Development of a Computational Thinking Module for Renewable Energy Education in Primary Science

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ABSTRACT

This study examines the effectiveness of a Computational Thinking–Integrated Module (CT-Module) in improving computational thinking skills and renewable energy awareness among Year 4 primary school students in Sabah, Malaysia. The module was developed based on constructivist learning theory and the Computational Theory of Mind using the ADDIE instructional design framework. It combined both plugged and unplugged learning activities within the primary science topic of energy, with emphasis on four key computational thinking components: decomposition, pattern recognition, abstraction, and algorithmic thinking.

A quasi-experimental pre-test and post-test control group design was employed involving 78 students, equally divided into treatment and control groups. Data were gathered using validated instruments measuring computational thinking skills and renewable energy awareness, alongside semi-structured interviews to gain deeper insights into students' learning experiences. Quantitative data were analysed using independent t-test, paired sample t-tests, mixed ANOVA, MANOVA, while interview responses were analysed thematically.

The findings indicate that students who participated in the CT-Module demonstrated significantly higher improvements in both computational thinking skills and renewable energy awareness compared to students who received conventional instruction. The treatment group consistently recorded higher post-test scores and maintained positive learning gains over time, suggesting strong retention effects. In addition, interview findings showed that the module encouraged greater student engagement, improved problem-solving abilities, and increased awareness of environmental sustainability issues.

Overall, the study suggests that integrating computational thinking into renewable energy education can provide a meaningful interdisciplinary approach for strengthening 21st-century skills and sustainability awareness among primary school students. The findings also offer practical implications for curriculum development, science teaching practices, and future sustainability-focused educational initiatives in Malaysia.

Keywords: Computational Thinking, Renewable Energy Awareness, Education for Sustainable Development, Primary Science, Module Intervention

INTRODUCTION

The demanding pace of Forth Industrial Revolution has reshaped expectations of school education, placing heightened emphasis on students' abilities to solve complex problems, reason systematically and apply knowledge across disciplinary boundaries. Within this context, computational thinking (CT) has emerged as a core cognitive skill that embarks beyond computer science to domains such as science education, sustainable education and environmental studies. In conjunction to these educational shifts, global concerns surrounding climate change, energy consumption and environmental degradation have intensified calls for effective Education for Sustainable Development (ESD).

Renewable energy education constitutes a critical component of ESD; however, its abstract and systemic nature presents substantial conceptual challenges for primary learners. Preliminary research presents traditional teaching method that emphasizes teacher-centred approaches often prioritise factual recall over higher order reasoning, resulting in limited conceptual understanding and weak translation of knowledge into environmentally responsible behaviour. Embedding CT into renewable energy context facilitates a promising pedagogical pathway due to its flexible interdisciplinary character. CT offers structured cognitive components such as decomposition, pattern recognition, abstraction and algorithm that aligns naturally with the energy context.

Despite rapid international concern and interest, empirical research examining CT-integrated sustainability instruction at the primary level unfortunately remains scarce, particularly within Southeast Asian contexts. In Malaysia, CT has been formally introduced within the primary curriculum, yet its integration beyond programming-orientated activities still underdeveloped. Addressing this gap, the present study design and develops a computational thinking module (CT-Module) to evaluate Year 4 students' CT gains while fostering renewable energy awareness (REA). In conjunction with energy context, the study addresses the following research objectives:

1. To determine the effectiveness of CT-Module in enhancing primary students' computational thinking skills
2. To examine CT -Module impact on students' renewable energy awareness.

Constructivism in Sustainability Education

Recent research in education has significantly expanded understandings of how computational thinking (CT) functions within broader learning environments, particularly in primary and STEM education. CT has evolved from a skill primarily associated with programming into a holistic cognitive framework that supports problem solving, systems reasoning, and interdisciplinary thinking (Palop et al., 2025). This reconceptualization emphasises not only decomposition, pattern recognition, abstraction, and algorithmic reasoning but also data-centred and metacognitive processes, positioning CT as foundational across all K–12 educational domains rather than isolated to computer science courses.

The design and development of the CT-module based on the analysis of various elements was proposed, which was the application of computational thinking skills, problem solving skills, implementation of STEM education in elementary schools, understanding elementary students' learning styles and its relation to learning and teaching theories. This module applies knowledge construction idea by adapting towards environmental issues following Piaget's theory of cognitive constructivism (1976). Piaget's theory is compatible with primary year 4 students in this research. It focuses on students' knowledge construction to environmental issues, renewable energy and its benefits, practice sustainable energy consumptions and so on. Through discussions and solutions to environmental issues, students would go through exploration and recognise the topic easily.

