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An Experiential Outreach Framework for University-School STEM Engagement: Insights from Biomedical and Mechatronics Activities in Malaysia

Rangka Kerja Jangkauan Experiential untuk Penglibatan STEM Universiti-Sekolah: Pandangan daripada Aktiviti Bioperubatan dan Mekatronik di Malaysia

DANNY WEE-KIAT NG, YEONG-NAN PHUA* & CHOON-HIAN GOH

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ABSTRACT

The Malaysian education policy actively encourages student participation in STEM streams. However, access to real-world engineering experiences remains limited for most school students. This disconnect between university-level engineering education and school-level STEM exposure creates a persistent challenge in Malaysia. University outreach programmes offer a practical means of addressing this issue. This paper presents an experiential outreach programme comprising twenty-eight STEM engagement sessions conducted by the Department of Mechatronics and Biomedical Engineering, Universiti Tunku Abdul Rahman (UTAR), for schools in the Klang Valley and at national events between June 2023 and November 2025. The sessions covered two domains: biomedical engineering and mechatronics. Students engaged directly in hands-on activities, including gait analysis, ECG monitoring, robotics, and drone operation. Our outreach methodology is based on three educational concepts: the experiential learning cycle, contextual learning theory, and a near-peer mentoring model. UTAR applied these frameworks across its outreach programmes to guide domain selection, session sequencing, and volunteer deployment. These systematic frameworks used in the two-domain outreach programme in the Malaysian secondary school context have demonstrated sustainable engagement through repeated invitations and requests for extended collaboration from participating schools. The approach offers a practical framework for university departments looking to establish active and collaborative connections with schools. This paper is presented as a theoretically grounded framework and practice report. A structured pre- and post-activity evaluation will constitute the next phase of the study.

Keywords: STEM outreach; experiential learning; university-school partnership; biomedical engineering; mechatronics

ABSTRAK

Dasar pendidikan Malaysia secara aktif menggalakkan penyertaan pelajar dalam aliran STEM. Walau bagaimanapun, akses kepada pengalaman kejuruteraan dunia sebenar masih terhad bagi kebanyakan pelajar sekolah. Jurang antara pendidikan kejuruteraan peringkat universiti dan pendedahan STEM peringkat sekolah ini menciptakan cabaran yang berterusan di Malaysia. Program jangkauan universiti menawarkan pendekatan praktikal untuk menangani isu ini. Kertas ini membentangkan program jangkauan berasaskan pengalaman yang merangkumi dua puluh lapan sesi penglibatan STEM yang dijalankan oleh Jabatan Kejuruteraan Mekatronik dan Bioperubatan, Universiti Tunku Abdul Rahman (UTAR), untuk sekolah-sekolah di Lembah Klang dan acara peringkat kebangsaan antara Jun 2023 dan November 2025. Sesi-sesi tersebut meliputi dua domain: kejuruteraan bioperubatan dan mekatronik. Pelajar terlibat secara langsung dengan aktiviti amali, termasuk analisis gaya berjalan, pemantauan ECG, robotik, dan operasi dron. Metodologi jangkauan kami berasaskan tiga konsep pendidikan: kitaran pembelajaran berasaskan pengalaman, teori pembelajaran kontekstual, dan model bimbingan rakan sebaya terdekat. UTAR mengaplikasikan rangka kerja ini merentasi program jangkaluannya bagi membimbing pemilihan domain, penjujukan sesi, dan penggunaan sukarelawan. Rangka kerja sistematik yang digunakan dalam program jangkauan dua domain dalam konteks sekolah menengah Malaysia ini telah menunjukkan penglibatan yang mampan melalui jemputan berulang dan permintaan kerjasama yang diperluas daripada sekolah-sekolah yang terlibat. Pendekatan ini menawarkan rangka kerja praktikal untuk jabatan universiti yang ingin menjalin hubungan aktif dan kolaboratif dengan sekolah. Kertas ini dibentangkan sebagai laporan rangka kerja dan amalan yang berteraskan teori. Penilaian berstruktur pra dan pasca aktiviti akan menjadi fasa seterusnya kajian ini.

