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Designing a computational thinking module for STEM teachers: a design and development approach

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ABSTRACT

This study investigates the necessity of computational thinking (CT) skills integration among science, technology, engineering, and mathematics (STEM) secondary school teachers, focusing on the development of the *McodE* pedagogical module for the topic of heat in solar still projects. Utilizing a design and development research (DDR) approach, the research aimed to design and develop a CT module tailored to enhance teachers' pedagogical strategies in solar still project. The case study was employed with 32 STEM secondary school teachers, through purposive sampling participated in the study based on their experience in integrating technology into pedagogy. A pre-test and post-test design was employed during a two-day workshop to assess the participants' CT skills before and after the intervention. An additional open-ended interview was conducted among three teachers to support the quantitative data. The results revealed significant improvements in various aspects of CT application. The findings demonstrated substantial increases in teachers' abilities to integrate CT into their teaching practices. The mean for pre-test score was 43.25, which significantly increased to 67.37 in the post-test, indicating a marked enhancement in CT skills. The t-test statistics for the pre-test (t=31.04, df=31, p<.001) and post-test (t=49.94, df=31, p<.001) confirmed a highly significant differences between the pre-test and post-test scores. The open-ended interview also showed the strong interest and necessity of the CT module among the respondents. The study concludes that there is a critical need for CT module among STEM teachers to better prepare students for the demands of modern STEM education.

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1. INTRODUCTION

Since January 2017, Malaysia has integrated computational thinking (CT) into its National Educational Curriculum for primary and secondary schools [1]. The Malaysian Ministry of Education (MOE) has undertaken this initiative to enhance digital skills across various academic subjects, initially focusing on computer science and gradually expanding to other disciplines [2], to support this integration, the MOE has provided comprehensive training for teachers on the application of CT. This initiative is part of the broader Malaysia Education Blueprint 2013-2025, which is currently in its third wave (2020-2025). The Blueprint emphasizes digital transformation and the incorporation of digital skills in education, aligning with the objectives of the Malaysian Economic Blueprint 2021 [3]. This strategic focus underscores the country's commitment to preparing students for a digital future and enhancing the quality of education through the integration of CT.

Science, technology, engineering, and mathematics (STEM) education's interdisciplinary nature necessitates comprehensive guidelines to support teachers in effectively integrating various disciplines. The complexity of STEM education often leads to professional identity conflicts among teachers who may be proficient in one or two areas but struggle to teach across all STEM fields. Comprehensive guidelines can bridge the competency gap between experienced and less experienced teachers, ensuring a uniform quality of STEM education [4]. Additionally, guidelines can provide a structured framework for incorporating modern technological advancements and innovative teaching methods, thereby enhancing the overall learning experience [5]. Many STEM' secondary school teachers exhibit a lack of confidence and expertise outside their specialized subjects, significantly hindering the effective delivery of integrated STEM education [6]. This lack of confidence is often due to insufficient training and professional development opportunities that do not adequately prepare teachers for interdisciplinary teaching. For example, teachers who are specialists in biology and physics may find it challenging to teach CT-integrated lessons involving engineering or technology concepts [7], [8]. This weakness is compounded by the rapid pace of technological advancements, which necessitate continuous professional development to keep teachers' skills and knowledge up to date.

Current educational modules often fail to effectively integrate CT into content, such as heat transfer in solar energy projects. This leads to misconceptions and inadequate assessments of heat transfer and temperature among teachers [9]. The complexity of the heat topic is well-documented [10] and is exacerbated by a lack of embedded CT skills needed for understanding and applying technological solutions like the Magnetcode microcontroller. Previous studies [11], [12] highlighted how this oversight limits student engagement and understanding in STEM topics. Additionally, current modules do not adequately foster critical thinking and collaboration skills [13] hindering teachers' ability to utilize emerging technologies. There is an urgent need for educational modules that incorporate CT seamlessly to enhance teaching efficacy and address complex challenges, ultimately improving educational outcomes. Therefore, the aim of the study is to design and develop the *McodE* pedagogical module based on CT skills focusing in topic heat for solar still project. The research study aims to design and develop the *McodE* pedagogical module based on CT skills focusing on the topic heat for solar still projects. The specific research objective is to identify the need of CT skills in the topic heat for solar still projects. The research question seeks to explore how to identify the need of CT skills in the topic heat for solar still projects?