In conjunction with students' ages (10-11 years old), Piaget's cognitive constructivism theory informs that these children lie within concrete operational stage where they can investigate and solve the concrete problems rationally (Pascual-Leone & Johnson, 2010). So, these students were exposed with stimulating materials such as environmental issues, pictorials to suit their cognitive stage. Murray et al. (2023) in his research also mentioned how independence and critical thinking especially in problem solving activities like designing energy efficient systems which rooted by Piagetian principles been enhanced among students. Apart from this, Rands and Gansemer-Topf (2017) discussed the effects of active learning classrooms based on Piaget's concept. They have mentioned student-based activities made them feel appreciated as learners and its ideal for renewable energy education where students build up their knowledge on computational skills from scratch. CT module which integrates constructivism theory engages students in various environmental problems and able to build their computational skills from basic to complex. In addition, (Allen, 2022) discussed constructivist approach that used mobile simulations helped students to actively construct their understanding about abstract topics such as algorithms in energy production. In this research, students' aged 10, will begin to construct their ideas about computational thinking from basic to complex with the aid of CT-Module to apply in "Energy" topic. This in turn will help them to grasp complex concepts, identify problems, solve problems using innovative and creative ideas.

Computational Theory of Mind in Module Development

The computational theory of mind says that our mind acts like a computing system. This theory stands primarily by its contribution to solving the mind-body problem, its ability to discover mental phenomena. The theory needs to be made compatible with the tractability of cognition, the situatedness and dynamical aspects of the mind, the way the brains work, intentionality and awareness (Cambridge University Press, 2023). Computational Theory of Mind (CTM) also known as computationalism, holds that the mind is computational system that is physically and mentally realised by neural activity in brain. There isn't any specific explorer in this theory to be mentioned but Warren McCulloch and Walter Pitts (1943) were the first to suggest that neural activity is computational. The theory was proposed in modern world by Hilary Putnam in 1967 and developed by cognitive scientist, Jerry Fodor from 1960s to 1980s. Theory of Computation, which is the branch that handles problem solving using model computation, algorithm, how efficient the problem can be solved. Both theories were applied in this module design and development where four computational concept and practices (Algorithm, Abstraction, Pattern Recognition and Decomposition) integrated mainly in learning renewable energy and related problem-solving situations. Students are exposed with these four subtopics in phase 1 and developed through activities in phase 2. In phase 3, students will undergo application of these concepts in solving problems related to renewable energy.

CTM aids in designing activities for the module, such as decomposition (breaking down environmental issues into solvable parts), abstraction (identifying the main problems to tackle out of the pictures), algorithms (organizing steps for energy production) and pattern recognition (addressing the correct sequence for renewable energy process). These processes indicate how the brain functions computationally to organize and process information systematically. Acevedo-Borrega et al. (2022) found that CTM based on computational principles moves beyond programming and enhance logical reasoning and conceptual understanding in educational background. The integration of both plugged and unplugged activities embedded in the module ensures accessibility and contextual relevance in diverse classrooms.

CTM also connects the gap between cognitive processes with emotional and social dimensions. Real life scenarios for instance identifying environmental problems in their own area not only develop cognitive and computational skills but also broadens their empathy and behavioural change, which is essential to achieve sustainability goals (Campbell & Yang, 2021; Sullivan et al., 2014). Acevedo-Borrega et al. (2022) in his research examined the role of computational thinking in modern education, focusing on its ability to blend cognitive skills and emotional change through plugged and unplugged activities proves the logical artifacts and abstractions increased interdisciplinary problem solving and behavioural change among students. An exploration study by Campbell & Yang (2021) also proves the cognitive and representational models used in computational learning activities increased students' understanding of complex systems such as renewable energy. Hence, CT module which emphasizes mainly on CTM ensures students computational skills enhanced apart from fostering behavioural change to create an empathetical generation towards environmental problem.

Renewable Energy Awareness in Malaysia

The National Philosophy of Education outlines holistic development of individuals which is achieved through integrated learning that emphasizes intellectual and spiritual growth, focusing students' ability to contribute to societal betterment. Besides, 'MyDIGITAL' and the Malaysian Economic Blueprint 2021 underpinned the commitment to preparing a future ready workforce intertwined with computational capabilities to drive a digital economy. Hence, local research demonstrates successful implementation of CT into sustainability educations. For instance, integrating STEM approaches across primary education have been proven to increase energy literacy to a high level, shifting student values from a personal perspective to a global one regarding resource conservation (Bharathi et al., 2022). Furthermore, the "McodE Module" which was developed to study heat concept in solar projects has significantly improved students' engagement and understanding in STEM through CT skills (Jaya et al., 2025). Also, the Solar -Powered IoT Hydrophonic Modules which was implemented to connect STEM elements parallel to SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action) embedded use of microcontrollers, environmental sensors, solar energy components and cloud based monitoring platforms to create accessible agricultural solution had positive impact on students where 90% overall students rated "excellent" or "good" experiences through their practical sessions besides their technical skills and positive attitudes towards environment increased drastically (Maizahtulakma et al.,2025). Besides, Zakaria et al. (2024) in her empirical research has supported the notion where the interactive mobile applications have proven effective, with over 98% of 9-year-old students improved their understanding and awareness of renewable energy. Despite the successes of these modules, projects and applications, students particularly in primary level still struggle with the synthesis of conceptual energy knowledge and algorithmic thinking in high complexity scenarios. The field of concurrently cultivating CT and environmental awareness scarcely under investigated with critical lack of empirical evidence on these two domains grow together. Hence, this study aims to address this gap by combining CT and renewable energy into simple introductory module to 10 years old students where their syllabus contains energy topic which comprises energy transfer, renewable energy, how energy created and sustainable energy The module will be an induction for CT concepts through energy literacy for students before they seek deeper knowledge in the upcoming years. This is significant as CT is not taught as stand-alone subject or concept in Malaysian Primary Education Syllabus, as it is embedded in multidisciplinary subjects. By getting to know basic concepts of CT concepts, students will be more prepared and able to understand abstract concepts systematically.

