addressing sustainability-related challenges within ICT, Mathematics, Science, and Engineering disciplines.

2.4 Data Collection Procedure

Prior to data collection, permission to conduct the study was secured from the respective higher education institutions. Participants were informed regarding the objectives of the study, confidentiality measures, voluntary participation, and their right to withdraw from the study at any stage without penalty.

Data were gathered through one-on-one semi-structured interviews conducted either face-to-face or through secure online platforms depending on participants' availability and preferences. Each interview lasted approximately 30 to 45 minutes and encouraged participants to openly share their experiences, practices, and perspectives related to innovation and sustainability within their disciplines.

With participants' consent, interviews were audio-recorded to ensure accuracy in transcription and analysis. Field notes and reflective observations were also documented throughout the data collection process to support contextual interpretation of the findings.

2.5 Data Analysis

The qualitative data gathered from the interviews were analyzed using Reflexive Thematic Analysis following the framework developed by Braun and Clarke (2019). Reflexive thematic analysis is a systematic qualitative approach used to identify recurring themes, patterns, and meanings across narrative datasets.

The analysis involved six 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 approach was employed to allow themes to emerge directly from participants' responses and experiences rather than from predetermined assumptions.

To strengthen trustworthiness and credibility, peer debriefing and reflective memoing were conducted throughout the analysis process. Repeated comparisons across participant narratives and disciplinary contexts were also performed to ensure consistency and coherence of interpretations.

2.6 Ethical Considerations

The study adhered to ethical principles in conducting qualitative educational research. Informed consent was secured from all participants prior to data collection. Participants' identities, institutional affiliations, and responses were treated with strict confidentiality and anonymity. All collected data were used solely for academic and research purposes, and participants were informed of their right to withdraw from the study at any stage of the research process.

RESULTS

Research Objective 1

To identify the innovative traits 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?

Theme 1: Strategic and Modular Problem-Solving Approaches

Participants described using strategic and modular approaches when solving complex academic and technical tasks. Learners emphasized the importance of breaking problems into manageable components to reduce difficulty, improve organization, and sustain motivation during problem-solving processes. The findings indicate that STEM learners demonstrate strategic planning, task organization, and adaptive problem-solving behaviors when dealing with complex 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."

Theme 2: Systematic Experimentation and Analytical Thinking

Another theme that emerged from the findings was systematic experimentation and analytical thinking. Participants emphasized carefully analyzing procedures, evaluating variables, and using reflective trial-and-error strategies in solving scientific and technical problems. The findings suggest that learners demonstrate analytical reasoning, reflective experimentation, and evidence-based problem-solving practices within STEM learning environments

"If a step fails, I don't panic. I check my notes, repeat the step, and change only one variable at a time so I can tell what caused the change."

"I approach complex experiments step by step and try to understand the reason behind each process instead of just copying procedures."

Theme 3: Visualization and Adaptive Planning

Participants also emphasized the importance of visualization and planning in generating innovative and sustainable solutions. Learners described creating sketches, diagrams, and design drafts before implementing projects or solutions. The findings indicate that visualization and adaptive planning support learners' creativity, flexibility, and sustainability-oriented design thinking.

"I always start with a clear plan or sketch because visualization helps me see the bigger picture and spot possible issues early."

"When I sketch things out, I can easily adjust parts if I notice something that won't work."

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

Theme 4: Creative and Interdisciplinary Innovation

Participants explained that innovative outputs often emerged when they integrated concepts from multiple disciplines, experimented with alternative approaches, and explored creative problem-solving strategies. The findings demonstrate that interdisciplinary integration and creative exploration contribute to learners' innovative outputs within STEM disciplines.

"I mixed concepts from architecture, physics, and technology to make my design more functional and creative."

"Math problems can be solved in multiple ways, and exploring different paths helps me become more flexible and creative."

Theme 5: Technology-Driven and User-Oriented Innovation

Another significant theme that emerged was technology-driven and user-oriented innovation. Participants emphasized improving system functionality, user experience, and efficiency through additional features and design improvements. The findings indicate that learners apply innovation by enhancing functionality, adaptability, and usability within technological and engineering contexts.

