Multi-Stakeholder Feedback Analysis of a Solar-Powered IoT Hydroponic STEM Module: Impact, Perceptions and Optimization

M. M. Khalid[1], N. Hasan[2], W.A. Manap[3]

[1]Politeknik Mersing,
86800 Mersing, Johor, Malaysia.

[2]Politeknik Sultan Mizan Zainal Abidin,
23000 Dungun, Terengganu, Malaysia.

[3]Politeknik Kuala Terengganu,
20200 Kuala Terengganu, Terengganu, Malaysia.

*Corresponding Author's Email: maizahtulakma@tvet.pmj.edu.my
Article History: Received 15 August 2025; Revised 1 October 2025; Accepted 28 October 2025;

Abstract
This study presents a comprehensive evaluation of a Solar-Powered IoT Hydroponic Module, implemented as a hands-on STEM educational workshop for secondary school students in collaboration with Universiti Malaysia Terengganu. Structured feedback was collected from student participants, accompanying teachers, and organizing committee members to assess the workshop's real-world impact. The results indicate strong engagement and satisfaction: 90% of students rated their overall experience as excellent, with 80% reporting high confidence in using IoT platforms. Teachers observed significant gains in student engagement, technical skills, and awareness of Sustainable Development Goals, particularly SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action). Committee members reported high satisfaction with event planning and collaboration, underscoring the value of multidisciplinary teamwork. Qualitative feedback also highlighted the module's strengths in fostering technical proficiency and environmental awareness, while also identifying areas for improvement such as increasing hands-on activities, optimizing session pacing, and enhancing technical support. These insights have informed actionable recommendations for future workshops. Supported by the 2024 IEEE Region 10 Educational Activities Development Grant, this feedback-driven analysis affirms the module's effectiveness in advancing experiential STEM learning and sustainability education, and provides a robust framework for continuous program improvement.

Keywords: Hydroponics; IoT in Education; STEM education.

1.0 Introduction
Sustainable agriculture has become a priority amid the mounting challenges posed by climate change, limited natural resources, and the increasing global demand for food and energy. The United Nations' Sustainable Development Goals (UNSDGs) particularly SDG 2 (Zero Hunger), SDG 7 (Affordable and Clean Energy), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) emphasize the need for innovative and interdisciplinary approaches within both technological practice and education. The integration of renewable energy and Internet of Things (IoT) solutions into agricultural contexts has demonstrated significant potential for increasing efficiency, resilience, and environmental sustainability.

While technological innovation forms the foundation of this initiative, its broader success depends on educational effectiveness. STEM education is critical for equipping students with problem-solving skills relevant to contemporary global challenges, yet traditional curricula often fail to resonate due to a lack of contextual and hands-on experiences (Holmegaard et al., 2014). To address this, project-based and experiential learning approaches that leverage current technologies can improve motivation and competency development (Hosman et al., 2022). Supported by the 2024 IEEE Region 10 Educational Activities Development Grant and conducted in close partnership with Universiti Malaysia Terengganu, the workshop offered secondary school students direct experience with building, programming, and monitoring a functional hydroponic system powered by solar energy and IoT connectivity. This setting provided a tangible link between STEM theory, sustainability principles, and the learning objectives of both the national curriculum and the UN SDGs.

While the initial paper focused on the technical architecture and rollout of the module, the present study concentrates on evaluating its educational outcomes through stakeholder feedback. Rigorous assessment grounded in participant input is essential for identifying strengths, opportunities for enhancement, and overall project effectiveness (Lee et al., 2021; Amani, 2025). Accordingly, this paper presents a comprehensive analysis of structured feedback from students, teachers, and organizers, examining their perspectives on engagement, skill development, and suggested improvements.

By systematically evaluating stakeholder experiences, this work aims to validate the pedagogical value of the solar-powered IoT hydroponic module, inform future refinements, and provide a practical, evidence-based framework for continuous improvement in hands-on STEM education initiatives targeting sustainable development and technology integration. Figure 1 illustrates the conceptual model guiding this project, outlining how STEM education, IoT, renewable energy, and sustainable agriculture can be effectively integrated to foster student learning and innovation in alignment with national and international sustainability priorities.