Kata kunci: Jangkauan STEM; pembelajaran berasaskan pengalaman; perkongsian universiti-sekolah; kejuruteraan bioperubatan; mekatronik

INTRODUCTION

In Malaysia, efforts to promote Science, Technology, Engineering, and Mathematics (STEM) learning have been increasing due to the growing demand for skills aligned with Industry 4.0. STEM education has emerged as a strategic priority for nations seeking to strengthen innovation capacity and transition toward knowledge-based economies (MOE, 2013). STEM encompasses the teaching and learning of science content and practices that integrate elements of science and mathematics with engineering practices and engineering design through appropriate technology (Bryan et al., 2015). Subjects encompassed within STEM include science, mathematics, design and technology, computer science, biology, physics, and chemistry. In this context, a STEM programme refers to structured educational initiatives that integrate these disciplines to promote interdisciplinary learning, while integrated STEM describes pedagogies that intentionally connect them through inquiry-based and project-based learning (Becker & Park, 2011). STEM education is broadly associated with the development of higher-order thinking skills, including critical thinking, creativity, problem-solving, and computational thinking, as well as workforce readiness competencies such as digital literacy, collaboration, and adaptability required for modern labour markets.

Limited exposure to modern technology continues to be one of the challenges for effective STEM engagement among students. A recent report by the Ministry of Education shows that STEM enrolment among upper secondary students reached 50.83% in 2024, up from 41.84% in 2019, and the 60% national target remains not meet (Anbalagan, 2024). The ministry has identified that low student awareness and limited real-world exposure are some of the key barriers. In addition, a recent review by Omar et al. (2026) highlights that approximately 78% of students report increased interest in STEM careers following programme participation, and only 15.2% enrol in pure science streams. University outreach programs could serve as a bridge between academic research and school-level learning, providing practical experiences that enhance student interest and understanding. When designed thoughtfully, these programs are able to create a positive impression of engineering and provide students with experience applying scientific principles to real-world problems. These experiential experiences have been shown to influence student interest, broaden career awareness, and foster a sense of belonging in STEM communities (Ng et al., 2024; Norazsida et al., 2025; Vennix et al., 2018). In Malaysia context, documented design models are particularly limited.

This paper presents the implementation of outreach activities conducted by the Department of Mechatronics and Biomedical Engineering at Universiti Tunku Abdul Rahman (UTAR) between June 2023 and November 2025. The initiatives featured gait analysis, ECG-based monitoring, robotics, and drone demonstrations, aimed at promoting STEM awareness through real-world engineering applications. Accordingly, UTAR has applied three conceptual frameworks: contextual learning (Johnson, 2002), experiential learning (Kolb, 1984), and near-peer mentoring (Tenenbaum et al., 2014), to guide the design of the outreach program.

STEM ENGAGEMENT IN MALAYSIA: CHALLENGES AND THE CASE FOR OUTREACH

STEM education in Malaysia has been recognized as a critical driver for the national development, economic growth, and technological advancement. Rashidin et al. (2023a) further asserted that STEM-oriented careers are central to expanding Malaysia's talent pool and sustaining competitiveness in the innovation economy. Hence, under the Malaysian Education Blueprint 2013–2025, the government is committed to nurturing a STEM-literate workforce to support national aspirations for an innovation-led economy (Ministry of Education, 2013). The report made by the Ministry of Education (Anbalagan, 2024) reveals that STEM enrolment at the upper secondary level dipped to 40.94% in 2022 (well below the 60:40 target), then recovered to 45.73% in 2023 and reached 50.83% in 2024. The ministry attributed these fluctuations to factors including low awareness among students and parents of the advantages of STEM careers, the perception that non-STEM fields offer equal opportunities, and insufficient, outdated infrastructure.

The roots of Malaysia's STEM policy commitment extend back to the early 1967, when the government introduced a 60:40 Science-to-Arts enrolment ratio as a foundational policy for the development of science and technology (Academy of Science Malaysia, 2017). In 2013, the Malaysia Education Blueprint was structured around three stages of implementation: (2013–2015) focused on improving STEM quality by strengthening the curriculum, training teachers, and adopting multimodal learning models; (2016–2020) prioritised raising public awareness through campaigns and collaboration with relevant agencies to increase STEM interest among individuals, families, and communities; and (2021–2025) seeks to transition STEM to an excellent level through increased operational flexibility and new initiatives (Rashidin, 2023b). Within this policy framework, STEM education is understood to develop higher-order thinking skills—encompassing critical thinking, creativity, problem-solving, and computational thinking—alongside workforce readiness competencies such as digital literacy, collaboration, and adaptability (Omar et al., 2026). The main goal is to meet the nation's future workforce needs for the IR 4.0.

Multiple studies have highlighted the challenges in student participation and retention in STEM streams, particularly at the secondary and tertiary levels (Rashidin et al., 2023b). The 60:40 Science-to-Arts student enrolment policy remains unmet. This is mainly attributed to factors such as low self-efficacy, socioeconomic barriers, and perceived difficulty of STEM subjects (Rashidin et al., 2023b; Nurul et al., 2025), discrepancies in STEM teachers' competency between urban and rural areas (Ahmad, 2017), negative teacher attitudes toward the implementation of integrated STEM learning (Thibaut et al., 2018), and weak foundational knowledge and skills among STEM teachers (Thomas & Walters, 2015).

