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Experiential Learning in Engineering Design, Manufacturing and Sustainability through Polyethylene Terephthalate (PET) - to - Filament Innovation

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ABSTRACT

Learning by doing is an experience in which knowledge is created through direct experience. A final-year project is a platform through which students can demonstrate the skills and knowledge acquired during the degree program by solving real-life or research problems. To mould technologically competent, sustainable, and socially responsible engineers, exposure to problem-based and project-based learning experiences is critical. This paper outlines the 360-degree learning approach used to enhance students' understanding through experiential learning and response to the global concern over plastic waste, particularly Polyethylene Terephthalate (PET) from food packaging. The project objective was to design and develop a low-cost PET filament extruder capable of converting post-consumer PET bottles into usable 3D printing filament for fused deposition modelling (FDM). The project involved the ideation of potential solutions, the application of engineering design and manufacturing process principles, the optimisation of extruder performance parameters, and the evaluation of the quality of the extruded filament. Completion of this project facilitated the student with essential soft skills beyond technical knowledge. Through the experience, skills in (a) leadership, (b) resilience, (c) innovation, (d) creativity, (e) solution-oriented, (f) independent learning, (g) professional and (h) ethics were developed. It was found that, across over 280 hours of allocated project time, the most frequently acquired skills were creativity, innovation, and solution orientation. The strongest Programme Outcomes (POs) according to the Engineering Accreditation Council (EAC) standard were design/development of solutions (PO3) and life-long learning (PO12). The outcomes demonstrate that experiential learning effectively nurtures competence, creating all-around, future-ready engineers.

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1. INTRODUCTION

Engineering education increasingly emphasises experiential learning as a core pedagogical approach to bridge the gap between theoretical understanding and real-world application. The “learning by doing” philosophy empowers students to translate classroom knowledge into tangible problem-solving capabilities, fostering a deeper comprehension of engineering principles. In Malaysia, the Engineering Accreditation Council (EAC) mandates that graduates demonstrate a comprehensive set of Programme Outcomes (POs), encompassing technical expertise, ethical responsibility, communication proficiency, and sustainability awareness. Final-year projects (FYPs) provide a valuable platform through which these competencies are applied and evaluated, drawing on applied academic knowledge and skills to address a specific practical, research-based, or industry-related problem, serving as a capstone experience that synthesises their learning.

Plastic pollution, particularly from Polyethylene Terephthalate (PET) used in food and beverage packaging, poses a significant environmental threat. Conventional recycling processes often result in downcycled products, limiting the reuse potential of PET waste. The development of PET 3D filament from recycled bottles demonstrates a practical application of circular economy principles, achieving a 90% utilization rate of PET waste, thus reducing the need for new raw materials and minimising waste (Oliveira, Lima, Corrˆ, & Oliveira, 2025; Mawaddah, Chalid, Maulidina, Ashanti, & Nugraha, 2023; Ragab, Elazhary, Schmauder, & Ramzy, 2023). Despite the benefits, there are challenges in using recycled PET, such as the need for quality control to ensure consistent filament diameter and mechanical properties. Additionally, impurities and plastic degradation during recycling can affect filament performance (Ogunsakin & Onitiri, 2025). Recycled PET filaments generally exhibit good printability, minimal warping, and acceptable surface finishes. However, challenges such as moisture sensitivity and diameter inconsistencies can affect the quality of the printed parts (Nikam et al., 2024; Raut, Bandre, & Sapkal, 2025).

Experiential learning initiatives, such as project-based learning, engage students in hands-on activities that bridge theoretical knowledge with practical skills, enhancing their problem-solving capabilities in sustainability contexts (Sundman et al., 2025). These types of projects encourage collaboration and innovation, essential for addressing complex sustainability challenges in engineering education (Alhassani, Saleem, & Messner, 2025). While the focus on experiential learning is promising, it is crucial to address the gaps in affective and socio-emotional learning dimensions, which remain underexplored in current sustainability education frameworks. This could limit the holistic development of competencies necessary for future engineers. Also, the rapid expansion of 3D printing presents an opportunity to reintroduce waste PET into productive use by developing an extruder that transforms post-consumer PET into fused deposition modelling (FDM) filament. Students are directly engaged with sustainable design principles, circular economy practices, and applied materials engineering.