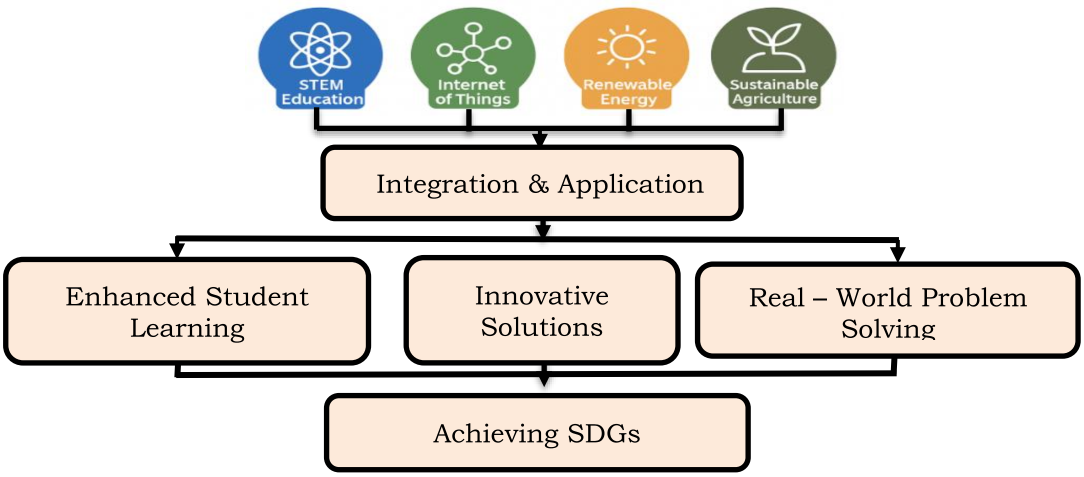

Figure 1: Conceptual framework of the Solar-Powered IoT Hydroponic STEM Module

The Solar-Powered IoT Hydroponic Module is fundamentally designed as a hands-on, project-based learning experience. Such experiential approaches, especially when integrating real-world technologies like the Internet of Things (IoT), have been consistently shown to significantly increase student motivation, enhance technical proficiency, and deepen the understanding of complex systems (Hosman et al., 2022). This type of experiential learning is instrumental in fostering essential 21st-century skills, including problem-solving, collaboration, and adaptability (Hosman et al., 2022; Tsybulsky & Sinai, 2022). Experiential learning opportunities are crucial for bridging the gap between theoretical concepts and tangible, real-world applications within STEM education (Thiagarajah et al., 2024). By embedding sustainability themes, such as the UNSDGs, the relevance and perceived impact of STEM education are further enhanced (Maidatsi et al., 2022). The integration of IoT into such project-based learning effectively engages students in computational thinking practices and develops critical skills directly relevant to the module's objectives (Tsybulsky & Sinai, 2022).

Feedback is an indispensable element for fostering continuous improvement within educational settings, ultimately enhancing both teaching practices and student learning outcomes (Amani, 2025). In the context of STEM education, this continuous refinement of programs based on stakeholder experiences is paramount (Lee et al., 2021). For the Solar-Powered IoT Hydroponic STEM Module, systematic feedback from its multiple groups—students, teachers, and facilitators—provides a comprehensive view of the program's strengths and areas for growth (Lee et al., 2021). This feedback-driven approach is essential for aligning educational interventions, such as the hydroponic module, with learners' needs and for sustaining engagement in rapidly evolving fields like IoT and renewable energy.

Best practices in educational feedback collection, pertinent to the evaluation of the hydroponic module, include the strategic use of structured surveys, open-ended questions, and mixed-methods analysis to capture both quantitative and qualitative data (Amani, 2025). This systematic process, illustrating the collection of feedback from various stakeholder groups (Students, Teachers, Organizers) leading to multi-stakeholder feedback analysis, program evaluation, and ultimately optimization for continuous improvement, is conceptually represented in Figure 2. The multi-stakeholder feedback collection adheres to these principles to gather actionable insights. Studies consistently highlight that such actionable feedback can directly inform program modifications, leading to measurable improvements in subsequent implementations. Addressing challenges in effectively implementing and tracking this feedback is vital for a systematic approach to program optimization (Amani, 2025).