Research further reveals that students demonstrate greater interest when STEM learning is oriented toward hands-on, object-based approaches rather than theory alone (McIntyre et al., 2021), and motivational learning alone does not sufficiently influence the development of students' career interest in STEM (Fazilah et al., 2020). In the study by Vela et al. (2020), on the students' perceptions towards STEM field and career, it was revealed that an informal learning environment positively contributed to students' perceptions toward STEM careers.

A study carried out by Nurul et al. (2022) found that self-efficacy, socioeconomic status, and academic achievement were significant predictors of students' persistence in STEM subjects. Similarly, Fadhilah et al. (2025) found that self-leadership strategies, including behavior-focused and constructive thought pattern strategies, mitigate academic anxiety and enhance the transition of STEM students toward higher education. Both studies come to the same conclusion and emphasise that fixing the curriculum is not sufficient if students do not feel confident or motivated in STEM. In a separate study by Chuana et al. (2025), it was reported that the declining enrolment in Additional Mathematics (a gateway to the science stream), particularly in East Malaysian schools, highlighted the regional disparities.

In the recent review by Omar et al. (2026), revealing that STEM education produces moderate positive effects on cognitive and academic outcomes with approximately 78% of students reporting increased interest in STEM careers following programme participation. These findings are broadly consistent with global meta-analyses, which report moderate but consistent improvements in learning outcomes from STEM interventions with stronger effects observed at the secondary school level (Becker & Park, 2011). The analysis also indicates only 15.2% of the students enrolled in pure science streams compared to the national target of 60%. This large gap is mainly attributed to exam-oriented pedagogy, uneven resource distribution, teacher preparedness, and sociocultural influences. In order to sustain STEM interest participation, these attributed conditions have to be overcome. University outreach can help in this by offering repeated, contextual, and application-rich exposure. It is an effective way to strengthen those conditions from outside of the formal curriculum.

Moreover, outreach models that integrate real-world applications have also shown measurable success in marginalized schools. Norazsida et al. (2025) implemented the STEMA Garden Module among rural B40 students in Pahang, combining agriculture, IoT, and entrepreneurship to enhance STEM interest and practical competence. The results were encouraging where students showed clear gains in STEM awareness, problem-solving skills, and creativity. The outcome demonstrates the efficacy of contextual and hands-on learning in promoting inclusivity and engagement. Additionally, the work by Nurul et al. (2022) highlighted that STEM concepts should be introduced as early as preschool through informal cooperative learning strategies in classroom activities to ensure foundational readiness for technological and industrial transformation.

The STEM Executive Consultation (STEMEC) initiative based on organisational development approach, was set up in 2019 (Liew and Teoh, 2022). This initiative is a collaboration between the Institut Aminuddin Baki (IAB) and the Curriculum Development Division (BPK) and it is under the Malaysia Education Blueprint Initiative to strengthen the integration of STEM education. A pilot run across 32 primary and secondary schools over the 3 years shows an improvement move from attempting to actively putting the STEM integration into practice. Later, Sariati et al. (2025) emphasise that the leadership and management roles of school principals are vital in enabling teachers to cultivate STEM-driven culture and sustain long-term educational transformation. Therefore, it is crucial to provide structural support for teachers and students to ensure STEM education remains relevant and impactful in the context of Industry 4.0 and beyond at the institutional level.

Experiential and technology-based learning has emerged as an effective approach to revitalizing STEM interest among students. Ng et al. (2024a) demonstrated the potential of drones as an educational tool to ignite STEM curiosity among Malaysian students, revealing that hands-on activities significantly enhance interest, engagement, and comprehension of engineering principles. The team has introduced a 3D-printed differential-drive robot platform with LiDAR and depth sensing, designed as a low-cost, open-source tool for educational and research applications (Ng et al., 2024b). These initiatives reflect efforts to bridge theoretical knowledge and practical skills through interactive learning experiences and align closely with the outreach objectives described in this paper.

The key elements in outreach activities are the involvement and experience gained by the student. Kolb's (1984) experiential learning cycle proposes that meaningful learning begins with concrete experience (direct, hands-on engagement with real phenomena), and moves through stages of reflection, conceptual understanding, and active experimentation. This cycle is difficult to complete in standard classroom settings, where experience is often deferred until after concepts have been introduced. Studies found that students engage more deeply when they understand the "How-Why" that relates to real-world application. This explains why well-designed outreach tends to work where classroom instruction alone does not. Furthermore, outreach activities that connected science to students' everyday experiences produced greater engagement and more positive attitudes toward STEM than those that felt abstract (Johnson, 2002; Vennix et al., 2018).