Several key factors, including sustainability, material performance, organisational characteristics, and global pressures, influence the adoption of PET filament innovation in engineering design and manufacturing. Larger firms often adopt innovations driven by internal factors, such as resource availability and strategic alignment, whereas global pressures may influence smaller firms more. The shift towards sustainable practices drives the adoption of PET-filament, as it offers recyclability and reduced waste compared to traditional materials (Agrawal & Bhat, 2025; Punia et al., 2025). The cost of equipment and materials plays a significant role in decision-making, with firms weighing the initial investment against long-term benefits. Within this context, the project served as an experiential learning tool to integrate mechanical design, thermoplastic processing, and sustainability-driven problem-solving into a cohesive educational experience.

This paper highlights the problem-based and project-based activities imposed on two FYP students working on the same topic. One of them gained international exposure during a 10-day visit to Japan. This study focuses on the implementation of an experiential learning project in which students designed and built a low-cost PET filament extruder to convert post-consumer plastic bottles into 3D-printing filament. The project not only addresses global concerns on plastic waste management but also exemplifies sustainable engineering practice within an educational framework.

2. METHODOLOGY

The project was undertaken by two FYP students from the Faculty of Mechanical Engineering. The primary objective was to recycle 1.5 L post-consumer PET bottles into solid and hollow filaments suitable for fused deposition modelling (FDM) or 3D printing. The work consists of two main components. First is on the project planning and execution. The second is the analysis of the student's perceived knowledge and skills gained through the project. The project duration is two semesters (28 weeks), totalling 280 hours.

2.1 Project planning and execution

The students were required to design a device capable of processing the 1.5L PET bottles into solid and hollow filaments. The project was structured into three phases of activities. (1) design of extruder, (2) fabrication and assembly of extruder and (3) production of solid and hollow filaments.

2.2 Perceived knowledge and skills

During the course of the project, students were exposed to four main learning components, namely (1) international mobility and networking, (2) technical, digital and self-learning, (3) hands-on experience and (4) consultation with supervisors.

2.3 Analysis

Time allocated to each project activity was recorded, and the corresponding soft skills developed were identified and analysed. The targeted skills included are (a) leadership, (b) resilience, (c) innovation, (d) creativity, (e) solution-oriented, (f) independent learning, (g) professional and (h) ethics. The frequency of each skill across all activities was then evaluated. Subsequently, both the projected time expenditure and the development of soft skills were assessed. Finally, these outcomes were mapped against the allocated program outcomes for the FYP.

3. RESULTS AND DISCUSSION

This section presents the findings from the study's major components: project planning and execution, and perceived knowledge and skills.

3.1 Project planning and execution

3.1.1 Design of the extruder

In the design process, the students proposed three alternative concepts for each subsystem in the extruder: the bottle cutter, extruder, and winding unit. The objectives were to establish a suitable and functional configuration. Each design idea was evaluated using key indicators such as performance consistency, user safety, ease of maintenance, and compatibility with integration.

The decision matrix method was employed to assess and rank all design options systematically. Evaluation criteria were established for the specific functions and purposes of each subsystem within the filament production process. The finalised assembly offers a balanced integration of printability, scalability, and operational efficiency. The device was named dFilEx, reflecting its ability to produce two types of filaments in parallel. The final design of dFilEx is shown in Figure 1. The estimated time spent on this activity is about 10 hours, during which students demonstrated the following skills: (b) resilience, (c) innovation, (d) creativity, (e) solution-oriented, (f) independent learning and (h) ethics.