Developing structured, contextually aligned modules is crucial for solving current lack of CT skills among students. By framing CT as cognitive mediator though which sustainability presents as core element, educators can fulfil national policy while elevating students' cognitive ability to tackle 21st century environmental challenges. The use of structured pedagogical modules has emerged as a primary solution for addressing the deficit in Computational Thinking (CT) skills involving sustainable education.

METHODOLOGY

This study employed quasi-experimental research design that utilizes pre-post-test and interview as research instruments involving treatment and control groups. The design was chosen because it allowed the study to be conducted in an actual classroom setting without disrupting the existing school structure or student placement.

The participants were divided into two groups. Students in the treatment group received instruction using the CT-Integrated Module, while students in the control group continued learning through conventional science instruction without the module intervention. Both groups completed pre-tests before the intervention and post-tests after the intervention meanwhile undergone interview after the intervention.

A quasi-experimental approach was considered suitable because the students remained in their existing classroom groups, although efforts were made to ensure that both groups had comparable academic backgrounds and learning abilities. This design enabled the researcher to examine changes in students' computational thinking skills and renewable energy awareness before and after the intervention, while also comparing learning outcomes between the treatment and control groups.

The study also incorporated a mixed-methods approach by combining quantitative and qualitative data. Quantitative data were collected through structured assessments, whereas qualitative data were obtained through semi-structured interviews to provide deeper insights into students' learning experiences and perceptions throughout the intervention.

Population and Sampling Frame

The study involved 78 Year 4 students from a public primary school in Sabah, Malaysia. The students were approximately 10 years old and were selected based on accessibility as well as comparable achievement levels in science.

The participants were equally divided into two groups: Treatment Group: 39 students; Control Group: 39 students. The school represented students from both semi-urban and rural backgrounds. Since students had different levels of digital access, the integration of both plugged and unplugged activities within the module was considered appropriate for the study context. Purposive sampling was used because the study specifically focused on students learning the Year 4 Science topic "Energy" in the Malaysian primary science curriculum.

CONCEPTUAL FRAMEWORK

The conceptual framework for this study was developed based on constructivist learning principles and the Computational Theory of Mind (CTM). The framework proposes that integrating computational thinking into

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renewable energy learning can simultaneously strengthen students' problem-solving skills and environmental awareness. TWO main theoretical foundations guided this study: Constructivist theory, the Computational Theory of Mind integrated with ADDIE instructional design model.

Constructivist Theory

This study was grounded in Piaget's Cognitive Constructivism Theory and Vygotsky's Social Constructivism Theory. Both theories emphasise active learning, collaboration, social interaction, and knowledge construction through meaningful experiences. Throughout the intervention, students were actively involved in inquiry-based learning activities, discussions, experiments, and collaborative problem-solving tasks related to renewable energy. These activities allowed students to gradually build their understanding from simple concepts to more complex reasoning processes.