In summary, despite policy efforts, practical engagement and exposure to real-world applications remain the most effective strategies for cultivating sustained interest in STEM. Consequently, initiatives to incorporate hands-on biomedical and mechatronics activities, such as gait analysis, health monitoring, robotics, and drones, directly address these gaps by fostering experiential learning, contextual understanding, and long-term student motivation. The reviewed literature thus highlights the necessity and impact of outreach programs that link the STEM principles to tangible applications in Malaysian education.

THE UTAR OUTREACH PROGRAMME IMPLEMENTATION

Between June 2023 and November 2025, a total of 28 STEM outreach sessions were conducted in collaboration with secondary schools and national STEM events, including the Kuala Lumpur Engineering Science Fair (KLESF) and the MOSTI STEM Workshop. These activities were organized by the faculty members from the Department of Mechatronics and Biomedical Engineering, Lee Kong Chian Faculty of Engineering and Science, Universiti Tunku Abdul Rahman (UTAR).

The sessions were conducted through interactive, inquiry-based learning approach, where it begins with conceptual briefings followed by guided hands-on exercises and reflective discussions. This sequencing placed experience before explanation throughout, which is consistent with the experiential learning model that underpins the programme's design (Kolb, 1984). The experiences gained from the outreach exercises have allowed the team to observe how the activities translated for different audiences and refine the delivery accordingly.

In terms of research methodology, this paper presents a practice-based framework where each outreach session followed a consistent four-step procedure: (1) a short conceptual briefing covering safety and context; (2) guided hands-on engagement with the equipment as the concrete experience; (3) facilitated discussion arising from what students had observed; and (4) a closing reflection connecting the activity to wider engineering principles. The programme observations reported in this paper are drawn from facilitator feedback and school requests for repeat and extended collaboration. The formal thematic analysis is not available at this stage of the study. A structured data collection and evaluation through pre- and post-activity instruments will form the basis of the next phase of the study. The evaluation design will incorporate interviews with accompanying teachers and school administrators to capture engagement indicators from the school's perspective, where participating schools are able to share such records, tracking of

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downstream indicators, such as science-stream selection among participating cohorts. These instruments will provide the formal empirical evidence base for the framework presented in the future study.

Each session engaged between 20 and 100 students and was facilitated by faculty lecturers supported by undergraduate volunteers from the department. Each session was designed to provide hands-on experiential learning aligned with two major thematic domains: Biomedical Engineering and Mechatronics. The biomedical modules focused on human biomechanics and physiological signal analysis. Meanwhile, the mechatronics modules introduced robotics, drone technology, and automation principles. Both domains gave the programme breadth while maintaining coherence around themes. The school students could easily grasp the topics without prior technical knowledge. Table 1 lists all sessions conducted across the programme period.

TABLE 1. UTAR STEM Outreach Sessions, June 2023 – November 2025

Date	Venue / School	Activity	Domain
12 Jun 2023	SJK (C) Sungai Way	Gait Analysis (G-Walk)	Biomedical
13 Jun 2023	SJK (C) Chung Hua	Robotics	Mechatronics
17 Jun 2023	UTAR Sungai Long	ChatGPT Talk	Mechatronics
24 Jun 2023	SMK Perimbun	Gait Analysis (G-Walk)	Biomedical
7 Jul 2023	MRSM Bentong	Drone Workshop	Mechatronics
27 Sep 2023	SMK Seksyen 18 Shah Alam	Drone Workshop	Mechatronics
27 Sep 2023	SMK Seri Kembangan	Gait Analysis (G-Walk)	Biomedical
11 Oct 2023	SMK Bandar Baru Sungai Long	Drone Workshop	Mechatronics
1 Dec 2023	Kuen Cheng High School	Robotics	Mechatronics
31 Jan 2024	SMJK Yu Hua	Gait Analysis (G-Walk)	Biomedical
31 Jan 2024	SMJK Yu Hua	Robotics	Mechatronics
15 Mar 2024	SMJK Sri Sentosa	Drone Workshop	Mechatronics
23 Mar 2024	SMJK Yu Hua	Robotics	Mechatronics
23 Mar 2024	SMJK Yu Hua	ECG Workshop	Biomedical
15 Jun 2024	Kuen Cheng High School	Drone Workshop	Mechatronics
22 Jun 2024	SJK (C) Choong Wen	Drone Workshop	Mechatronics
21 Aug 2024	MOSTI STEM Workshop (Multiple Schools)	Drone Workshop	Mechatronics
9 Sep 2024	Kuen Cheng High School	ECG Workshop	Biomedical
25 Sep 2024	MOSTI STEM Workshop (Multiple Schools)	Drone Workshop	Mechatronics
22–24 Oct 2024	Chan Wa School, Seremban	Gait Analysis (G-Walk)	Biomedical
8–11 Nov 2024	KLESF	Gait Analysis (G-Walk)	Biomedical
8–11 Nov 2024	KLESF	Robotics	Mechatronics
13 Feb 2025	SMJK Keat Hwa (1)	Drone Workshop	Mechatronics
13 Feb 2025	SMJK Keat Hwa (1)	Gait Analysis (G-Walk)	Biomedical
24 Apr 2025	SMK Bandar Utama Damansara	Robotics	Mechatronics
7 May 2025	Lai Meng International School	Drone & Robotics	Mechatronics
7 May 2025	Lead International School	Drone & Robotics	Mechatronics
12 Jul 2025	SMJK Yu Hua	Drone Workshop	Biomedical
24 Nov 2025	Chung Hua High School, Seremban	Robotics	Mechatronics

