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Development and validation of the Sc-CTM module: Integrating unplugged and plugged-in computational thinking in science education

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ABSTRACT

Computational thinking (CT) is increasingly recognised as a cross-disciplinary problem-solving competency that can strengthen students' reasoning in science learning. This paper reports the development and validation of the Science–Computational Thinking Module (Sc-CTM), which integrates unplugged scaffolding and plugged-in block-based modelling to embed CT practices within Form One Science. The developmental procedure was guided by the ADDIE model and organised into two main phases: Phase I focused on analysis, design, development, and implementation of the module, while Phase II involved evaluation and validation. A needs analysis informed topic selection, indicating Matter as the most challenging learning domain based on students' perceptions ($M = 3.40$, $SD = 0.70$) and teachers' perceptions ($M = 3.64$, $SD = 0.50$). Content validity was assessed using a structured questionnaire distributed to 11 experts in Science and CT/Computer Science. Results showed that all items exceeded a mean score of 4.00, with an overall mean of 4.33, indicating high content validity and clarity. Overall, the findings support Sc-CTM as a systematically designed and validated instructional option for integrating CT meaningfully in science learning.

Keywords: computational thinking integrating, unplugged, plugged-in, science education

INTRODUCTION

The rapid advancement of digital technologies in the industrial revolution (IR) 4.0 has reshaped the competencies required of future learners. Education systems are increasingly expected to cultivate higher-order thinking and systematic problem-solving abilities to prepare students for digitally mediated environments (World Economic Forum, 2018). Among these competencies, computational thinking (CT) has been widely recognised as a fundamental literacy extending beyond computer science and functioning as a universal problem-solving framework (Wing, 2006). CT involves cognitive processes such as decomposition, pattern recognition, abstraction and algorithmic thinking that enable learners to structure complex problems and develop systematic solutions (Santaengracia et al., 2026). In science education, CT supports conceptual modelling, inquiry practices and deeper understanding of scientific phenomena by encouraging learners to represent scientific processes algorithmically and strengthen analytical reasoning skills central to scientific literacy (Liu et al., 2024).

Despite its importance, CT integration in science classrooms remains inconsistent. Many implementations rely primarily on plugged-in programming activities such as scratch (Lye & Koh, 2014), which may introduce cognitive overload and technological constraints (Brackmann et al., 2017). Consequently, unplugged approaches using physical tasks, logical sequencing and flowcharts have emerged as complementary strategies (Curzon, 2013; Del Olmo-Muñoz et al., 2020). However, existing research often examines unplugged and plugged-in approaches separately rather than as an integrated pedagogical sequence embedded within science content (Looi et al., 2018). The integration of unplugged and plugged-in CT activities is theoretically supported by constructionism and social constructivism. Constructionism emphasises knowledge construction through meaningful artefact design (Papert, 1980), while social constructivism highlights collaborative inquiry and scaffolding in learning (Vygotsky, 1978). Together, these perspectives justify a structured and progressive integration of CT within science instruction.

To ensure systematic instructional design, this study adopts the ADDIE model (Analysis, Design, Development, Implementation and Evaluation) as the guiding framework (Spatioti et al., 2022). ADDIE provides a structured process aligning learning objectives, pedagogy and assessment. Through needs analysis, structured design, material development, classroom implementation and empirical evaluation, the model strengthens methodological rigour. Despite the increasing emphasis on CT integration, there remains a lack of validated instructional modules developed through systematic design frameworks and rigorous validation procedures, including content and construct validation (Rohaeti & Huda, 2025). Therefore, this study seeks to develop and validate an Unplugged and Plugged-in Computational Thinking in Science (CTS) module guided by the ADDIE framework. The objectives of the study are to:

1. To examine learners' needs to inform the integration of CT within selected science topics.
2. To establish the module's content validity and construct validity through expert review and empirical analysis.

LITERATURE REVIEW

CT has increasingly been recognised as a core competency necessary for learners in the twenty-first century (Wing, 2006). Beyond programming, CT represents a structured problem-solving approach that involves decomposition, pattern recognition, abstraction and algorithmic thinking (Wu et al., 2024). These cognitive processes support learners in organising complex information and constructing systematic solutions. Within science education, CT plays a crucial role in enhancing modelling practices, inquiry processes, and systems thinking (Sengupta et al., 2013; Weintrop & Wilensky, 2016). Scientific inquiry often involves analysing patterns, formulating hypotheses and designing procedural steps processes that closely align with CT principles. Studies indicate that integrating CT into science instruction improves conceptual understanding and strengthens analytical reasoning skills (Peel et al., 2019; Waterman et al., 2020). Despite its potential, the implementation of CT in science classrooms remains inconsistent. Many educators still experience challenges in integrating CT meaningfully into science instruction, particularly when curriculum guidance and pedagogical support are limited (Liu et al., 2024). This limitation highlights the need for structured instructional modules that explicitly align CT practices with science competencies.