2. LITERATURE REVIEW

The CT skills require teachers to approach problems from a CT perspective and highlights how this CT perspective can be supported teaching and learning [14], [15]. According to Wing [16] CT should be taught as a fundamental skill across the school curriculum. However, teachers often struggle with misconceptions when aligning CT skills with STEM concepts [13]. Various teaching and learning modules have been developed and implemented in a new STEM course at the secondary school level [17]. However, incorporating the four key elements of CT skills such as decomposition, pattern recognition, abstraction, and algorithms into pedagogical modules remains insufficient [10]. Decomposition is the ability to dissect a large and/or problems in addition to possible solutions problem into more manageable parts [18]. Thus, teachers must embed the CT skills into the subject based to encourage students to learn abstract, algorithmic and logical thinking, and be prepared to solve complex and open-ended problems. Thus, Meseguer and Serrano [19] addressing teacher' pedagogical approaches to CT in teaching and learning remain scarce and reflect the lack of consensus on its definition and components [18], [20].

Many researchers have studied and found that CT through coding and robotics is an ideal platform for the teaching and learning [21], [22]. The module development through coding and robotic must be edutainment and align with subject contents [22]. Therefore, incorporating the four elements of CT skills such as decomposition, pattern recognition, abstraction, and algorithms in the pedagogical module are crucial. Decomposition is the ability to dissect a large and/or problems in addition to possible solutions problem into more manageable parts [18]. When creating problems, teachers need explicit instruction at the beginning on how to break problem based on STEM contents into smaller manageable pieces [23]. Through the pattern recognition, the teacher guided students to recognize the smaller problems with known solutions and guide a student's confidence in problem-solving. According to Yasin and Nusantara [24], pattern recognition characteristics in CT can be identified as: i) understanding the problem by looking for information on the problem context; ii) matching questions with a similar description of the questions stored in the students' mind (past information); iii) extracting the problem's components; iv) looking for a relationship from the extraction results; v) exploring all possible relationships from the extracted results to find a regularity; vi) estimating the patterns from all combinations of extracted results; and vii) selecting the pattern found from the forecast results based on the problem [24], [25].

Abstracting is the ability to focus on what is essential while ignoring what is not [18]. It involves breaking down problems into manageable components, emphasizing essential elements, and organizing them systematically. Modularizing is a reasoning strategy that complements abstraction by structuring problems into distinct, self-contained modules. According to Sjödahl and Eckert [18], level of the abstraction components can be understood as level of algorithms. Algorithms should allow for creating a step-by-step process that provides instructions that repeat the solution [18]. Computerizing smaller pieces of solutions through a series of ordered steps can simplify the most complex problems [26]. Not all algorithms are the same; the teacher should help students understand the solution's effectiveness [27]. Because CT is cross-curricular, any subject can integrate the four pillars to facilitate solving problems. To effectively break down the elements of CT skills in *McodE* pedagogical module in a solar still project, the researcher was integrated facets of CT to ensure that teachers can decompose problems into smaller tasks, define the sequence of steps, and apply conditional commands or loops as needed. By teaching algorithmic thinking, teachers enable students to think logically, plan systematically, and solve problems effectively. This skill is crucial for students to apply CT in a structured and organized manner. In developing the *McodE* pedagogical module, the researcher was consolidating these CT skill elements, as illustrated in Figure 1.