Computational Theory of Mind

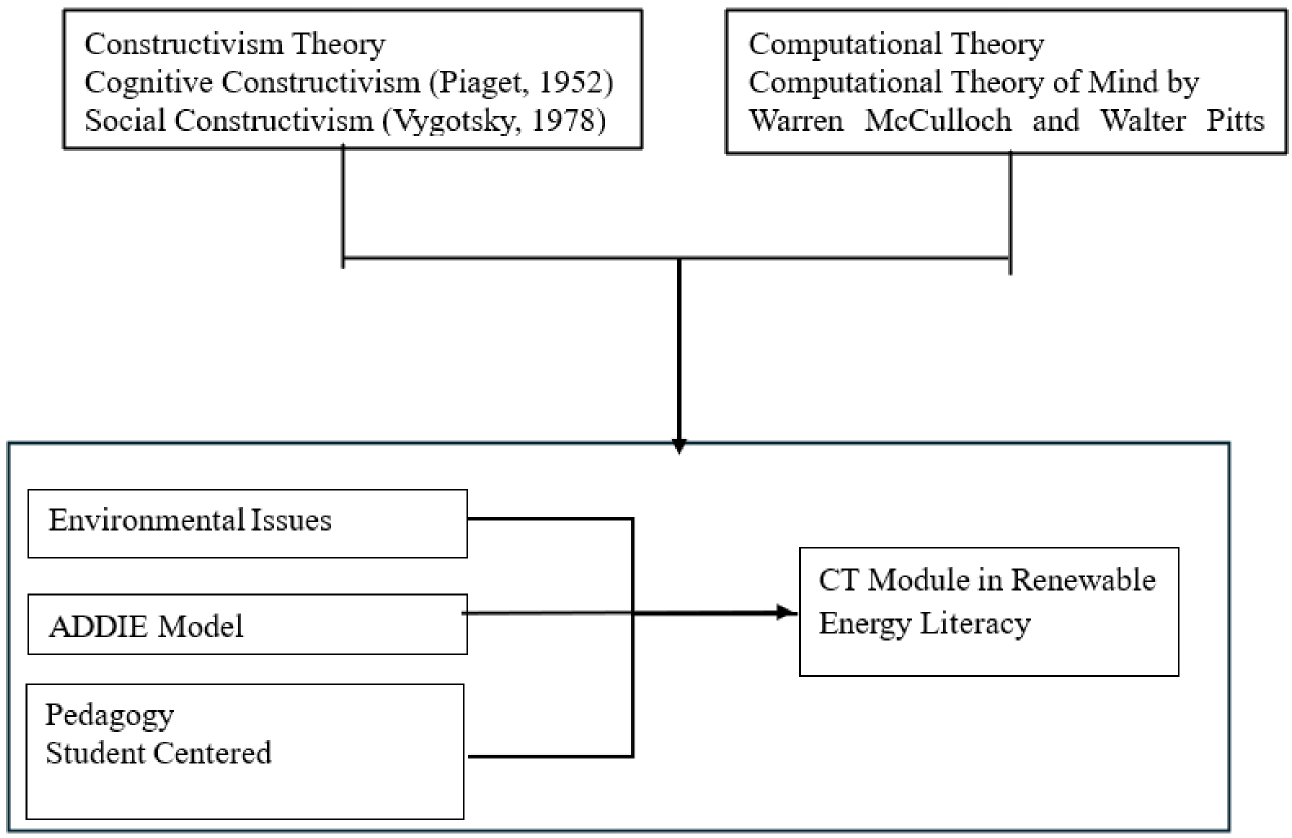
The Computational Theory of Mind explains cognition as a process that functions similarly to computational operations. This theory informed the integration of four core computational thinking components in the module: Decomposition; Pattern recognition; Abstraction; and Algorithmic thinking.

These components helped students analyse renewable energy problems systematically and develop logical solutions to real-world situations.

Instructional Design Model

The CT-Module was developed using the ADDIE instructional design framework, which consists of five phases: Analysis, Design, Development, Implementation and Evaluation The ADDIE model provided a structured process for planning, developing, implementing, and evaluating the module throughout the study. Figure 1 shows the conceptual framework of this study.

Figure 1. Conceptual Framework of Study



Computational Thinking Module (CT-Module)

The effectiveness of teaching and learning lies on meticulous selection of reasonable teaching and learning materials. Among the increasingly popular resources emerging in education nowadays, modular strategy has still been at the top selection because of its diversity which can be applied in various methods such as distance learning, e-learning, self-guided learning, teaching aids in classroom and more. This study focused on evaluation of instructional material in the form of module among 10-year-old students. A well planned, designed instructional module is essential for the successful learning outcome of a subject. The CT-module is the main instrument that will be used for students in treatment group to teach computational thinking in renewable energy lesson. The design of module is based on Constructivism Learning Theory and Computational Theory of Mind. The module was built based on ADDIE model developed by Dick and Carry (1996) for building learning systems. The term ADDIE is an acronym for Analysis, Design, Development, Implementation and Evaluation. From the acronym ADDIE, it signifies the application of module at five levels which propel the practice of developing module. Each of these elements or levels doesn't need to comply a sequential pattern, rather, the levels involved informs one another in a design system (Suratnu, 2023).

The module will be used to teach Energy topic with the integration of computational thinking and environmental sustainability awareness. Table 1 shows the details and steps involved during each phase.

Table 1. Module Activities Breakdown

Phase	Topic	Activity
1	Introduction to energy	• Renewable energy and non-renewable energy • Definition, examples
2	Clean energy	• Concept • Examples
3	Saving Energy	• Examples of electric saving at home and school
4	Introduction to computational thinking	• Decomposition • Pattern Recognition • Abstraction • Algorithm • Examples • Questions and Discussion
5	Problem Solving Activity	• Environmental scenario • DIY projects • Presentations
6	Group Activity	• Renewable energy DIY projects

Development of the CT-Integrated Module

The CT-Integrated Module was systematically developed using the ADDIE instructional design framework. The module integrated computational thinking skills into the Year 4 Science topic of Energy with a specific focus on renewable energy awareness.