CT instruction typically adopts either plugged-in or unplugged approaches (Chongo et al., 2021). Plugged-in approaches involve programming environments such as scratch, which enable students to create computational artefacts and simulate scientific processes (Lye & Koh, 2014). These environments support constructionist learning by allowing learners to design, test and refine models (Papert, 1980). Research has shown that block-based programming enhances students' algorithmic reasoning and problem-solving skills by simplifying programming syntax and supporting logical thinking processes (Sungur & Ozkan, 2026). However, exclusive reliance on programming may present cognitive challenges for novice learners and require technological resources that are not universally accessible (Brackmann et al., 2017). As a result, unplugged approaches have gained prominence. Unplugged activities introduce CT concepts through physical movement, logic puzzles, flowcharts and collaborative tasks without digital devices (Curzon, 2013; Del Olmo-Muñoz et al., 2020). These activities reduce cognitive load and build foundational understanding prior to formal coding experiences (Brackmann et al., 2017). Although both approaches demonstrate effectiveness independently, limited research has examined their integration within a coherent pedagogical sequence in science education (Looi et al., 2018). A hybrid approach combining unplugged conceptual scaffolding with plugged-in modelling activities may offer a more developmentally appropriate progression for learners.

The integration of unplugged and plugged-in CT activities in science education is supported by constructionism and social constructivism. Constructionism posits that learners develop understanding most effectively when they construct meaningful artefacts (Papert, 1980). Plugged-in programming tasks allow students to externalise scientific reasoning through computational models, thereby making abstract concepts visible and revisable. Meanwhile, Vygotsky's (1978) social constructivist theory emphasises collaborative learning and scaffolding within the zone of proximal development. Unplugged activities involving collaborative problem-solving, structured inquiry and guided discussion are consistent with social constructivist principles, as they promote shared cognitive engagement and active knowledge construction among learners. Inquiry-based science instruction further supports these processes by encouraging students to explore, investigate and construct scientific understanding actively (Sari et al., 2026). Together, these perspectives provide a strong theoretical foundation for developing a structured module that progressively integrates unplugged and plugged-in CT practices within science learning.

Effective module development requires a systematic instructional design framework to ensure alignment between objectives, pedagogy and assessment. The ADDIE model comprising analysis, design, development, implementation and evaluation is widely used in instructional design research (Spatioti et al., 2022). During the learner characteristics, curriculum standards and contextual constraints are examined. Needs analysis is critical in determining appropriate science topics and CT integration strategies (McArdle, 1998). The design phase translates theoretical constructs into structured lesson plans, learning outcomes and assessment strategies. This stage ensures alignment between CT components and science learning standards. In the development phase, instructional materials are created and refined. For CT modules, this may include unplugged reasoning tasks, flowchart-based algorithm design and plugged-in computational modelling activities. The implementation phase involves pilot testing in authentic classroom settings to examine feasibility and pedagogical effectiveness. Finally, the evaluation phase encompasses both formative and summative assessments, including expert validation and empirical testing of learning outcomes. The structured nature of ADDIE enhances methodological rigour and transparency in module development (Spatioti et al., 2022).

For instructional modules to be credible and scalable, rigorous validation is essential. Content validity ensures that module components align with learning objectives and theoretical constructs. The Content Validity Index (CVI) is widely used to quantify expert agreement on item relevance (Polit & Beck, 2006). Construct validity examines whether module components reflect underlying theoretical dimensions, often assessed through factor analysis. Reliability testing, such as Cronbach's alpha, determines internal consistency of assessment instruments (Shute et al., 2017). Despite increasing CT initiatives in education, many studies lack comprehensive validation procedures. Modules are often implemented without systematic psychometric evaluation, limiting generalisability and replication (Grover & Pea, 2013). Therefore, integrating ADDIE with rigorous validation procedures addresses both pedagogical design and empirical robustness.