"After finishing the main requirements, I added user-friendly features and animations to improve the system."

"I treated the project like a real system by separating the logic, design, and user interaction modules."

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

Theme 6: Resource Efficiency and Environmental Responsibility

Participants associated their innovative practices with sustainability through efficient resource utilization, waste reduction, and environmentally responsible problem-solving approaches. The findings indicate that learners connect innovation with environmental responsibility and sustainable resource management practices

"Breaking problems into modules helps reduce wasted time and resources while making systems more efficient."

"When systems use fewer resources, they reduce electricity consumption and environmental impact."

Theme 7: Long-Term and Systems-Oriented Thinking

Another theme that emerged from the findings was long-term and systems-oriented thinking. Participants emphasized considering future impacts, sustainability outcomes, and long-term functionality during planning and decision-making processes. The findings suggest that learners demonstrate sustainability-oriented thinking by integrating long-term planning and systems awareness into their problem-solving practices.

"Analyzing patterns helps me understand long-term impacts and make better decisions."

"Sustainability means using resources wisely today without compromising future needs."

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

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

Theme 8: Balancing Performance, Cost, and Sustainability

Participants described challenges related to balancing efficiency, performance, affordability, and sustainability within their respective disciplines. The findings indicate that STEM learners recognize practical and economic challenges associated with implementing sustainability-oriented solutions.

"Designing systems that use less energy but still work efficiently is difficult because high performance usually consumes more resources."

"Sustainable structures often cost more at the start, so it's difficult to convince people about the long-term benefits."

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

Theme 9: Sustainability-Oriented Innovation and Advocacy

Participants explained that they addressed sustainability challenges through modular design, data-driven decision-making, sustainable planning, and advocacy for long-term environmental benefits. The findings suggest that learners demonstrate sustainability-oriented innovation through practical problem-solving and responsible decision-making practices.

"I focus on modular designs so systems can be upgraded instead of replacing everything."

"I defend sustainable solutions by explaining their long-term benefits even if the initial cost is higher."

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

Theme 10: Responsible and Future-Oriented Innovation

Participants emphasized that their contributions to sustainability involve designing adaptable systems, minimizing waste, applying evidence-based decision-making, and prioritizing long-term environmental responsibility. The findings indicate that STEM learners demonstrate responsible and future-oriented innovation practices that contribute to sustainable development within ICT, Mathematics, Science, and Engineering contexts.

"I design systems with modular structures so parts can be updated without replacing everything."

"I use mathematical modeling to predict future outcomes and create more sustainable strategies."

DISCUSSION

The findings of the study revealed that STEM learners demonstrate innovative traits through strategic problem-solving, analytical thinking, adaptive planning, interdisciplinary integration, and sustainability-oriented decision-making. Participants described innovation as a process that involves creativity, flexibility, experimentation, and long-term thinking when addressing academic and real-world challenges. These findings support Amabile (2020), who emphasized that innovation involves generating meaningful and practical solutions through creative and analytical processes. Similarly, Dyer et al. (2019) explained that innovative individuals demonstrate experimentation, observation, adaptability, and problem-solving behaviors that contribute to transformative and socially relevant solutions.

The findings further revealed that STEM learners commonly utilize modular and systematic approaches when addressing complex tasks in ICT, Mathematics, Science, and Engineering contexts. Participants described breaking tasks into smaller components, organizing processes strategically, and applying reflective experimentation during problem-solving activities. These findings align with Kolodner et al. (2019), who emphasized that problem-based and experiential learning environments strengthen learners' analytical reasoning, adaptability, and innovation practices. Likewise, Pinar et al. (2025) explained that scientific problem-solving approaches encourage learners to develop creativity, experimentation skills, and reflective thinking within STEM education contexts.

Another important finding of the study was the role of visualization and adaptive planning in supporting innovation and sustainability-oriented practices. Participants emphasized the importance of sketches, diagrams, prototypes, and design planning in identifying possible problems and improving solutions before implementation. These findings support Grancharova (2024), who explained that STEM learning environments promoting experiential and design-oriented activities strengthen learners' innovative thinking and sustainability awareness. Similarly, Beers et al. (2020) noted that collaborative and experiential learning practices enhance learners' capacity to develop creative and adaptive solutions for sustainability-related challenges.