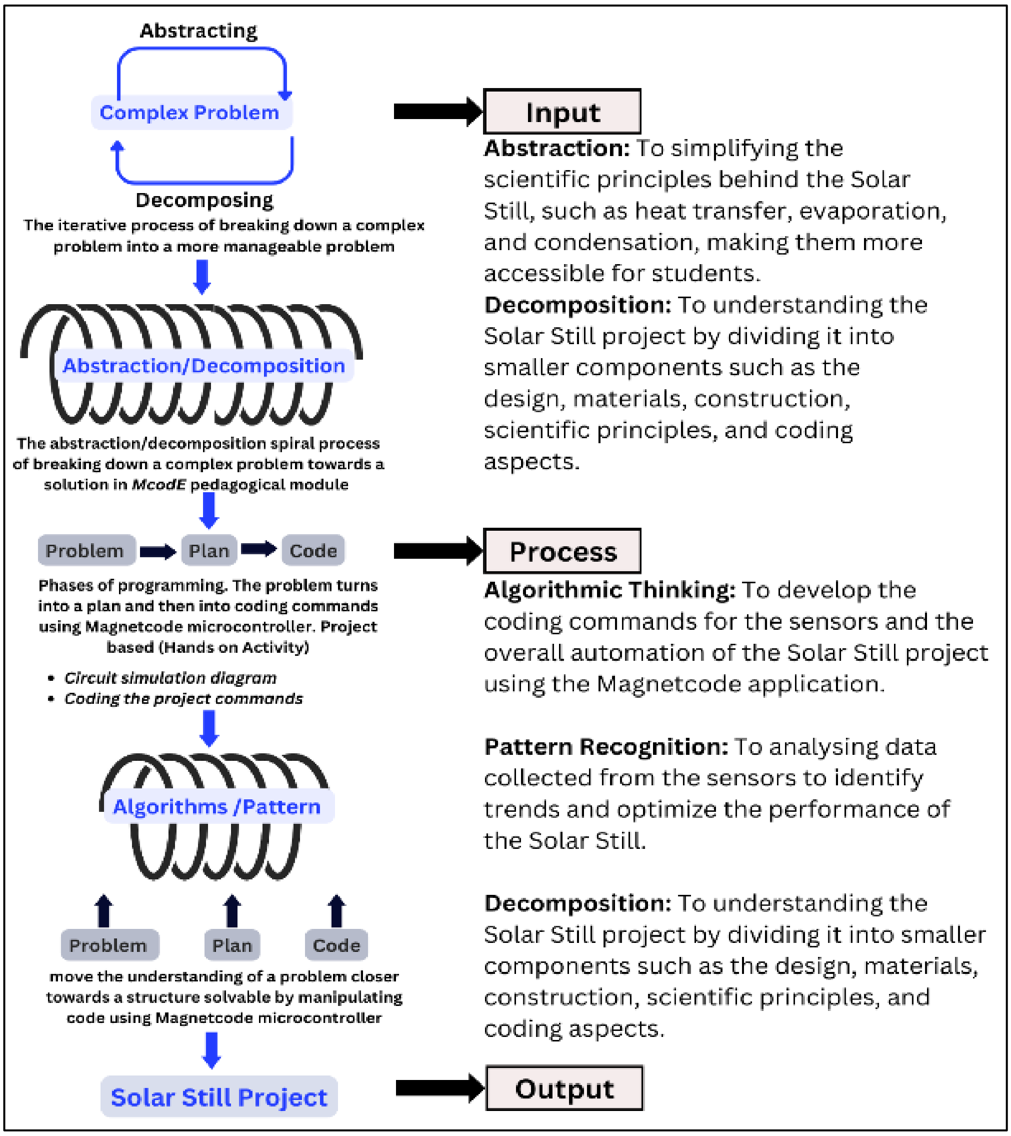

Figure 1. The consolidation of CT skills elements in *McodE* pedagogical module

The researcher illustrates the iterative processes of abstraction, decomposition, algorithmic thinking, and pattern recognition in the *McodE* pedagogical module, as shown in Figure 1. These CT skills encompass:

- Decomposition: this involves breaking down the solar still project into smaller, manageable components such as design, materials, construction, scientific principles, and coding aspects [23], [28]. This iterative process facilitates a more effective understanding and resolution of the problem by addressing each smaller part individually.
- Pattern recognition: utilizing sensors to collect temperature data, this step involves analyzing the data to identify trends and patterns, which can then be applied to optimize the solar still's performance. Recognizing these patterns is vital for generating insights that can be transferred to similar problems [28].
- Abstraction: this simplifies complex scientific principles like heat transfer, evaporation, and condensation, making them more accessible and understandable for students. By doing so, it aids their comprehension and application to the project [29], [30].
- Algorithmic thinking: this involves developing coding commands for the sensors and the overall automation of the solar still project using the Magnetcode application. It requires creating a structured set of instructions that the microcontroller can execute to achieve the desired outcomes, thereby enhancing both scientific and computational learning for the students [31].

By integrating these CT facets, the *McodE* pedagogical module ensures that teachers can guide students in breaking down problems, defining sequences of steps, and applying conditional commands or loops as needed. This approach fosters logical thinking, systematic planning, and effective problem-solving, which are crucial for applying CT in a structured and organized manner.