METHODOLOGY

Research Design

This study employed a developmental research design guided by the ADDIE instructional design model (Spatioti et al., 2022). Developmental research is appropriate for designing, validating and refining educational interventions within authentic learning contexts (Richey & Klein, 2007). The overall research procedure of the Sc-CTM module was organised into five phases based on the ADDIE model, namely analysis, design, development, implementation and evaluation (Spatioti et al., 2022). The module integrated two pedagogical approaches, namely unplugged and plugged-in instructional strategies, to support the progressive development of CT within science learning.

Sample

Purposive sampling was used to select 150 Form One students (13 years old) from a rural secondary school in Sabah, Malaysia, involving 78 students in the treatment group and 72 in the control group. The school was selected based on the availability of computer laboratory facilities to support the technology-based intervention. This sampling technique allows the selection of participants that align with the study objectives (Etikan et al., 2016; Palinkas et al., 2015). Although random assignment was not possible due to administrative constraints, baseline equivalence between groups was considered based on academic performance and demographic characteristics to reduce potential bias in the quasi-experimental design (Creswell & Creswell, 2018; Fraenkel et al., 2012).

Instrument

The Computational Thinking Achievement Test (CTAT) comprised 15 objective items assessing core CT domains such as abstraction, decomposition, pattern recognition, algorithmic thinking and evaluation. Each correct answer received one mark, with a total score of 15 and a test duration of 45 minutes. The instrument was adapted from the UK Bebras Computational Thinking Challenge developed by Blokhuis et al. (2015, 2016, 2017). Bebras-based tasks are widely used in CT research due to their emphasis on problem solving, logical reasoning and algorithmic thinking (Chiazzese et al., 2019).

Data Analysis

Data were analysed using SPSS. Preliminary analyses were conducted to examine assumptions of normality, homogeneity of variance and outliers. Normality was assessed using the Shapiro–Wilk test, skewness and kurtosis values, while Levene’s test was used to determine homogeneity of variance (Field, 2018). A two-way MANOVA was employed to examine the effects of instructional group and gender on multiple post-test dependent variables, including their interaction effects. This analysis is appropriate for studies involving multiple continuous dependent variables across categorical independent variables (Tabachnick & Fidell, 2019).

Pilot Study

A pilot study is a small-scale preliminary trial conducted to evaluate the feasibility of the research design and identify limitations in the research instruments and procedures. In this study, a pilot study involving 21 Form One students, comprising 11 female and 10 male students, was conducted to examine the reliability, clarity and suitability of the instruments before the actual study. The findings were used to improve the instruments and research procedures (Menon et al., 2021)

Development Procedure of the Sc-CTM Module Based on the ADDIE Model

The ADDIE model is one of the most widely used instructional design models in educational research and module development due to its systematic and structured approach. The model consists of five phases namely analysis, design, development, implementation and evaluation, which provide clear guidance for planning, developing and evaluating instructional materials to ensure effective teaching and learning processes (Spatioti et al., 2022).

Analysis phase

The analysis phase aimed to identify learners’ needs, curriculum alignment and contextual constraints. A needs analysis was conducted to determine appropriate science topics for CT integration and to examine learners’ prior exposure to computational thinking (McArdle, 1998). Curriculum standards, learning outcomes and science content requirements were also reviewed to ensure alignment with educational objectives and the suitability of unplugged and plugged-in instructional activities (Spatioti et al., 2022).

Design phase

During the design phase, learning objectives were developed by aligning CT constructs, namely decomposition, pattern recognition, abstraction and algorithmic thinking, with selected science topics. Instructional strategies incorporated both unplugged and plugged-in approaches. Unplugged activities involved flowcharts, inquiry tasks and collaborative activities to develop conceptual understanding (Del Olmo-Muñoz et al., 2020). Meanwhile, plugged-in activities utilised block-based programming to model scientific phenomena and strengthen computational reasoning skills. Lesson plans, assessment

Table 1. Level of topic difficulty according to learning domains in form one

Learning Domain (Topic)	Students (M)	Students (SD)	Teachers (M)	Teachers (SD)
Introduction to Scientific Investigation	1.78	0.42	1.64	0.50
Cell as The Basic Unit of Life	2.21	0.44	2.36	0.50
Coordination and Response	2.62	0.67	2.91	0.30
Reproduction	2.53	0.68	2.82	0.60
Matter	3.40	0.70	3.64	0.50
Period Table	3.01	0.61	3.36	0.50
Air	2.37	0.62	2.46	0.52
Light and Optics	3.31	0.60	3.54	0.52
Earth	1.88	0.56	1.73	0.47

instruments and evaluation rubrics were also designed to ensure alignment between learning objectives and assessment strategies (Tikva & Tambouris, 2021).