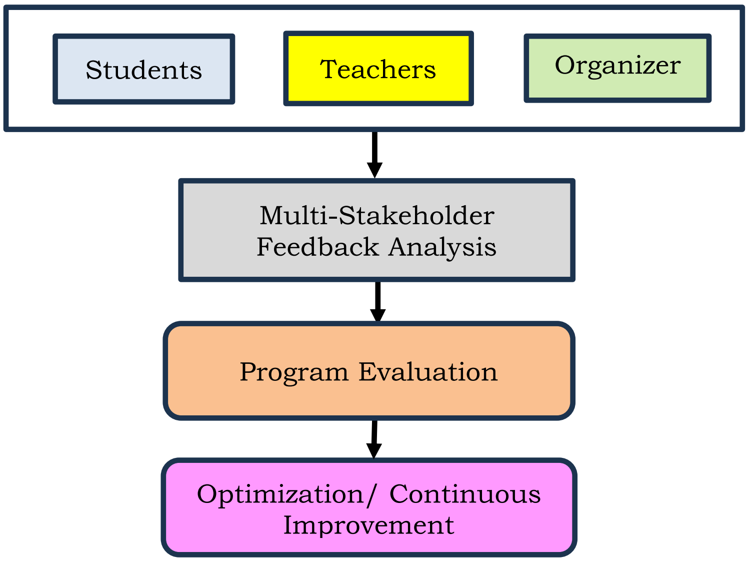

Figure 2 : Multi-stakeholder feedback analysis flow for the Solar-Powered IoT Hydroponic STEM Module

This section outlines the critical role of continuous improvement models, particularly within PBL methodologies, for enhancing hands-on STEM education in alignment with national educational goals. To ensure sustained effectiveness, programs like the Solar-Powered IoT Hydroponic Module must integrate systematic frameworks for evaluation and iterative enhancement (Amani, 2025). The module's core PBL approach inherently supports this by engaging students in an iterative cycle of design, implementation, testing, and refinement. This method significantly boosts student motivation and technical proficiency (Hosman et al., 2022). The key benefits of employing experiential and project-based learning in STEM education are further detailed in Table 1, encompassing areas such as enhanced motivation, technical proficiency, 21st-century skills, real-world application, and computational thinking. This approach aligns directly with the Ministry of Education Malaysia's (MOE) emphasis on inquiry-based, problem-based, and project-based learning for solving real-world challenges, and the Malaysian TVET 4.0 Framework's thrust on applied innovation.

Table 1: Key benefits of experiential and project-based learning (PBL)

Benefit Area	Activity Description
Enhanced Motivation	Experiential and project-based approaches significantly increase student motivation, making the learning process more exciting than just theoretical learning. Students develop a sense of satisfaction and self-efficacy from coping with challenges. (Hosman et al., 2022)
Technical Proficiency	Students gain practical technical abilities, improving their understanding and application of complex systems. This includes mastering scientific and computational skills relevant to the project. (Hosman et al., 2022; Tsybulsky & Sinai, 2022)

21st-Century Skills	PBL effectively develops essential 21st-century skills such as critical thinking, problem-solving, teamwork, collaboration, leadership, information, and media literacy. (Hosman et al., 2022; Tsybulsky & Sinai, 2022)
Real-World Application	Experiential learning bridges the gap between theoretical concepts and tangible, real-world applications in STEM education. Students learn by actively applying ideas in an environment that emulates professional settings. (Thiagarajah et al., 2024)
Computational Thinking	The integration of IoT into project-based learning engages students directly in computational thinking practices, such as algorithm design and automation of experiments. (Tsybulsky & Sinai, 2022)

2.0 Methodology

The Solar-Powered IoT Hydroponic STEM Workshop was designed as an immersive, hands-on educational intervention to bridge the gap between theoretical STEM concepts and real-world applications in sustainable agriculture. Conducted on August 10–11, 2024, at Universiti Malaysia Terengganu, the workshop targeted secondary school students (aged 13–16) from top schools in Kuala Terengganu. The initiative was delivered through a strategic collaboration between Universiti Malaysia Terengganu and a diverse team of facilitators from Malaysian Polytechnics, with financial and strategic support from the 2024 IEEE Region 10 Educational Activities Development Grant.