2.1. Need analysis

The first phase of this research in applying the design and development research (DDR) approach is the needs analysis. During this phase, researchers determine an appropriate data collection method, sampling technique, and reference model to form the study's foundation [32]. These elements are essential to align with the research questions aimed at designing and developing the *McodE* pedagogical module, which is based on CT skills for a solar still project. The needs analysis phase involves identifying and assessing the needs and problems of a target population, as well as the potential solutions. This phase relies on several established models.

a. Discrepancy model: it is argued that the discrepancy or gap model is the most widely used approach to needs assessment. The model emphasizes normative expectations and involves three phases: i) goal setting, identifying what ought to be; ii) performance measurement, determining what is; and iii) discrepancy identification, ordering differences between what ought to be and what is.
b. Marketing model: this model emphasizes analyzing the needs and feedback used by an institution or organization to assess the customer's needs. The analyzing process involves three important things, namely:
   - Selecting the target population (target population) involves a target with a high probability of using a service provided and then making changes required by customers or users.
   - Quantification: this process involves measuring and evaluating customer needs and analyzing the value of a product and the customer's interest in the product or service.
   - Synthesis: this phase involves the preparation of an index of needs that needs to be done by an organization. This index will provide an overview of the actual requirements and information related to the product required by the customer.

In this study, the researcher used the discrepancy model as a support model in the needs analysis phase because this model is the most widely used approach in needs analysis assessment. The researcher identifies five steps in needs analysis:

a. Step 1: identify users and the needs analysis.
   - The user of the needs analysis are STEM secondary school teachers and STEM experts.
   - Needs analysis will focus on problems and solutions that can be entertained.
b. Step 2: describe the target population.
   - The target population in this research is STEM secondary school teachers in Penang and STEM experts. It is all individuals who possess the desired characteristics (inclusion criteria) to participate in the research study.
c. Step 3: identify needs of the module.
   - The researcher will identify the problems revealed by comparing expectations with outcomes. One group pre-test and post-test and open-ended interviews provide the findings for the phase 1, need analysis.

- The expectations are based on the behavior of the target informants. Their comments, ideas, concerns, and suggestions will capture both explicit needs mentioned directly and implicit needs that may emerge indirectly.
- To evaluate the solution, the researcher will use the impact of the needs analysis on the target population to gain a holistic understanding of the overall needs.

d. Step 4: assess the importance of the needs.
   - The needs of the target informants will be evaluated once the problems and their solutions have been identified.

e. Step 5: communicate the results of the needs analysis.
   - The needs results are analyzed, and decision-makers communicated to users and relevant audiences. The needs analysis will be analyses based on the themes, patterns, and recurring needs among the informants.

3. METHOD

The study employed a case study in phase one DDR approach, focusing on needs analysis as the initial step to identify research questions. This needs analysis aligns with McKillip's framework also known as problem analysis where issues are identified and evaluated. Therefore, multiple sources of data are used in a case study [33]. Sample sizes in case studies are typically small and research questions for a case study can be both quantitative and qualitative with the same focus on research objective. Therefore, 32 STEM secondary school teachers were selected through purposive sampling. Selection criteria included the ability to provide detailed data, experience in managing technology in STEM programs, and responsibility for integrating technology into pedagogy. This aligns with the standards set by the MOE. Participants in this research were specifically chosen to meet certain criteria as indicated ensuring they were all secondary STEM teachers. The selected participants adhered to the following criteria: i) all participants were secondary school teachers specializing in STEM subjects; ii) each participant had more than two years of experience in teaching at the secondary school level; and iii) all participants possessed a significant level of knowledge and expertise in using technological approaches for teaching.

The study utilized a one-group pre-test and post-test design in a two-day workshop approved by the Education Planning and Research Division (ERPD) and the Penang Education Department. The workshop aimed to assess participants' CT skills before and after the intervention, focusing on programming knowledge. Pre-test and post-test results were analyzed using SPSS version 29.0 with a dependent samples t-test to identify mean differences. Additionally, qualitative insights were gathered through open-ended interviews with selected STEM teachers, exploring their perspectives on CT skills and module needs. These interviews were audio-recorded, transcribed, and analyzed using a structured checklist [34]. The validity of the interview protocols and questionnaire was reviewed by three experts in psychometric education, curriculum, and linguistics, ensuring both content and internal validity. The validation process focused on the accuracy, format, and variables of the instruments to ensure alignment with the study's objectives [33].