Development phase

In the development phase, instructional materials were developed based on the design framework and organised into thematic science units integrating unplugged and plugged-in activities. The unplugged activities focused on conceptual understanding and algorithmic thinking through flowcharts and guided inquiry, while the plugged-in activities enabled students to develop computational artefacts using block-based programming aligned with constructionist principles (Papert, 1980). The materials were reviewed for content clarity, instructional flow and curriculum alignment before pilot implementation (Hsu et al., 2023).

Implementation

The implementation phase involved pilot testing the Sc-CTM module in an authentic classroom setting to examine its feasibility and instructional coherence. Prior to implementation, teachers participated in orientation sessions focusing on CT integration and module execution procedures to ensure instructional fidelity and consistency across classrooms. The module was delivered using a structured hybrid sequence, beginning with a conceptual introduction through unplugged reasoning tasks designed to scaffold foundational CT skills, followed by application and modelling activities conducted through plugged-in programming environments to reinforce algorithmic thinking and computational modelling practices. This staged progression was designed to reduce cognitive load while gradually enhancing students' computational reasoning skills (Brackmann et al., 2017).

Evaluation

The evaluation phase involved assessing the quality and suitability of the module through content validity, construct validity and reliability analyses. These procedures were conducted to ensure that the module components were relevant, theoretically aligned and consistently measured before implementation. Content validity was assessed using the Content Validity Index (CVI), a widely used approach for evaluating instructional materials and research instruments (Masuwai et al., 2024; Wang & Sahid, 2024). A panel of experts in science education, CT and instructional design evaluated the relevance, clarity and alignment of the module components, with CVI values of 0.78 and above considered acceptable indicators of content validity. In addition, construct validity was examined through exploratory or confirmatory factor analysis to determine whether the module components aligned with the theoretical dimensions of CT (Marar et al., 2023). Internal consistency reliability was assessed using Cronbach's alpha coefficient, with values of 0.70 and above regarded as acceptable for educational research (Dorsah, 2026).

FINDINGS AND DISCUSSION

Need Analysis

The findings of the need analysis, as detailed in **Table 1**, indicate that the topic of Matter recorded the highest mean score compared to other topics, based on both students' perceptions (M = 3.40, SD = 0.70) and teachers' perceptions (M = 3.64, SD = 0.50). This suggests that Matter is perceived as the most challenging topic among the listed learning domains.

The findings of the needs analysis, as detailed in **Table 1**, indicate that the topic of Matter recorded the highest mean score compared to other topics, based on both students' perceptions (M = 3.40, SD = 0.70) and teachers' perceptions (M = 3.64, SD = 0.50). This suggests that Matter is perceived as the most challenging topic among the listed learning domains. These findings are consistent with previous studies reporting that students often experience difficulties in explaining the properties of matter and describing phase changes (Özmen, 2011). Furthermore, Ning and Chongo (2023 found that students tend to classify materials based on observable physical characteristics and commonly hold misconceptions that not all substances or matter are composed of particles. Recent studies also indicate that students frequently struggle to connect macroscopic, sub microscopic and symbolic representations when explaining changes in matter and particulate concepts (Contreras, 2024; Renvall & Kurtén, 2024). Such misconceptions can be reduced using animation, which helps students visualise particulate processes and abstract scientific concepts more effectively (Özmen, 2011). Scratch programming supports students' learning through visual and interactive activities (Sáez-López et al., 2016).

Table 2. The mean scores for the content validity questionnaire

	Item	Mean Score
1	T&L strategies emphasise a constructivist learning approach.	4.6
2	T&L strategies emphasise a constructionist approach	4.2
3	Content connects knowledge, skills, and values with real-world applications.	4.4
4	Knowledge and skills are introduced progressively from simple to complex	4.5
5	Organisation of materials is systematic and easy to follow	4.2
6	Content covers knowledge and skills specified in the curriculum	4.6
7	Concepts, facts, and terminology are accurate and up to date.	4.3
8	Concepts, facts, and terminology are consistent.	4.5