A mixed-methods research design was adopted to rigorously assess the workshop's effectiveness and overall performance. This approach integrates both quantitative and qualitative methods to gain a more complete understanding of program effectiveness and impact (Fàbregues et al., 2023). Quantitative data collected through structured surveys provided measurable insights into participant satisfaction, engagement, and technical skill development (Amani, 2025). Qualitative data, gathered via open-ended responses, captured detailed perceptions, contextual factors, and actionable suggestions from students, teachers, and organizers (Amani, 2025). By integrating and triangulating these data sources, the study delivers a comprehensive evaluation of both the workshop's impact and areas for targeted improvement (Fàbregues et al., 2023).

Participants engaged in a structured sequence of hands-on activities, including:

i. **Hydroponic System Setup:**
Transplanting seedlings, preparing nutrient solutions, and monitoring plant growth using TDS and EC meters.

ii. **IoT Integration:**
Assembling environmental sensors (DHT11, water-level sensors) with ESP32 microcontrollers, programming via Arduino IDE, and configuring data transmission to the ThingSpeak cloud platform for real-time monitoring and visualization.

iii. **Renewable Energy Application:**
Connecting solar panels and charge controllers to power the hydroponic system, reinforcing the principles of sustainable energy.

iv. **Verification and Mentorship:**
Each task was supervised and verified by facilitators using a structured checklist, ensuring technical accuracy and supporting participant learning at every stage. This approach fostered an active learning environment, where students could directly connect STEM theory to practical, sustainability-focused applications. Facilitators and lecturers provided continuous mentorship, reinforcing technical concepts and encouraging inquiry.

The workshop incorporated feedback from three key stakeholder groups: student participants, accompanying teachers, and the organizing committee and facilitators. These groups provided a multi-faceted perspective on the program's impact and effectiveness. The student participants were secondary school students from various top schools in Kuala Terengganu, representing a diverse gender mix within the overall group. The accompanying teachers offered professional insights from their observational roles, while the organizing committee and facilitators contributed perspectives on the planning, delivery, and overall execution of the event. Detailed demographics for each group are presented in Table 2. The workshop incorporated feedback from three key stakeholder groups:

Table 2: Workshop stakeholder demographics

Stakeholder Group	Number	Key Demographics
Student Participants	20	Aged 13–16 years old. Represented various top secondary schools around Kuala Terengganu, Terengganu. 16 male participants and approximately 4 female participants. Group was male-dominant, though high satisfaction levels were maintained across both genders.
Accompanying Teachers	5	2 female teachers and 3 male teachers. Accompanied students from the 5 participating schools
Organizing Committee and Facilitators	15	Comprised of nearly 10 facilitators from Malaysian Polytechnics with backgrounds in electrical engineering, and 5 lecturers holding doctoral degrees from Universiti Malaysia Terengganu. Roles included planning, delivery, and post-event evaluation.

To ensure a thorough and actionable evaluation of the workshop, feedback was thoughtfully gathered from all stakeholder groups at the close of the event using customized Google Forms. This structured approach reflects current best practices in educational program assessment, emphasizing the importance of systematic feedback to drive meaningful improvement. Each survey blended closed-ended questions such as Likert scales and yes or no items to capture quantitative trends, with open-ended prompts designed to elicit richer, qualitative insights into participants' experiences and suggestions. The structure of the student feedback instrument, which informed the design of all stakeholder surveys, is detailed in Table 3.

Table 3: Student feedback form components

Section/Question Type	Data Type (Quantitative/Qualitative)	Purpose/Example
Section 1: Participant Information	Qualitative	Collects basic demographic details (Full Name, School Name, Age, Gender, Email Address).
Section 2: Event Feedback	Quantitative & Qualitative	Assesses satisfaction with program logistics (Program Flow, Facilities, Timing, Speakers). Includes Likert scale ratings and open-ended comments.
Section 2: Knowledge & Interest in IEEE	Quantitative & Qualitative	Gauges prior IEEE familiarity and post-workshop interest. Includes multiple-choice and open-ended questions for future topics.
Section 3: Workshop Content Feedback	Quantitative & Qualitative	Evaluates relevance and understanding of content (Hydroponic Farming, Solar-Powered Solutions, IoT Integration) linked to specific SDGs. Uses Likert scales and open-ended insights.