The Biomedical Engineering sessions aim to introduce the fundamentals of biomechanics and biomedical signal acquisition through two key modules: Gait Analysis using G-Walk and Electrocardiography (ECG) Signal Processing. Students were introduced to basic human movement analysis and learned how to interpret biomechanical data. The students will record and analyze walking gait cycles using BTS G-Walk wearable sensor. This process also allows student learning about temporal and spatial parameters related to locomotion. For most students, this was their first encounter with medical-grade instrumentation. Such a personalized experience with seeing their own body as a data source will effectively generate strong engagement. Besides, the activity also involved hands-on circuit building using the ESP32 microcontroller and the ADS8299 analog-to-digital converter to acquire and process the electrocardiogram signals. Students will then learn how biosignals are acquired, filtered, and visualized. The session concluded with a live demonstration of resting ECG measurement and data interpretation. In this exercise, students are left having seen their own heart signal on screen. Such an experience outcome made abstract concepts in electronics and physiology immediately tangible. These topics are not covered in school curricula, and the exposure provided a practical preview of what biomedical engineering at the university level entails.

The Mechatronics session focuses on robotics and unmanned aerial systems (UAS) to foster students' understanding of automation, control, and embedded systems. By using LEGO-based educational robots, students are taught to modify block-based programs to implement line-following algorithms, followed by practical demonstrations of path-following and basic control logic. In addition, students were also introduced to an industrial-grade 6-DOF collaborative robots (cobots) to demonstrate real-world robotic manipulation applications. The contrast between the accessible educational robot and the industrial cobot illustrated the range of engineering applications within the field and gave students a great sense of how school-level programming connects to real-world professional engineering practice. For the drone session, students also learned the principles of flight, control systems, and drone operation safety. The theoretical understanding will be reinforced through practical navigation exercises. Students are then given the opportunity to pilot drones through preset obstacle courses under peer mentoring. These workshops were particularly popular and featured at multiple school- and national-level events, including the MOSTI STEM Workshop (2024) and KLESF 2024.

UTAR'S OUTREACH APPROACH: THREE CONCEPTUAL FRAMEWORKS IN PRACTICE

Across twenty-eight sessions between 2023 and 2025, the department drew on three established conceptual frameworks to guide how activities were selected, structured, and operated: (1) Johnson's (2002) contextual learning theory, which shaped domain selection; (2) Kolb's (1984) experiential learning cycle, which shaped how sessions were sequenced; and (3) Tenenbaum et al.'s (2014) near-peer mentoring model, which shaped the role of undergraduate volunteers. These three frameworks, applied consistently across diverse school settings, gave the programme its coherence and informed the way each session was designed. The first consideration in designing the outreach programme was which engineering domains to bring into schools. Drawing on Johnson's (2002) contextual learning theory — where knowledge is acquired most effectively when it is embedded in contexts the learner already recognises and values, the department selected biomedical engineering and mechatronics as its two thematic domains. Besides, Vennix et al. (2018) provide empirical support for this approach, showing that outreach activities related to real-world science connected to students' everyday out-of-school experiences consistently produced stronger engagement and more positive attitudes toward STEM than activities that felt abstract or removed from daily life. Biomedical engineering offered a direct connection to something every student carries with them, that is, a body that moves and functions in ways that can be measured and understood. Mechatronics offered a connection to the automation and robotic technology students encounter in everyday life. Neither of the selected domains requires prior in-depth technical knowledge, whereas both offer an entry point that feels immediately accessible. By anchoring its outreach in these two contextually grounded domains, students will encounter engineering not as an abstract subject but as something directly connected to their lived experience (the essential condition for contextual learning).