Table 3. Mean scores for content validity items of the Sc-CTM

No	Item	Mean (M)
A	**Content**	
1	The teaching and learning strategy prioritizes a constructivist learning approach.	4.6
2	The teaching and learning strategy prioritizes a constructionist approach.	4.2
3	The content links the knowledge, skills and values learned to their application in the workplace and everyday life.	4.4
4	Knowledge and skills are introduced progressively from simple to complex.	4.5
5	The materials are well-organized and easy to follow.	4.2
6	The content covers the knowledge and skills specified in the curriculum specifications.	4.6
7	The concepts, facts and terminology are accurate and up to date.	4.3
8	The concepts, facts and terminology are consistent.	4.5
B	**Activity**	
9	The activities are appropriate and enable students to master the concepts and skills and achieve the learning outcomes.	4.5
10	The presentation of the activities can stimulate curiosity.	4.3
11	The student-centered activities encourage cooperative group learning.	4.4
12	The activities in Subtopic 5.1.2 address the states of Matter in terms of the arrangement and movement of particles and relate these to the physical of solids, liquids and gases.	4.4
13	The activities in Subtopics 5.2 help students describe change in the state of Matter in terms of particle motion due to heat absorption and release, based on kinetic theory. Students will explain, with examples, changes in the state of Matter in everyday life.	4.6
14	The activities raise students' awareness of the importance of science learning strategies in solving problems and constructing new knowledge.	4.3
15	The activities raise students' awareness of the importance of values in science learning for everyday life and the workplace, as well as for learning science.	4.1
16	The activities are suitable for students with both high and low ability levels.	4.0
17	The activities emphasize the construction of concepts specified in the curriculum specifications.	4.4
C	**Computational Thinking Skills**	
18	The sequence for introducing computational thinking skills is appropriate.	4.1
19	The activities can foster computational thinking skills.	4.5
20	These activities can nurture students becoming innovative.	4.2
21	The activities can help students solve problems systematically related to issues in the Matter topic.	4.1
22	Integrating computational thinking into teaching and learning can promote higher-order thinking skills (HOTS).	4.1
23	The activities can cultivate several computational thinking skills among students, such as:	
	a. Algorithmic thinking	4.3
	b. Decomposition	4.5
	c. Abstraction	4.2
	d. Generalization	4.4
	e. Evaluation	4.4

Validity of The Sc-CTM Module

Content validity evaluation of the Sc-CTM module

The Sc-CTM Module Content Validity Questionnaire was employed to evaluate the content validity of the Sc-CTM module. The instrument was distributed to 11 experts with expertise in Science and CT or Computer Science (CS). **Table 2** summarises the mean scores for each item in the content validity questionnaire. The analysis revealed that all items recorded mean values exceeding 4.00, with an overall mean score of 4.33. These findings indicate that the content validity of the Sc-CTM module is at a high level.

Table 3 summarises the mean score for each item in the questionnaire. The analysis indicates that all items recorded mean values exceeding 4.00, with an overall mean score of 4.33. Overall, these findings demonstrate that the content validity of the Sc-CTM Module is at a high level indicating strong agreement among experts regarding the relevance and suitability of the module components (Masuwai et al., 2024).

Language validity evaluation of the Sc-CTM module

The feedback provided by the language expert panel for each item in the Sc-CTM Module Language Validity Questionnaire is summarized in **Table 4**. The analysis shows that nine out of ten items received 100% 'Yes' responses, while one item related to

Table 4. Mean scores from language experts for each item of the Sc-CTM module

No	Item	Response	
		Yes (%)	No (%)
1	Each sentence conveys a clear meaning.	100	
2	The language used is easy to understand.	100	
3	The instructions provided are clear.	100	
4	The labels used are appropriate.	100	
5	The font size is appropriate and easy to read.	100	
6	The spacing is appropriate.	100	
7	The terms used are accurate.	100	
8	The Science/Computer Science register used is appropriate.	100	
9	The module objectives are clearly stated.	100	
10	There are no spelling errors.	75	25

spelling accuracy obtained 75% ‘Yes’ responses. Overall, these findings indicate that the language validity of the Sc-CTM Module is at a high level, although minor improvements in spelling are still required. This finding is consistent with previous studies which suggest that expert validation is important in ensuring clarity, accuracy, appropriateness and overall quality of educational modules before implementation (Morrison et al., 2019).