Both the teacher feedback form and the committee or organizer feedback form were structured similarly to the Student Feedback Form, but each was thoughtfully tailored to reflect the unique perspectives and responsibilities of their respective groups. The teacher form focused on key areas such as student engagement, observed learning outcomes, and the relevance of workshop content to classroom practice. In contrast, the committee or organizer form explored aspects of personal commitment, team collaboration, event planning, and execution.

A mixed-methods approach was employed to comprehensively evaluate the workshop's effectiveness and inform future improvements. Structured feedback was collected from all stakeholder groups at the conclusion of the event using tailored google forms. Each survey combined closed-ended questions such as Likert scales and yes or no items for quantitative measurement of satisfaction, engagement, and perceived learning outcomes, with open-ended prompts that captured qualitative insights and detailed suggestions. This integration of quantitative and qualitative data allowed for a holistic analysis: quantitative results provided clear indicators of overall trends and participant satisfaction, while qualitative responses added depth by highlighting specific experiences, challenges, and recommendations.

3.0 Results and Discussion

The quantitative feedback analysis revealed a strong positive impact of the Solar-Powered IoT Hydroponic STEM Workshop across all stakeholder groups as shown in Figure 3. Overall satisfaction was high: 90% of student participants rated their experience as excellent, with the remainder indicating it was good. Teachers echoed this sentiment, with 80% rating the workshop excellent and 20% good, praising the program's organization, smooth delivery, and adherence to schedule. The organizing committee and facilitators also reported high levels of commitment and satisfaction, with 60% rating their involvement as excellent, 30% as good, and 10% as average.

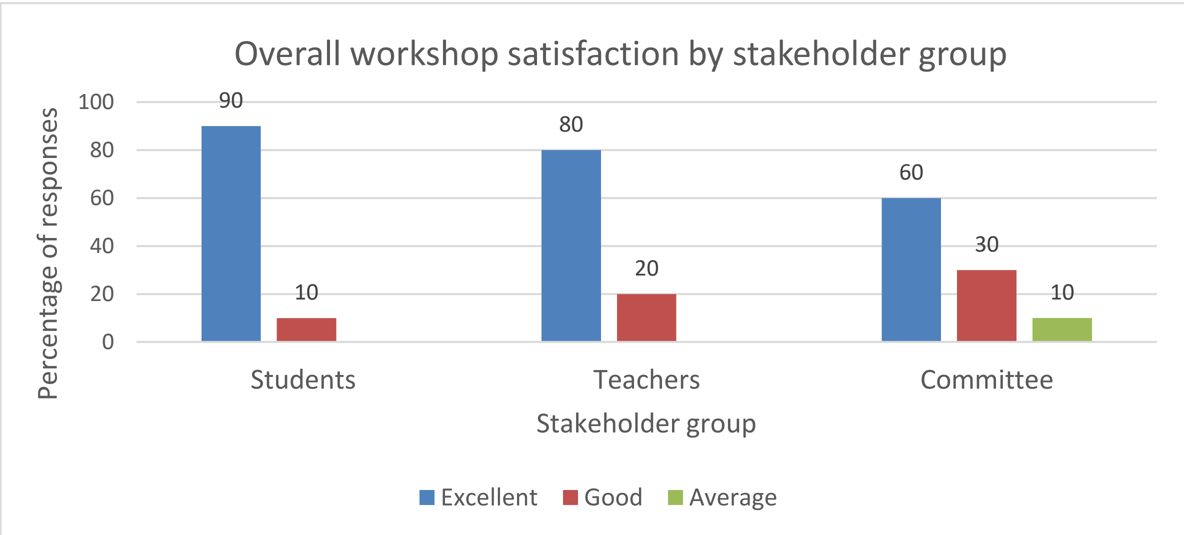

Figure 3: Overall workshop satisfaction by stakeholder group

Student feedback highlighted significant gains in both technical skills and confidence. 70% rated the hydroponics module as excellent and 30% as good, noting increased understanding of sustainable agriculture and hands-on experience with IoT and renewable energy technologies. The solar-powered energy session was similarly well received, and 80% of students reported feeling very comfortable using IoT platforms. Teachers confirmed these learning outcomes, observing high engagement and skill development among students, and agreed that the hands-on activities were valuable and relevant to the curriculum.