The second framework guiding the UTAR programme was Kolb's (1984) experiential learning cycle, which the department applied to determine how each session would be arranged. Kolb's model positions concrete experience as the starting point of meaningful learning instead of its culmination. Kolb's cycle comprises four stages: Concrete Experience (direct, hands-on engagement with real phenomena), Reflective Observation (looking back on what was experienced), Abstract Conceptualization (forming an understanding of the underlying principles), and Active Experimentation (applying that understanding to new situations). Each UTAR session was deliberately mapped onto these four stages: the hands-on activity provided the Concrete Experience; the guided discussion that followed prompted Reflective Observation; the facilitator-led explanation linking the activity to engineering principles supported Abstract Conceptualization; and the opportunity to retry, adjust, and explore the equipment further enabled Active Experimentation. Instead of opening sessions with a lecture, UTAR structured every session so that students engaged with the hands-on activity first, and the explanation followed from what they had just experienced. Students assembled circuits before fully understanding what the circuit would do. They piloted drones before the physics of flight had been explained in detail. They watched their own ECG appear on screen before the signal processing behind it was discussed. In each case, the experience created the question that the explanation then answered. A student who has just seen their gait data appear on a screen is prepared to understand what biomechanics means in a way that no prior explanation could produce. In each session, the opening briefing was kept short to make the activity safe and clear. From there, students worked with the equipment, and discussion grew out of what they observed and experienced. Closing each session with a short reflection that connected what students had done to wider engineering principles completed the cycle. Facilitator feedback from these closing reflections captured recurring patterns in how students articulated their experience. Although these observations are informal, they illustrate the reflective observation stage of Kolb's cycle, which is important in understanding the students' positive attitude toward STEM.

The third framework applied by UTAR was the near-peer mentoring model (Tenenbaum et al., 2014), which the department used to define the role of undergraduate volunteers in each outreach session. Instead of treating undergraduates as logistical helpers, UTAR positioned them as active facilitators and near-peer role models. They are the people close enough in age and educational stage to be genuinely relatable to school students. Tenenbaum et al. (2014) found that this model contributed to personal, educational, and professional growth for undergraduate mentors, while increasing interest and engagement in STEM among secondary school students. The participation of undergraduate mentors offered relatable role models for younger students, further engage the pathway toward engineering and scientific careers. For school students, the gap between themselves and a university lecturer can feel very wide in terms of age, knowledge, and institutional position. Undergraduate volunteers close that gap. They are recent products of the same educational pathway that school students are currently on, and they have made engineering choices recent enough to discuss and explain in relatable terms. The near-peer model works precisely because mentors are close enough in age and experience to be genuinely approachable, as they share the recent memory of navigating the same educational decisions their mentees are now facing. For this component to work well, undergraduate volunteers need preparation that goes

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beyond technical briefing. They need to know how to facilitate rather than demonstrate, such as asking guiding questions, encouraging hesitant students, and briefly and genuinely sharing their own experience of choosing engineering. Near-peer mentoring also benefits the undergraduates themselves, as the experience of communicating engineering concepts to non-specialist audiences and representing their university in a public-facing role develops professional skills that are increasingly valued in engineering graduate profiles (Tenenbaum et al., 2014).

The feedback we have received from participants and accompanying teachers indicated a positive reception, with many schools submitting requests for follow-up workshops or extended collaborations with the university. This sustained demand from schools is itself a meaningful form of evidence. When a school returns for a second or third session, or writes to request an extended partnership, it signals that something in the experience resonated with students, with teachers, or with both. These relationship-level indicators reflect the kind of engagement that formal survey instruments often fail to capture, and they point to a quality of outreach that goes well beyond a one-off visit. Building on this foundation, the next phase of this programme will introduce a structured evaluation component through pre- and post-activity surveys to quantitatively assess changes in students' interest, knowledge, and confidence in STEM fields, to formalise the efficacy of the approach. Such instruments would allow the team to track shifts in student engagement with STEM — not just knowledge acquisition in the narrow sense, but changes in interest, confidence, and sense of belonging in Malaysian engineering contexts.