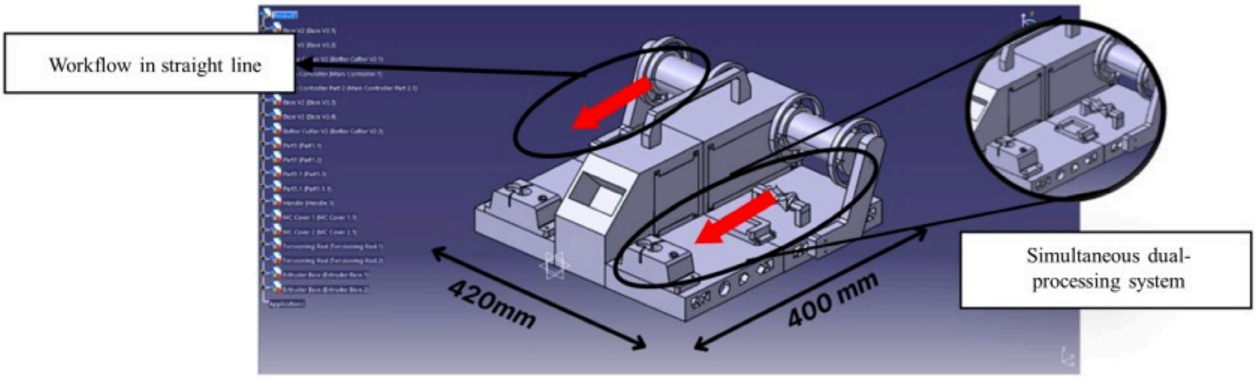


Fig. 1 *The final design of the filament extruder, dFilEx*
Source: Author (2026)

3.1.2 Fabrication and assembly of the extruder

The fabrication phase of the dFilEx extruder involved using FDM to manufacture all major components from PLA, followed by integrating all subsystems into a single functional product. The subsystems were subsequently integrated into a single operational unit. To support the subsystems, a structural platform comprising the base, main casing and main casing cover was designed and printed.

In total, approximately 1,433 grams of PLA were used, with a cumulative printing time of 218 hours on an Ender-3 printer. Figure 2 shows the fully assembled dFilEx, integrating all subsystems into a cohesive system. During this stage, students enhance several soft skills, particularly (b) resilience, (c) innovation, (d) creativity, (e) solution-oriented, (f) independent learning and (g) professional.

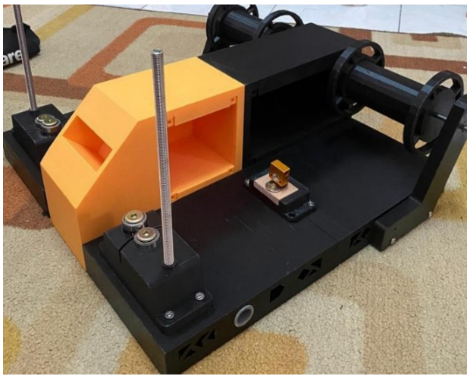


Fig. 2 *The dFilEx after fabrication and assembly*
Source: Author (2026)

3.1.3 Production of solid and hollow filaments

A selected brand of 1.5L PET bottle was used in the preliminary experiments to maintain consistency in the results. Each bottle was cut into a continuous strip approximately 7 mm in width. These PET strips were then fed into a heated extruder to produce solid filament. A key challenge during this process was preventing the formation of hollow sections in the solid filament, which can occur due to incomplete melting, inconsistent feeding, or inadequate extrusion pressure. For the production of hollow filaments, the PET strips were first rolled circumferentially before entering the heated extruder, thereby creating an internal void. Maintaining the geometry of the hollow filament during extrusion was essential to prevent collapse or distortion. The most effective extrusion conditions were achieved at 210°C and a winding speed of 6 mm/s. Ambient air at room temperature provided adequate cooling and solidification, while a tight nozzle fit maintained internal pressure and facilitated air evacuation. Under these conditions, both solid and hollow filaments consistently achieved a uniform diameter of approximately 1.75 mm with no observable hollow sections, confirming the effectiveness of these parameters.

The successfully extruded solid and hollow filaments are shown in Figure 3. Based on trials using a single 1.5L PET water bottle, approximately 60% to 75% of the total plastic material was successfully converted into usable 3D printing filament, yielding about 18 to 21 grams of filament, with an average production time of 1 hour per type. The key skills developed during this phase included a) leadership, (b) resilience, (c) creativity, (d) solution-oriented, (e) independent learning, (f) professional and (h) ethics.