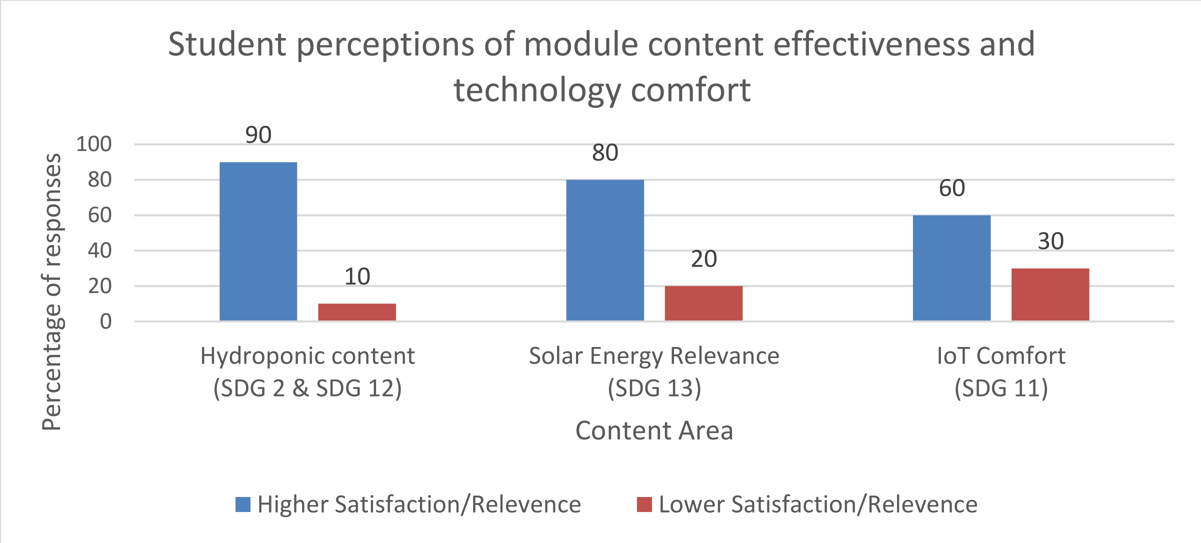

Figure 4: Student perceptions of module content effectiveness and technology comfort

Stakeholder feedback also provided practical suggestions for future optimization in Table 4. Students and teachers recommended expanding hands-on activities, introducing more advanced technical challenges, and improving session pacing such as listed in Table 5. Some reported minor technical issues, such as software compatibility, and expressed interest in additional learning resources beyond the workshop. Committee members highlighted logistical and technical challenges encountered during planning and delivery, but overall rated the event's execution positively and recognized the value of teamwork and clear communication.

Table 4: Consolidated key suggestions for future workshop improvement (from students and teachers)

Suggestion Category	Specific Examples / Details
Program Content & Activities	More hands-on activities. Incorporate more project-based and interactive activities. Include more real-world examples. Use more examples of SDG challenges. Reduce lecture time. Involve activities with physical movement.
Program Pacing & Duration	Adjust pacing and duration. Add short breaks between sessions to allow students to digest information and discuss what they have learned. Consider extending the workshop to cover more topics.
Logistics & Comfort	Improve seating arrangements to ensure greater comfort, particularly during extended sessions.
Post-Workshop Engagement	Provide follow-up resources and opportunities to engage with SDGs after the workshop.

Table 5: Common challenges reported by organizing committee members

Challenge Category	Specific Examples / Details
Planning & Communication	Challenges related to planning and communication. Need for more detailed timeline and planning. Need for proper team planning and discussion. Understanding methods.
Participant Management	Challenges in managing students, including handling younger participants. Dealing with unexpected situations, such as lack of responses.
Operational & Technical	Dealing with unexpected situations, such as handling multiple component sets. Software compatibility issues (e.g., for MacBook users). Need for early software preparation.

In summary, the mixed-methods evaluation demonstrates that the workshop effectively enhanced technical competencies, fostered engagement in STEM, and provided actionable feedback for continuous improvement. The integration of perspectives from students, teachers, and organizers offers a comprehensive understanding of the program's strengths and areas for refinement, supporting the ongoing optimization of experiential STEM education initiatives.