DISCUSSION

Although recent improvement in national STEM enrolment from 41.84% in 2019 to 50.83% in 2024 has shown a positive sign, the Ministry of Education (Anbalagan, 2024) acknowledged that low student awareness and limited exposure to real-world STEM applications remain key barriers to reaching the 60% target. University outreach is crucial for addressing these challenges to strengthen STEM literacy and engagement. Students who participate in hands-on engineering sessions at the school level are likely to be better informed about what STEM careers entail and more confident in their ability to engage with technical subjects, both of which influence stream choices before enrolment decisions are made. If the outreach engagement begins early can produce meaningful and lasting shifts in students' attitudes toward STEM subjects (Vennix et al., 2018). Furthermore, closing the gap between interest and enrolment in STEM requires not just better teaching but also a broader network of supporting conditions, and direct exposure to engineering practice is more effective (Omar et al., 2026).

The three-framework approach used by the UTAR outreach programme addresses the disconnection between the engineering knowledge and equipment that exists in universities and the STEM experience available to students in schools. As schools have their regular equipment, it is a challenge for them to maintain G-Walk sensors, cobots, and drone flight. Instead, it highlights a structural gap that outreach is uniquely positioned to fill. The outreach activities conducted by UTAR are well-suited and able to provide hands-on and technology-driven learning to foster the curiosity and understanding of STEM concepts effectively. Hence, a university department can serve as an active contributor to school-level STEM culture without requiring large infrastructure investments or formal institutional agreements at the outset. The activities were run with existing departmental equipment, facilitated by faculty alongside their regular teaching responsibilities, and supported by undergraduate volunteers. Such an ecosystem is able to provide the experiential

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exposure component that classroom instruction cannot consistently deliver and help in building the university-school relational infrastructure that sustains repeated engagement and creates the near-peer visibility of engineering careers that influences student aspirations before formal stream selection.

The success of the programme can be directly attributed to how each framework operated within the two domains. Contextual learning theory (Johnson, 2002) explains the strong engagement observed in both domains: the biomedical modules succeeded because students' own bodies served as the learning context (their gait, their heartbeat), while the mechatronics modules succeeded because drones and robots connected to technologies students already encounter and aspire to use. The experiential learning cycle (Kolb, 1984) explains why the experience cycles worked consistently across both domains: in the ECG and gait analysis sessions, seeing one's own physiological data generated the questions that the subsequent explanation answered, while in the drone and robotics sessions, the trial-and-error of piloting and programming naturally carried students through reflection and conceptualization toward repeated experimentation. The near-peer mentoring model (Tenenbaum et al., 2014) functioned in both areas, with undergraduate volunteers acting as a bridge between school students and engineering practice. This was especially noticeable during hands-on troubleshooting, where students preferred seeking help from near-peer mentors over lecturers. The consistency of these mechanisms across these two technically distinct domains indicates that the framework is the driver of the observed engagement.

This method directly addresses disengagement from STEM streams due to a preference for hands-on learning and limited career exposure, as highlighted by McIntyre et al. (2021) and Vela et al. (2020), respectively. Outreach activities in real-world engineering domains can cultivate higher-order thinking skills such as critical thinking, creativity, and problem-solving. These experiences could also enhance students' competencies, especially in collaboration, adaptability, and digital literacy, which are essential for Malaysia's transition to an innovation-driven economy (Omar et al., 2026; Becker & Park, 2011).

Among the two domains provided by UTAR, the biomedical engineering modules give students practical experience of how engineering principles intersect with human health. This connects abstract scientific concepts to real-world applications. The students have experience in analyzing their own biomechanics in the Gait Analysis sessions and working with real instrumentation during the ECG workshop. They engaged with concepts usually reserved for university labs. These early exposures make the complex topics feel approachable. It helps them perceive biomedical engineering as a realistic future discipline. The mechatronics-focused workshops, particularly those involving drones and robotics, were the clear favourite. This reflects their genuine excitement for the technology. Building and programming the hardware, combined with the thrill of actually piloting drones, naturally pushed the students to collaborate and troubleshoot on the fly. The demonstration of industrial cobots has provided an insight into emerging automation technologies and its relevance to future career paths.

During the outreach exercise, the lecturer played a dual role in facilitating content delivery and mentoring students. These interactions will enrich students' learning experiences and strengthen the university-school relationship. This builds a shared community to promote STEM education. The participation of undergraduate mentors offered relatable role models for younger students and could further encourage the pathway toward engineering and scientific careers. This is consistent with what Eilam and Bigger (2016) describe as bottom-up outreach initiatives. These grow from individual academic networks and disciplinary passion rather than top-down institutional mandate. The UTAR outreach programme follows this model exactly.

It is important to note that the present framework is based on the motivational factors highlighted in these studies: self-efficacy, confidence, and interest, which are the key factors that influence the students' stream choices. By offering hands-on, personalized engineering experiences, in our case through the 2 engineering domains, such as seeing one's own ECG on screen or flying a drone for the first time, the aim is to boost students' interest in STEM and their self-belief.