The findings also demonstrated that learners associate innovation with sustainability-oriented thinking and environmental responsibility. Participants emphasized reducing wasted resources, improving system efficiency, minimizing environmental impact, and designing long-term solutions within their disciplines. These findings are consistent with Bai et al. (2021), who emphasized that innovation within technological and scientific fields should support sustainable resource utilization, responsible technological development, and environmental sustainability. Likewise, Cordaro et al. (2025) explained that STEM education contributes to sustainable development when learners integrate ethical awareness, systems-oriented thinking, and long-term sustainability considerations into problem-solving practices.

Another significant finding of the study was the importance of interdisciplinary integration in generating innovative outputs. Participants described combining concepts from ICT, Mathematics, Science, and Engineering to create more functional, efficient, and sustainable solutions. These findings support Cordaro et al. (2025), who emphasized that interdisciplinary collaboration strengthens learners' ability to address complex sustainability challenges through integrated and innovative approaches. The findings further suggest that sustainability-oriented innovation within STEM education extends beyond technical competence and involves collaborative, reflective, and systems-oriented thinking practices.

The study also revealed that STEM learners encounter challenges related to balancing efficiency, sustainability, affordability, and long-term impact within their disciplines. Participants described difficulties in designing energy-efficient systems, promoting data-driven sustainability decisions, and encouraging support for sustainable innovations despite higher initial costs. These findings support Bai et al. (2021), who explained that sustainability-oriented innovation often involves tensions between performance, resource consumption, and economic considerations. Similarly, Lai (2023) emphasized that sustainability-focused technological innovation requires balancing practicality, efficiency, and long-term environmental responsibility.

Despite these challenges, participants demonstrated sustainability-oriented innovation through modular system design, mathematical modeling, data-driven planning, and advocacy for environmentally responsible solutions. Learners emphasized designing adaptable systems, minimizing waste, and promoting long-term sustainability benefits within their respective fields. These findings align with Bandura's Social Cognitive Theory, which explains that innovative and socially responsible behaviors develop through interactions among individual experiences, environmental influences, and problem-solving engagement (Bandura, 1986). The findings therefore suggest that STEM learning environments significantly influence learners' development of innovation-oriented and sustainability-focused practices.

The findings imply that higher education institutions play a crucial role in strengthening sustainability-oriented innovation among STEM learners. Educational institutions may benefit from integrating experiential learning, interdisciplinary collaboration, project-based instruction, and sustainability-focused problem-solving activities within STEM curricula. These practices may further support the development of innovation-driven learners capable of addressing sustainability-related challenges within technological, scientific, and engineering contexts.

Despite the positive findings of the study, several limitations should be acknowledged. The study involved a limited number of participants from selected higher education institutions in the Philippines, which may affect the generalizability of the findings across broader educational settings. In addition, the study relied primarily on learners' self-reported experiences and perceptions regarding innovation and sustainability practices. Future studies may further examine sustainability-oriented innovation among STEM learners using longitudinal designs, classroom observations, mixed-methods approaches, and larger participant populations across multiple institutional contexts.

CONCLUSION

The study concluded that STEM learners demonstrate innovative traits through strategic problem-solving, analytical thinking, adaptive planning, interdisciplinary integration, and sustainability-oriented decision-making within ICT, Mathematics, Science, and Engineering contexts. Learners actively apply these innovative practices in addressing sustainability-related challenges through resource-efficient solutions, modular system design, mathematical modeling, and environmentally responsible planning.

The findings further revealed that STEM learners associate innovation with long-term sustainability, ethical responsibility, and collaborative problem-solving. Participants demonstrated awareness of the importance of reducing environmental impact, optimizing resources, and developing adaptable and sustainable solutions within their respective disciplines.

The study suggests that higher education institutions may strengthen sustainability-oriented innovation among STEM learners by integrating experiential learning, interdisciplinary collaboration, and project-based sustainability activities within STEM curricula. Future studies may further explore the long-term development of innovative and sustainability-focused practices among STEM learners across broader educational and institutional contexts.

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