4.0 Conclusion

This study demonstrates the effectiveness of a feedback-driven, mixed-methods approach in evaluating and optimizing a Solar-Powered IoT Hydroponic STEM workshop. High satisfaction and technology acceptance rates among students, teachers, and organizers confirm the value of hands-on, real-world STEM modules for enhancing engagement and technical competency. The integration of multi-stakeholder feedback not only provided a comprehensive assessment of the workshop's impact but also generated actionable recommendations for continuous improvement. By systematically incorporating both quantitative and qualitative perspectives, this approach sets a strong foundation for ongoing module refinement and broader adoption of experiential, technology-enhanced STEM education.

Acknowledgements

The author would also like to express his gratitude to the Politeknik Mersing, Politeknik Sultan Mizan Zainal Abidin, Politeknik Kuala Terengganu and Jabatan Pendidikan Politeknik dan Kolej Komuniti who have made significant contributions to various parts of this research effort. This work was supported by the Research Fund provided by the 2024 IEEE Region 10 Educational Activities Development Grant.

Author Contributions

M.M. Khalid: Conceptualization, Abstract, Introduction, Analysis, Discussion, Conclusion; **N. Hasan**: Methodology, Result and Editing; **W. A. Manap**: Result, Discussion and Writing-Reviewing.

Conflicts Of Interest

The manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the review, agree with its Submission and declare no conflict of interest in the manuscript.

References

Amani, J. (2025). What students really think: Unpacking AI ethics in educational assessment. International Journal of Educational Technology, 12(1), 1–22. https://educationaltechnologyjournal.springeropen.com/counter/pdf/10.1186/s41239-025-00556-8.pdf

Fàbregues, S., Molina-Azorín, J. F., & Fetters, M. D. (2023). Integrating quantitative and qualitative approaches in mixed methods research: A review of current practices. Journal of Mixed Methods Research, 17(1), 5–23. https://doi.org/10.1177/15586898221106660

Holmegaard, H., Madsen, L. S., & Ulriksen, L. (2014). The process of choosing what to study: A longitudinal study of upper secondary school students' identity work when choosing a STEM education. International Journal of Science Education, 36(2), 316–339. https://doi.org/10.1080/09500693.2013.832554

Hosman, R., Constantinescu, A., Wu, Y., & Kluge, S. (2022). Development of extended reality projects: The role of project-based experiential learning. Cogent Education, 9(1), 2506872. https://doi.org/10.1080/.2022.2506872

Lee, M., Kim, J., & Wolterinck-Broekhuis, M. (2021). Enhancing feedback practices and formative assessment in education: A systematic review of teachers' data literacy. Educational Assessment, *36*(2), 145–168. https://doi.org/10.1007/s11092-024-09436-7

Maidatsi, K., Christopoulou, E., & Oikonomou, K. (2022). Using STEM learning concepts with IoT technology on the road of education for sustainability: A short literature review. Proceedings of the 7th South-East Europe Design Automation, Computer Engineering, Computer Networks and Social Media Conference (SEEDA-CECNSM 2022), pp. 1–6. https://doi.org/10.1109/SEEDA-CECNSM57760.2022.9932896

Amani, N.U. (2025). Evaluating technical training outcomes through structured survey analysis. Journal of Vocational Education and Training Research, 19(2), 45–62.

S. Folarin, E. Akinlabi, A. Atayero (2022). The United Nations and Sustainable Development Goals. Palgrave Macmillan

Thiagarajah, S. P., Lo, Y. C., Kung, F. W. L., Alias, M. Y., Mahmud, A., Shaik, M. A., Yang, T. T., & Zing, L. (2024). Effectiveness of an Internet of Things-based smart farming workshop model for enhancing science, technology, mathematics, and engineering awareness and seeding. *IEEE Potentials*. https://doi.org/10.1109/MPOT.2024.3469471

Tsybulsky, D., & Sinai, M. (2022). Experiential learning in teacher professional development: Fostering 21st-century skills through maker education. Teaching and Teacher Education, *112*, 103648. https://doi.org/10.1016/j.tate.2022.103648