Analysis Phase

The analysis phase focused on identifying students' learning difficulties, instructional needs, and curriculum gaps. Several methods were used during this phase, including diagnostic assessments, classroom observations, teacher interviews, and informal discussions with students. The findings showed that many students struggled to understand renewable energy concepts and apply higher-order thinking skills when solving science-related problems. The analysis also indicated that conventional teacher-centred instruction often limited opportunities for active participation, inquiry, and critical thinking.

Design Phase

Based on the findings from the analysis phase, the module was designed to combine renewable energy concepts with computational thinking activities.

The module consisted of five main subtopics:

1. Introduction to Renewable and Non-Renewable Energy
2. Clean Energy
3. Computational Thinking
4. Problem Solving
5. Creative Applications

Learning objectives, classroom activities, instructional strategies, and assessment tasks were carefully aligned with the Year 4 Science curriculum and the objectives of the study. Both plugged and unplugged learning activities were included to accommodate students with different levels of access to digital technology.

Development Phase

During the development phase, teaching materials, lesson plans, worksheets, multimedia resources, quizzes, and assessment rubrics were prepared. Interactive learning materials such as animations, diagrams, games, collaborative tasks, and environmental problem-solving activities were integrated into the module to increase student engagement and understanding. Expert reviews were also conducted to ensure that the content was accurate, suitable for primary school students, and aligned with computational thinking and renewable energy learning outcomes.

Implementation Phase

The CT-Module was implemented over eight weeks during Year 4 Science lessons. Students in the treatment group participated in structured computational thinking activities related to renewable energy topics. These activities included collaborative problem-solving, unplugged computational tasks, online quizzes, inquiry-based investigations, environmental discussions, and creative renewable energy projects. Meanwhile, students in the control group continued learning through conventional teaching methods without exposure to the CT-Integrated Module.

Evaluation Phase

Evaluation was carried out continuously throughout the intervention using both formative and summative assessment approaches. Formative evaluation included classroom observations, feedback from teachers and students, and pilot testing of the learning materials. These processes allowed improvements to be made throughout the implementation phase. Summative evaluation focused on analysing students' pre-test and post-test results to determine the effectiveness of the intervention in improving computational thinking skills and renewable energy awareness.

Research Instruments

Several instruments were used to collect both quantitative and qualitative data.

Computational Thinking Skills Test

A validated computational thinking assessment was used to measure students' abilities in decomposition, pattern recognition, abstraction, and algorithmic thinking. The test consisted of structured questions aligned with the Year 4 Science curriculum and the computational thinking constructs addressed in the module.

Renewable Energy Awareness Test

The Renewable Energy Awareness Test was designed to measure students' understanding, awareness, and attitudes towards renewable energy and environmental sustainability. The instrument assessed students' knowledge related to renewable energy sources, environmental issues, sustainable practices, and energy conservation behaviours.

Semi-Structured Interviews

Semi-structured interviews were conducted with selected students from the treatment group after the intervention.

The interviews aimed to explore students' learning experiences, perceptions of renewable energy, engagement with computational thinking activities, and experiences in solving problems throughout the intervention.

Data Collection

Data collection was conducted over an eight-week period. Prior to implementation, approval was obtained from the school administration, teachers, and students' guardians. The data collection process involved four stages.

Stage 1: Pre-Test Administration

Both the treatment and control groups completed the Computational Thinking Skills Test and the Renewable Energy Awareness Test before the intervention began. These assessments established the students' baseline levels prior to the implementation of the module.

Stage 2: Intervention

The treatment group participated in learning activities using the CT-Integrated Module during science lessons, while the control group continued learning through conventional teaching approaches.

Stage 3: Post-Test Administration

At the end of the intervention, both groups completed the same assessments to measure changes in computational thinking skills and renewable energy awareness. After the post-test 1, students repeated the same test 2 weeks after as post-test 2 to study the retention computational thinking skills and awareness in renewable energy.

Stage 4: Interviews

Semi-structured interviews were conducted with selected students from the treatment group to obtain deeper insights into their learning experiences and perceptions of the module activities. All collected data were anonymised to protect participant confidentiality.

Data Analysis

Both quantitative and qualitative approaches were used to analyse the collected data.

Quantitative Data Analysis

Quantitative data from the pre-tests and post-tests were analysed using the Statistical Package for the Social Sciences (SPSS).The analyses included descriptive statistics such as mean and standard deviation, as well as

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inferential statistical tests including Independent Samples t-tests, Paired Samples t-tests mixed ANOVA and Multivariate Analysis of Variance (MANOVA). These analyses were carried out to identify differences between groups, measure improvements over time, and evaluate the effectiveness of the CT-Integrated Module.

Qualitative Data Analysis

Interview data were analysed using thematic analysis. The interview responses were first transcribed before significant statements were coded and grouped into themes. Recurring patterns and meanings were then interpreted to understand students' experiences and perceptions throughout the intervention. The qualitative findings complemented and strengthened the interpretation of the quantitative results.

Validity and Reliability

Several procedures were carried out to ensure the validity and reliability of the study.