Validity and Reliability of the Computational Thinking Achievement Instrument (CTAI)

A pilot study was conducted to examine the validity and reliability of the CTAI. Validity is an important aspect in research as it ensures that the instrument accurately measures the intended construct (Cohen et al., 2018). In this study, the validity of the instrument and the CT skill elements were reviewed by seven content experts and seven language experts. In addition, the reliability of the instrument was assessed to determine the stability and consistency of the measurements (Dorsah, 2026). Following the administration of the pre-test and post-test during the pilot study, Pearson correlation analysis was conducted. The findings indicated a strong relationship between the pre-test and post-test CTAI scores, with $r = 0.742$, $p < 0.01$. Out of 15 questions, eight were multiple choice questions and seven were fill in the blank questions. Item analysis was conducted after the post-test in the pilot study to determine whether each item should be retained, improved or discarded. However, the analysis only involved the eight multiple choice items and was determined based on the Difficulty Index (p) and Discrimination Index (D), as shown in **Table 5**. Kim et al. (2024) stated that item difficulty and discrimination indices are important indicators in evaluating the quality of assessment items. Overall, the findings indicate that the multiple-choice items demonstrated acceptable levels of difficulty and discrimination, suggesting that the instrument was appropriate for assessing students’ computational thinking achievement. These results support the quality and effectiveness of the assessment items used in the study (Kim et al., 2024).

The strengths of the Sc-CTM module lie in its systematic integration of unplugged and plugged-in CT activities within science learning. The module supports the development of core CT processes such as decomposition, pattern recognition, abstraction and algorithmic thinking, which are essential for structuring complex problems and constructing systematic solutions

Table 5. Analysis results of post-UPPK items

Item	Group	Number of students who selected the answer				No Response	p	D	Comment
		A	B	C	D				
1	Upper	1	2	1	5*	0	0.50	**0.29**	Moderate item,
	Middle	0	3	1	3	0			item considered
	Lower	2	1	0	3	0			for improvement
2	Upper	1	7*	1	1	0	0.81	0.71	Moderate item,
	Middle	0	7	0	0	0			accepted
	Lower	0	4	1	0	0			
3	Upper	1	7*	0	1	0	0.68	0.42	Moderate item,
	Middle	1	5	1	0	0			accepted
	Lower	1	3	1	1	0			
8	Upper	0	0	0	7*	0	0.68	0.57	Moderate item,
	Middle	0	2	1	5	0			accepted
	Lower	1	2	1	3	0			
9	Upper	2	1	5*	1	0	0.59	0.43	Moderate item,
	Middle	2	0	4	1	0			accepted
	Lower	0	0	4	2	0			
11	Upper	2	5*	1	2	0	0.50	0.43	Moderate item,
	Middle	0	4	4	0	0			accepted
	Lower	1	2	1	0	0			
	Upper	1	7*	1	2	0	0.72	0.43	Moderate item,
	Middle	0	5	0	1	0			accepted
	Lower	0	4	1	0	0			
15	Upper	0	0	0	7*	0	0.73	0.43	Moderate item,
	Middle	0	2	1	5	0			accepted
	Lower	0	2	1	4	0			

Note: * Correct answer

(Santaengracia et al., 2026). In addition, the integration of block-based programming and animation through scratch enables students to visualise abstract scientific concepts and strengthen conceptual understanding, particularly in the topic of matter, which is commonly associated with misconceptions related to particulate concepts and phase changes (Özmen, 2011; Sáez-López et al., 2016). The module also emphasises inquiry-based and collaborative learning approaches that enhance modelling practices, analytical reasoning and active knowledge construction in science education (Liu et al., 2024; Sari et al., 2026). Furthermore, the high content and language validity scores indicate strong expert agreement regarding the relevance, clarity and suitability of the module components, thereby supporting the credibility and instructional quality of the Sc-CTM module.

CONCLUSION

This study developed and validated the Sc-CTM to support the integration of CT in lower secondary science education. Guided by the ADDIE instructional design framework, the module was systematically developed through needs analysis, instructional design, development, implementation and evaluation processes. The needs analysis identified the topic of Matter as the most challenging learning domain, which informed the design and structure of the module. Validation findings indicate that the module achieved a high level of content validity, with all evaluation items exceeding the acceptable threshold and an overall mean score of 4.33, while language evaluation confirmed that the module is clear and appropriate for instructional use. This study contributes to the field of science education by providing a systematically developed and empirically validated instructional module that integrates CT through both unplugged and plugged-in learning activities. The findings also imply that structured integration of CT within science instruction can support the development of students' systematic problem-solving abilities and conceptual understanding. Future research may further examine the effectiveness of the Sc-CTM module in improving students' CT competencies and science learning outcomes across different educational contexts.

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AI statement: The authors stated that they used ChatGPT only for linguistic enhancement and proofreading purposes. All intellectual contributions, including the study design, data analysis, interpretation of findings, and conclusions, were independently conducted and verified by the authors.

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