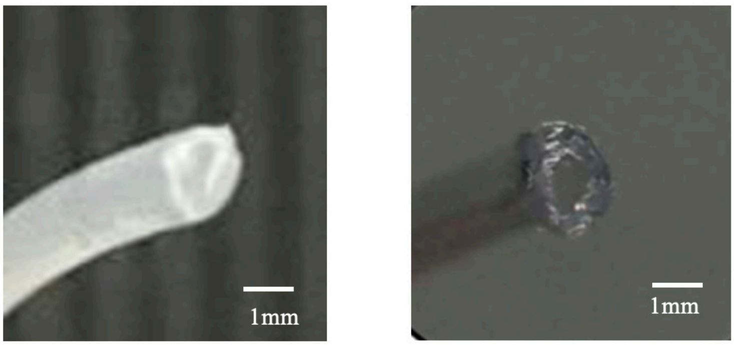
3.2 Perceived knowledge and skills

3.2.1 International exposure

One of the two students, referred to as Student F, participated in an international mobility in Japan under the Sakura Science Exchange Program (SSEP). The program was attended by participants from Tokyo University of Agriculture and Technology (TUAT), Japan, The University of British Columbia (UBC), Canada and National Central University (NCU), Taiwan.

This ten-day program provided exposure to research and innovation activities, laboratory facilities and management, a global academic network and Japanese culture. Approximately 150 learning hours were recorded for this program. These hours are considered in addition to the 280 hours allocated for the course, as the program was conducted during the semester break. Upon returning, Student F shared his experiences and insights with his teammate, Student N. Figure 4 presents a group photo taken during a visit to the Yamanashi Prefectural Maglev Exhibition Centre.

Although only one student directly attended the program, both students were considered to have gained (a) leadership, (c) innovation, (d) creativity and (g) professional skills through knowledge sharing and reflection on the experience.



a b

Fig. 3 *Extrusion of PET filament (a) solid filament (b) hollow filament (with about 0.62mm internal diameter)*
Source: Author

Fig. 4. *Visit to Yamanashi Prefectural Maglev Exhibition Centre, Japan*
Source: Author (2026)

3.2.2 Technical, digital and self-learning

To complete the project, the students engaged in various digital and self-learning activities. These included exploring the online database for recent and relevant journal publications, reviewing tutorial videos on a self-made extruder, and utilising the learning management system (LMS) to prepare the project presentations, technical report, and final thesis.

Through these activities, the students developed digital literacy and independent learning competencies, enabling them to generate innovative ideas and experience personalised learning. The skills strengthened during this stage were (c) innovation, (d) creativity, (e) solution-oriented, (f) independent learning and (h) ethics. Total time spent on this activity was estimated at 12 hours.

3.2.3 Hands-on experiences

Throughout the design, fabrication and production of filaments, students were directly involved. This strengthens the practical experience and problem-solving capabilities. The experience includes 3D modelling, machine assembly, trials on filament extrusions and troubleshooting. These activities required the students to apply theoretical knowledge from previous coursework. In addition, systematic analysis and optimisation of process parameters were undertaken to ensure consistent PET strip cutting and consistent filament quality.

This experiential learning component provides students with a deeper understanding of manufacturing, materials processing, and machine design. It also nurtured all soft skills, namely (a) leadership, (b) resilience, (c) innovation, (d) creativity, (e) solution-oriented, (f) independent learning, (g) professional and (h) ethics. The estimated time devoted to hands-on fabrication, assembly and testing was approximately 10 hours (excluding the fabrication time as mentioned in Section 3.1.2).

3.2.4 Consultation and Discussion

Regular consultation with the project supervisor, approximately 14 hours per semester, played a crucial role in guiding the student through each project phase. Weekly meetings lasted at least 1 hour per person to review progress, evaluate results, and provide constructive feedback. The session also encouraged critical discussion of decision-making, ethics, and documentation. The process functioned as academic mentorship and professional coaching. As a result, students developed competencies in (b) resilience, (c) innovation, (d) creativity, (e) solution-oriented, (g) professional and (h) ethics.

3.3 Analysis of Findings

3.3.1 Time spent

Figure 5 shows the time spent on completing the project and developing skills throughout the experience. A total of 280 hours were recorded throughout the completion of this project, encompassing various phases of design, fabrication, experimentation, consultation, and self-learning activities. The largest portion of time was dedicated to the fabrication process (218 hours), reflecting the intensive nature of constructing the dual-filament PET extrusion system. This stage required students to assemble mechanical and heating components, troubleshoot technical issues, and ensure the extruder's operational capability. There are 28 hours allocated to consultation sessions with supervisors and peers to discuss progress, challenges, and analysis of results. The students spent 12 hours self-learning through online journals, videos, and digital resources on PET recycling and extrusion systems. Meanwhile, design activities (10 hours) involved preliminary sketches, component selection, and conceptual planning of the extrusion mechanism. Moreover, an additional 10 hours were dedicated to hands-on experimentation, allowing students to operate, test, and refine the prototype they developed. Filament production took 2 hours for both solid and hollow filaments.