Content Validity

The research instruments and module materials were reviewed by experts in science education, educational technology, and computational thinking. The experts evaluated the instruments in terms of relevance, clarity, suitability, and alignment with the research objectives. Their feedback was used to refine the instruments and improve the quality of the module materials.

Reliability

Pilot testing was conducted prior to the main study. Internal consistency reliability was analysed using Cronbach's Alpha coefficient, and the obtained values indicated acceptable levels of reliability for all instruments used in the study.

Credibility of Qualitative Data

Several strategies were employed to strengthen the credibility of the qualitative findings, including member checking, methodological triangulation, and detailed documentation of the interview procedures and analysis process. The integration of quantitative and qualitative findings further enhanced the trustworthiness of the study.

RESULTS

Effectiveness of Computational Thinking Module in Increasing Computational Thinking Skills among Students

The analysis addresses the first research question which is:

To determine the effectiveness of computational thinking module in increasing computational thinking among primary science students.

In conjunction with the research questions, researcher developed hypotheses:

H_1: There is significant difference in increase of computational thinking skills between control and treatment group.

H_o: There is no significant difference in increase of computational thinking skills between control and treatment group.

Descriptive Statistics

Descriptive statistical analyses were conducted to examine students' performance in computational thinking skills before and after the intervention. Table 2 shows descriptive statistics for computational thinking skills scores.

Table 2. Descriptive Statistics for Computational Thinking Skills Scores

Group	Pre-Test Mean	Post-Test 1 Mean	Post-Test 2 Mean	SD
Treatment	54.28	86.92	82.74	6.12
Control	53.11	61.33	58.87	5.94

The descriptive findings indicate that both groups recorded relatively similar scores during the pre-test stage, suggesting comparable baseline levels of computational thinking skills prior to the intervention. Following the implementation of the CT-Module, the treatment group showed a substantial increase in post-test scores compared to the control group. The treatment group also maintained relatively high scores during Post-Test 2, indicating that the learning effects were sustained over time.

Independent Samples t-Test

Independent Samples t-tests were conducted to compare the mean scores between the treatment and control groups before and after the intervention. Table 3 shows independent samples t-test for computational thinking skills.

Table 3. Independent Samples t-Test for Computational Thinking Skills

Assessment	Group	Mean	t	p
Pre-Test	Treatment	54.28	1.831	.071
	Control	53.11		
Post-Test	Treatment	86.92	11.564	.000*
	Control	61.33		

*Significant at $p < .05$

The pre-test analysis showed no significant difference between the treatment and control groups, indicating that both groups began the study with relatively similar levels of computational thinking skills. However, a significant difference was observed in the post-test scores, with the treatment group achieving substantially higher mean scores than the control group after the intervention.

Paired Samples t-Test

Paired Samples t-tests were conducted to determine whether significant improvements occurred within each group between the pre-test and post-test assessments. Table 4 shows paired sample t-test for computational thinking skills.

Table 4. Paired Sample t-Test for Computational Thinking Skills

Variable	Group	Pre-Test Mean	Post-Test Mean	t	p
Computational Thinking Skills	Treatment	56.41	86.92	18.443	.000*
	Control	53.11	61.33	4.128	.062

*Significant at $p < .05$

The paired samples t-test results indicate that the treatment group showed a significant improvement in computational thinking skills from the pre-test (M = 56.41) to the post-test (M = 86.92), with a statistically significant difference, $t = 18.443$, $p < .05$. This suggests that the intervention was effective in enhancing students' computational thinking skills.

In contrast, although the control group recorded a slight increase in mean scores from 53.11 to 61.33, the difference was not statistically significant, $t = 4.128$, $p > .05$. This indicates that no significant improvement occurred among students who did not receive the intervention.

Mixed-Design ANOVA

A mixed-design ANOVA was conducted to examine changes in students' computational thinking skills across time and between groups. Table 5 shows mixed design anova for computational thinking skills.

Table 5. Mixed-Design ANOVA for Computational Thinking Skills

Source	F	p	Partial η²
Time	247.05	.000*	.765
Group	198.44	.000*	.723
Time × Group	157.28	.000*	.674

*Significant at $p < .05$

The analysis revealed a significant main effect of time, indicating that students' computational thinking scores improved significantly across the testing periods. A significant interaction effect between time and group was also identified, suggesting that the treatment group experienced greater learning gains compared to the control group over time.

Effectiveness of Computational Thinking Module in Increasing Renewable Energy Awareness among Students

The analysis addresses the second research question which is:

To determine the effectiveness of computational thinking module in increasing renewable energy awareness among primary science students.

In conjunction with the research questions, researcher developed hypotheses:

H_1: There is significant difference in increase of renewable energy awareness between control and treatment group.

H_o: There is no significant difference in increase renewable energy awareness of between control and treatment group.