4. RESULTS AND DISCUSSION

The analysis of the pre-test and post-test results reveals a significant improvement in the basic CT skills of STEM secondary school teachers. This study investigates the need of CT skills in the topic heat for solar still projects among STEM secondary school teachers. Table 1 shows the average pre-test score of 43.25 illustrated a significant rise to 67.37 in the post-test, reflecting a substantial improvement in CT skills.

Table 1. One-sample t-test

Test value=0	t	df	Significance		Mean	95% confidence interval of the difference	
			One-sided p	Two-sided p	difference		
Mean pre-test	31.04	31	<.001	<.001	43.25	40.41	46.09
Mean post-test	49.94	31	<.001	<.001	67.37	64.62	70.13

Table 1 illustrated the t-test results for the one group pre-test and post-test design indicate a significant improvement in CT skills among the participating STEM secondary school teachers. The mean pre-test score was 43.25, with a 95% confidence interval ranging from 40.41 to 46.09. This score significantly increased in the post-test, with a mean score of 67.37 and a 95% confidence interval from 64.62 to 70.13. The t-test statistics for both pre-test ($t=31.04$, $df=31$, $p<.001$) and post-test ($t=49.94$, $df=31$, $p<.001$) indicate highly significant differences between the pre-test and post-test scores, confirming that the intervention had a substantial positive effect on the teachers' CT skills. These results underscore the necessity and effectiveness of the proposed CT module for enhancing the pedagogical capabilities of STEM secondary school teachers. As shown in research from Suryani *et al.* [35], CT pedagogical model has proven effective in enhancing CT by breaking down complex problems into manageable sub-goals. In addition, the researcher also conducted open-ended interview with three respondents to support the finding in the pre-test and post-test data. Two broad themes emerged from the analysis illustrated in Figure 2.

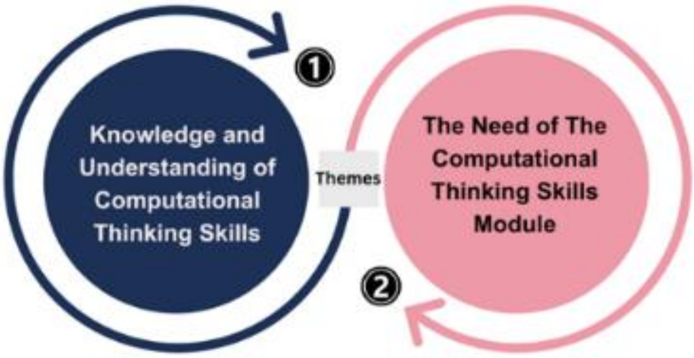

Figure 2. The themes

Based on the interview finding from the three respondents, R1, R2, and R3 it was discovered that the respondent lack of knowledge in incorporating CT in their pedagogical strategies. Respondents R1, R2, and R3 all indicated that they do not know how to incorporate CT into their teaching activities and lesson plans. This is primarily due to a lack of knowledge and understanding of how to integrate CT skills and the Magnetcode application into their lessons. The response received from open-ended interview for R1, R2, and R3 are as stated:

R1: "*I need more explosure on the contents of computational thinking. Besides, I also want to know other ways how to integrate computational thinking in my lesson*." [Interview:17.4.24]
R2: "*Lack of knowledge in methods/ways to create teaching aids and incorporate Magnetcode elements into the lesson content.*" [Interview:17.4.24]
R3: "Because *computational thinking is applied in problem-solving related to an issue, but the flowchart for 'algorithm thinking' is only introduced in the subject ASK (Basic Science Computer).*" [Interview:17.4.24]