The international exposure program provided additional learning opportunities in innovation and engineering practice that went beyond the course allocation. Overall, the distribution of time spent on project activities demonstrates a strong emphasis on practical implementation and experiential learning, supporting both technical and professional growth.

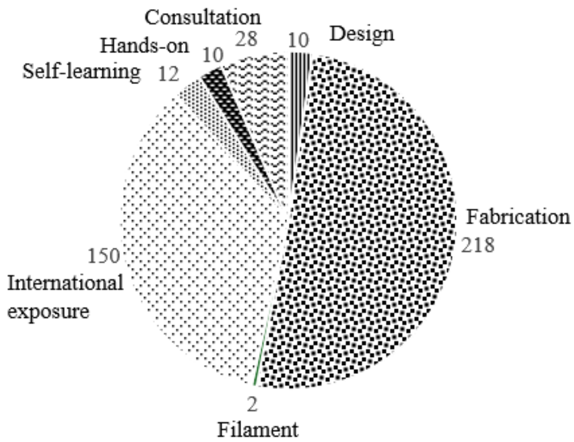


Fig. 5 *Time spent to complete the project and skills enhancement*
Source: Author (2026)

3.3.2 Developed soft skills

The frequency of the developed soft skills through this project is illustrated in Figure 6. The finding shows that the three most prominent skills demonstrated by the students were creativity, innovation, and solution-oriented thinking. These outcomes reflect the open-ended, hands-on nature of the project, in which students were required to design and fabricate a dual-filament PET extruder. The need to address real technical challenges encouraged the students to think creatively, test multiple design options, and develop effective solutions to ensure consistent filament quality.

The high frequency of creativity and innovation indicates that students were able to apply theoretical knowledge to practical situations while exploring new design possibilities. The ability to transform PET waste into usable 3D-printing filament demonstrates an inventive approach aligned with the Engineering Accreditation Council (EAC) outcomes in design and investigation. The iterative design and testing process strengthened critical thinking and problem-solving abilities, particularly when optimising extrusion temperature, feed rate, and filament geometry.

In addition to these dominant skills, the students also developed resilience, independent learning, professionalism, and ethics. These were cultivated through prolonged project engagement, teamwork, and regular supervisory consultations. Such experiences fostered persistence, accountability, and the ability to manage uncertainty, qualities essential to becoming professional engineers. Overall, the project effectively integrated both technical and non-technical competencies, demonstrating that experiential and project-based learning can holistically develop students in accordance with outcome-based education principles.

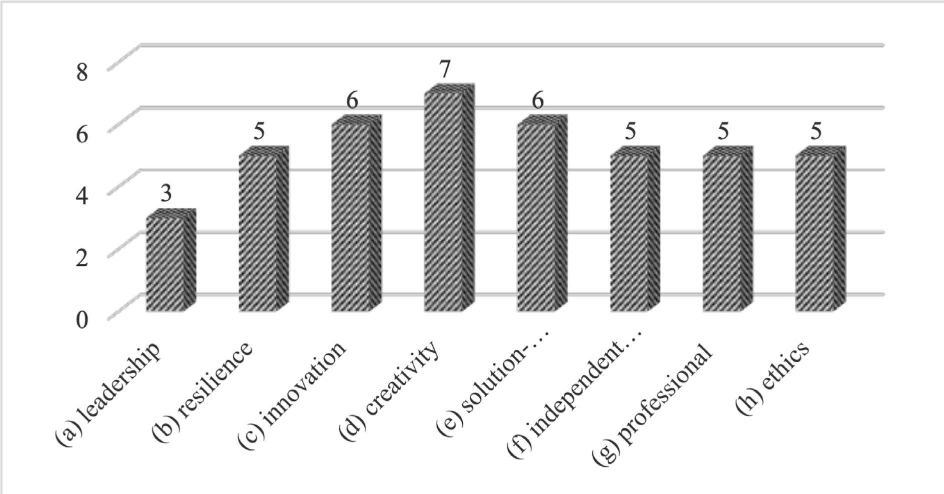


Fig. 6 *Frequency of the developed skills through the project*
Source: Author (2026)