The framework adopted here could serve as a foundation for institutional support for future outreach activities. Universities' adoption of this approach is not a one-off activity; it requires a sustained commitment. The schools get access to equipment and experiences they cannot provide themselves. Meanwhile, universities build strong relationships with schools to support recruitment, community engagement, and the development of undergraduate communication and mentoring skills.

The outreach becomes less a service activity and more a genuine partnership. This is precisely what Sadler et al. (2018) mark as a sign of sustainable engagement. The framework presented is not a standalone involvement. It serves as one component of the wider STEM ecosystem that Malaysia's education system is working to build. The longer-term aspiration for outreach programmes is not simply to run more sessions, but to develop a STEM ecosystem — a stable, cross-sector network in which students, educators, families, and university partners share responsibility for sustained STEM engagement (Taylor, 2026). Achieving this vision requires a systemic approach that aligns policy aspirations with classroom practice, teacher capacity, and socio-cultural support—a challenge that extends well beyond the scope of any single outreach programme, but one to which consistent, well-documented university engagement makes a meaningful contribution (Omar et al., 2026).

CONCLUSION

An experiential outreach of twenty-eight STEM engagement sessions was conducted by the Department of Mechatronics and Biomedical Engineering, Universiti Tunku Abdul Rahman (UTAR), for schools in the Klang Valley and national events between June 2023 and November 2025. The sessions covered two domains -biomedical engineering and mechatronics, featuring hands-on activities including gait analysis, ECG monitoring, robotics, and drone operation. Students have gained practical insights into fundamental engineering and scientific principles.

The feedback from schools was positive, with many schools submitting requests for follow-up workshops or extended collaborations with the university. This highlights the effectiveness of experiential learning in promoting STEM awareness and interest. This highlights the effectiveness of experiential learning in promoting STEM awareness and interest. The reported outreach activities demonstrate how the engineering department applied the three conceptual frameworks: contextual learning to guide domain selection; experiential learning cycle to guide session sequencing; and the near-peer mentoring model to guide the role of undergraduate volunteers, to build and sustain a meaningful university-school outreach programme calibrated to the Malaysian engineering education context. The approach is offered as a practical model for university departments looking to build meaningful partnerships with schools.

Students who joined the outreach programme left with practical skills and career insights that standard school lessons could find difficult to provide. Students who take part in hands-on STEM activities gain more than knowledge. They develop skills that are directly useful for their future. By engaging students in object-based, application-rich experiences, the outreach activities help build higher-order thinking skills. These include critical thinking, creativity, and problem-solving. Students learn to observe, inquire, and work through challenges step by step. These are not skills that can be taught through lectures alone.

The activities also nurture workforce readiness competencies. These include collaboration, adaptability, and digital literacy. Malaysia's national education agenda has identified these as essential for Industry 4.0. Students who join the sessions are therefore better prepared for the demands of modern careers. Such experiences leave with a clearer picture of what engineering work looks like in practice.

In doing so, the outreach programme responds directly to the systemic barriers identified in the literature. Many students have limited exposure to STEM careers, and classroom teaching tends to focus heavily on examinations rather than application, while practical engineering experiences are largely absent from standard school curricula. These gaps discourage students from pursuing STEM pathways. The outreach activities address all these barriers in a direct and accessible way (Ahmad, 2017; Vela et al., 2020; Becker & Park, 2011).

Continued collaboration between universities and educational institutions is essential to sustain this momentum and to inspire the next generation of innovators in science and engineering. As Malaysia works toward the STEM participation goals set out in its national education agenda, and as official data confirms that the 60% target remains a work in progress despite recent gains, the role of universities as active partners in school-level STEM culture becomes increasingly important and to strenghthening Malaysia’s STEM ecosystem.

The framework presented here offers a meaningful, experience-tested pathway for universities to play that role and as a sustained contributor to the engineering futures of the students they are working to reach.

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BIODATA OF AUTHORS:

DANNY NG WEE KIAT
University Tunku Abdul Rahman,
Bandar Sungai Long,
43000 Kajang, Selangor, Malaysia
Email: ngwk@utar.edu.my

PHUA YEONG NAN (Corresponding author)
University Tunku Abdul Rahman,
Bandar Sungai Long,
43000 Kajang, Selangor, Malaysia
Email: phuayn@utar.edu.my

GOH CHOON HIAN
University Tunku Abdul Rahman,
Bandar Sungai Long,
43000 Kajang, Selangor, Malaysia
Email: gohch@utar.edu.my