Descriptive Statistics

A descriptive analysis was conducted to examine students' renewable energy awareness scores in both the treatment and control groups before and after the intervention. The analysis focused on the mean scores and standard deviations to provide an overview of students' performance. Table 6 shows descriptive statistics for renewable energy scores.

Table 6. Descriptive Statistics for Renewable Energy Awareness Scores

Group	Pre-Test Mean	Post-Test Mean	SD
Treatment	56.41	88.97	5.48
Control	55.46	62.33	6.03

The descriptive results show that both groups started with almost similar levels of renewable energy awareness before the intervention was carried out. The treatment group recorded a slightly higher mean score ($M = 56.41$,

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SD = 3.416) compared to the control group (*M* = 55.46, *SD* = 3.094). However, the difference between the two groups was small, suggesting that students had a comparable understanding of renewable energy concepts at the beginning of the study.

After the intervention, improvements were observed in both groups. However, the increase in scores was much more noticeable among students in the treatment group. Students who learned using the CT Module achieved a post-test mean score of 88.97 (*SD* = 8.219), while students in the control group obtained a mean score of 62.33 (*SD* = 3.702).

The findings suggest that the CT Module helped students improve their renewable energy awareness more effectively than the conventional teaching method. Although students in the control group also showed some improvement, the progress was considerably smaller compared to the treatment group.

Independent Sample T-Test Analysis

Independent Samples t-tests were conducted to compare the mean scores between the treatment and control groups before and after the intervention. Table 7 shows independent samples t-test for renewable energy awareness test score.

Table 7. Independent Sample T-Test for Renewable Energy Awareness Pre-Post Test

Assessment	Group	Mean	t	p
Pre-Test	Treatment	56.41	1.224	.225
	Control	55.46		
Post-Test	Treatment	88.97	14.218	.000*
	Control	62.33		

*Significant at $p < .05$

The findings indicate that no significant differences existed between groups during the pre-test stage. Following the intervention, the treatment group demonstrated significantly higher renewable energy awareness scores compared to the control group.

Paired Sample T-Test Analysis

Paired Samples t-tests were conducted to determine whether significant improvements occurred within each group between the pre-test and post-test assessments. Table 8 shows paired sample t-test for renewable energy awareness test score.

Table 8. Paired Sample T-Test for Renewable Energy Awareness Pre-Post Test

Variable	Group	Pre-Test Mean	Post-Test Mean	t	p
Renewable Energy Awareness	Treatment	56.41	88.97	20.176	.000*
	Control	55.46	62.33	3.542	.074

*Significant at $p < .05$

The results show that students in the treatment group demonstrated significant improvements in renewable energy awareness after participating in the CT-Integrated Module. The control group showed only slight improvements between pre-test and post-test assessments, and these improvements were not statistically significant.

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Multivariate Analysis of Variance (MANOVA)

MANOVA was conducted to determine the combined effects of the CT-Integrated Module on computational thinking skills and renewable energy awareness simultaneously. Table 9 shows MANOVA results of current study.

Table 9. MANOVA Results for Combined Learning Outcomes

Multivariate Test	Value	F	p	Partial η²
Pillai's Trace	.859	228.67	.000*	.859

*Significant at p < .05

The MANOVA analysis revealed a significant multivariate effect of the intervention on the combined dependent variables. This indicates that participation in the CT-Integrated Module significantly improved both computational thinking skills and renewable energy awareness simultaneously.

Descriptive Analysis of Interview Responses

Semi-structured interviews were conducted with 20 students, consisting of 10 students from the control group and 10 students from the treatment group. The interview instrument contained 10 items administered during Post 1 Interview and Post 2 Interview sessions. Each response was scored using a structured scale (0-4), and the total scores for each student were calculated. Descriptive statistical analysis was conducted to compare the interview performance between the control and treatment groups across both interview sessions. Table 10 shows descriptive statistics for interview scores.

Table 10. Descriptive Statistics for Interview Scores

Group	Interview Session	N	Mean	Standard Deviation	Minimum	Maximum
Control	Post 1 Interview	10	11.20	2.78	7	16
Control	Post 2 Interview	10	4.40	2.17	2	9
Treatment	Post 1 Interview	10	29.90	1.66	27	32
Treatment	Post 2 Interview	10	19.80	2.39	16	23

The findings show clear differences between the control and treatment groups across both interview sessions. During the Post 1 Interview, students in the treatment group recorded a substantially higher mean score (M = 29.90, SD = 1.66) compared to students in the control group (M = 11.20, SD = 2.78). This suggests that students exposed to the CT-Integrated Module demonstrated stronger understanding, engagement, and ability to respond to the interview questions related to computational thinking and renewable energy concepts.

A similar pattern was observed in the Post 2 Interview. The treatment group continued to achieve higher scores (M = 19.80, SD = 2.39) than the control group (M = 4.40, SD = 2.17). Although scores for both groups were lower compared to the Post 1 Interview, the treatment group consistently maintained substantially stronger performance.The smaller standard deviation values in the treatment group also indicate more consistent responses among students who participated in the CT-Integrated Module. In contrast, the wider spread of scores within the control group suggests greater variation in students' understanding and responses during the interviews.