The findings highlight a critical need for CT modules among STEM secondary school teachers, as many lack the necessary knowledge and skills to effectively incorporate CT into their teaching practices. The limited of understanding of how to integrate CT skills into their teaching also supported by Cozzens and Carpenter [36], which emphasizes that many educators struggle to integrate CT into their lessons due to a lack of proper guide in teaching and learning [5], [36]. This aligns with the need for CT modules to enhance teachers' capabilities as mentioned by Lapawi and Husnin [10]. Therefore, to address this gap, the development of the *McodE* pedagogical module, is essential. This module will include comprehensive training and resources to help teachers integrate CT skills into their lesson plans effectively. The findings also illustrated the respondents unanimously indicated a need for CT modules related to pedagogical strategies in science, specifically through coding with Magnetcode in projects like the solar still. The open-ended interview from respondent 1, respondent 2, and respondent 3 are as stated:

R1: "*Because to makes learning more interesting and using the right ways and method to increase our understanding. Changing from traditional ways to digitalization technology using Magnetcode.*" [Interview:17.4.24]
R2: "*Methods for utilizing Magnetcode and alternative power sources, such as replacing batteries, to facilitate the production of clean water in the solar still project.*" [Interview:17.4.24]
R3: "*In the teaching and learning process, students learn about different heat transfer concepts that affect temperature changes.*" [Interview:17.4.24]

The finding highlighted the high demand for CT modules focused on Magnetcode and heat topics directly aligns with the article's objective to identify the need for such modules among STEM teachers. Developing comprehensive CT modules that incorporate Magnetcode and address topics like heat transfer can significantly enhance teaching and learning experiences. According to Mensan *et al.* [37], pedagogical module should include practical applications and project-based learning to foster deeper understanding and student engagement [10], [38]–[40].

The open-ended interview findings highlight a clear and pressing need for comprehensive CT modules among STEM secondary school teachers. The identified themes reveal significant gaps in STEM's teachers prior knowledge in CT. Similar findings were observed in a study by Rahmawati and Fauzi [41] utilized CT in pedagogical strategies where educators needed guidance to incorporate CT into pedagogical strategies [35], [41]. The findings also show that the respondents' strong interest in CT modules related to Magnetcode and specific scientific topics like heat transfer underscores the importance of such educational tools. These insights align with the need for CT modules among STEM secondary school teachers. The findings support the need for developing *McodE* pedagogical module that address these gaps, emphasizing practical, project-based learning, ethical considerations, and the seamless integration of CT skills into various teaching contexts. This comprehensive approach is crucial for enhancing the quality of STEM education and preparing teachers and students for the technological challenges of the future [22], [42].

5. CONCLUSION

The study highlights the urgent requirement for developing and implementing CT module to better prepare STEM secondary school teachers for modern educational challenges. The *McodE* pedagogical module, with its focus on practical, project-based learning, offers a promising solution to enhance teachers' pedagogical capabilities and improve student engagement and understanding in STEM education through CT skills. This comprehensive approach is essential for equipping teachers with the skills necessary to navigate the evolving landscape of digital and computational education, ultimately leading to more effective teaching practices and better educational outcomes for students.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that there is no conflict of interest regarding the publication of this article. The research was conducted independently, and there are no financial, personal, or professional relationships that could inappropriately influence the work reported in this manuscript. All authors have contributed significantly to the study and have reviewed and approved the final manuscript.

INFORMED CONSENT

This study was conducted in accordance with the ethical guidelines and procedures approved by the Human Research Ethics Committee of Universiti Sains Malaysia (JEPeM-USM). Prior to participation, all individuals were fully informed about the research objectives, procedures, potential risks, and benefits. Written informed consent was obtained from all participants before their involvement in the study. They were assured of their anonymity and confidentiality, and they retained the right to withdraw from the study at any stage without any consequences. The consent process followed the ethical standards outlined in the Declaration of Helsinki, International Conference on Harmonization (ICH) Guidelines, Good Clinical Practice (GCP) Standards, and Council for International Organizations of Medical Sciences (CIOMS) Guidelines.

ETHICAL APPROVAL

This study protocol was reviewed and approved by the Human Research Ethics Committee of Universiti Sains Malaysia (JEPeM-USM) under the ethical approval code USM/JEPeM/PP/24080708. The approval is valid from 4th October 2024 until 3rd October 2025. The study complies with international ethical standards, including the World Health Organization (WHO) Standards and Operational Guidance for Ethics Review of Health-Related Research, and follows ethical regulations required by USM. Any amendments to the study protocol or adverse events were reported to JEPeM-USM as per the ethical guidelines.

DATA AVAILABILITY

All data supporting the findings of this study are included in the manuscript. No additional data are available.

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