3.3.3 Program outcomes (POs) for FYP

The POs assessed in this project correspond to the EAC standards (EAC, 2020): PO3: Design/development of solutions, PO4: Investigation of complex problems, PO5: Modern tool usage, PO6: The engineer and society, PO10: Communication and PO12: Lifelong learning. Each outcome was evaluated on a 100-point scale based on students' project performance, reports and presentations. Student F achieved consistently higher scores across all outcomes, ranging from 79.0 to 93.8, compared to Student N's range of 68.9 to 81.2. The average PO achievement was 85.2% for Student F and 76.8% for Student N. Both students demonstrated proficiency above the 70% competency threshold typically considered satisfactory in outcome-based education (OBE) assessment. The performance for both students can be observed in Figure 7.

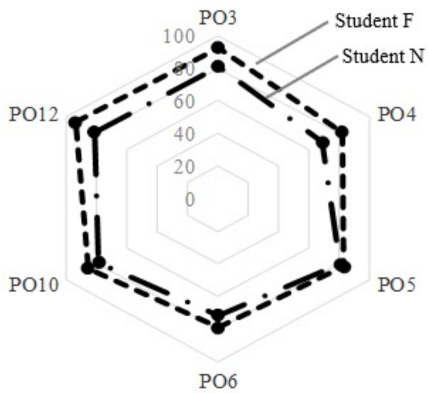


Fig. 7 *PO attainments for FYP*
Source: Author (2026)

Design/development of solutions (PO3) and Life-long Learning (PO12) were the strongest domains for both students, indicating effective application of design thinking, adaptability, and self-learning skills reinforced by the hands-on and exploratory nature of the FYP. Investigation (PO4) and the engineers and society (PO6) showed relatively lower scores, particularly for Student N. This may suggest a need for deeper integration of analytical reasoning, sustainability awareness, and global impact assessment. Communication (PO10) scores remained strong for both students, reflecting their ability in report writing and presentations. Tool Usage (PO5) results suggest that both students demonstrated competent use of computer-aided design and analysis, 3D printing, and analytical tools throughout the project.

The higher performance of Student F may be attributed to the additional international exposure gained through the SSEP, which expanded the global perspective, leadership skills, and motivation. However, both students achieved a holistic development of technical and professional competencies as envisioned in the EAC PO framework. The results demonstrate that the dual-filament PET extrusion project effectively supports PO attainment in multiple domains, balancing technical design capability with lifelong learning and professional development outcomes.

4. CONCLUSIONS

This work demonstrated the design and fabrication of a dual-filament PET extrusion system (dFilEx) capable of converting 1.5 L post-consumer PET bottles into solid and hollow 3D-printing filaments. The project achieved consistent filament quality under optimised extrusion conditions and contributed to sustainable material utilisation. Beyond the technical success, the project indirectly enhanced students' creativity, innovation and solution-oriented skills. Regarding the PO attainment outlined by EAC, the top two domains acquired by both students are lifelong learning and the design/development of solutions. The combination of technical application and experiential learning proved effective 360 learning in developing both engineering competence and professional attributes, highlighting the value of project-based learning in nurturing future-ready engineers. The project has been submitted for copyright with certification number CRLY2025W06991.

5. SUGGESTIONS

For future work, improvements on the dFilEx can be made through automating the feed control. In addition, material property analysis, namely strength and impact, can be conducted to explore the potential product that can be formed from recycled PET filaments. In terms of education, future studies may include a larger number of students and appropriate assessment tools to evaluate skill development, learning progress, and PO achievement. This can further strengthen the experiential and sustainable engineering education, producing graduates with both technical proficiency and strong professional attributes.

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8. AUTHORS' CONTRIBUTIONS

The authors affirmed that there is no conflict of interest in this article. Norliana Mohd Abbas carried out fieldwork, consultations, research methodology, and data analysis. Yusuf Olanrewaju Busari conducted fieldwork, consultations, literature reviews, and manuscript reviews for coherence and cohesion. The authors confirmed that the submitted work is original and free from plagiarism.

9. CONFLICT OF INTEREST DECLARATION

We certify that the manuscript is the original work created by the authors. It has not been published previously, nor has it been considered for publication elsewhere. We further confirm that the authors have made substantial contributions to the work and take full responsibility for the integrity of the content and presented data for submission to IJELHE.

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