The minimum and maximum values in Table 9 represent the lowest and highest interview scores obtained by students in each group. For example, in the Post 1 Interview, the control group recorded scores ranging from 7 to 16, while the treatment group recorded scores ranging from 27 to 32. Similarly, during the Post 2 Interview, the control group scores ranged from 2 to 9, whereas the treatment group scores ranged from 16 to 23. These findings indicate that students in the treatment group consistently achieved higher interview scores compared to students in the control group. The narrower score range within the treatment group also suggests more consistent responses and understanding among students who participated in the CT-Integrated Module.

Overall, the descriptive analysis supports the quantitative findings of the study. Students in the treatment group demonstrated better conceptual understanding, stronger engagement, and more positive learning experiences compared to students who received conventional instruction.

DISCUSSION

This study set out to examine whether the Computational Thinking–Integrated Module (CT-Module) could improve computational thinking skills and renewable energy awareness among Year 4 students in Sabah, Malaysia. Overall, the findings indicate that the intervention was effective. Students in the treatment group consistently performed better than those in the control group across the post-tests, retention tests, and interview sessions. The quantitative findings were further supported by interview responses, where students in treatment group scored more than control group.

Computational Thinking Skills

Research Objective 1 aimed to investigate the effectiveness of CT-Module in increasing computational thinking among students. The findings clearly show that the CT-Module contributed to significant improvements in students' computational thinking skills. Students who participated in the module achieved substantially higher post-test scores than students who learned through conventional teaching approaches. This suggests that embedding computational thinking activities within science lessons can strengthen students' reasoning, problem-solving, and analytical abilities at the primary school level. One possible explanation for this improvement lies in how the module was designed. The learning activities were structured around four key computational thinking components: decomposition, pattern recognition, abstraction, and algorithmic thinking. Rather than teaching these skills in isolation, the module embedded them within renewable energy topics and science-related problem-solving tasks. As a result, students were able to apply computational thinking in meaningful and familiar learning contexts. The findings also reinforce the idea that computational thinking is not limited to programming or coding activities alone. The notion also supported by Sun et al., (2022) in a study in which introducing unplugged activities before plugged activities could significantly enhance students understanding about computational thinking components. Similarly, studies by Hermans & Aivaloglou (2017) and Guzdial (2022) also supported that computational thinking reaches beyond programming alone. Their findings strengthens that unplugged learning improves participation, self-efficacy, confidence besides preparing them for plugged acitivites. In this study, both plugged and unplugged activities were used throughout the intervention. This approach appeared particularly suitable for the study context, where students came from different backgrounds and levels of digital access. The demographic profile revealed that 72.14% of the students were from suburban areas in the district with relatively good access to digital network, while 27.86% were from rural areas with limited digital facilities. Since a portion of the students lived in rural areas with limited technological resources, the inclusion of unplugged activities ensured that all students could participate actively in the learning process.

These findings are consistent with previous studies which reported that unplugged learning activities can effectively support computational thinking development without requiring extensive programming experience. Similarly, earlier research has argued that computational thinking should be viewed as a broader cognitive process rather than merely a coding skill. The present study supports this perspective, as students demonstrated improvements in logical reasoning and systematic problem-solving even in activities that did not involve computers directly. Constructivist learning theory also provides a useful explanation for the effectiveness of the module. Throughout the intervention, students were actively involved in collaborative discussions, inquiry-based tasks, environmental investigations, and group problem-solving activities. These learning experiences encouraged students to construct understanding gradually through interaction, reflection, and exploration. Instead of passively receiving information, students became active participants in the learning process. In addition, the use of student-centred activities such as simulations, visual materials, discussions, and real-world environmental scenarios appeared to increase students' engagement and critical thinking. This notion is also supported by Rands and Gansemer-Topf (2017). Students were encouraged to think systematically, organise ideas logically, and evaluate possible solutions to renewable energy-related problems. This may explain why students in the treatment group demonstrated stronger computational thinking performance compared to students in the control group. Hence, it can be concluded that CT-module significantly improved students' computational thinking skills, and therefore Hypothesis 1 (H_1) is supported.

Renewable Energy Awareness

Research Objective 2 examines the effectiveness of CT-Module in increasing students' renewable energy awareness. The findings indicate that the CT-Module significantly improved students' renewable energy awareness. Students in the treatment group recorded substantially higher awareness scores after the intervention, while students in the control group showed only limited improvement. The improvement in renewable energy awareness may be linked to the experiential and constructivist nature of the learning activities implemented throughout the module. Likewise, a study Ji and Wong support these findings where it has been found that Problem-Based Learning within a constructivist learning approach improves students' engagement their understanding in environmental studies. Students were not only exposed to theoretical explanations, but were also actively involved in hands-on investigations, environmental discussions, online quizzes, DIY activities, and collaborative projects related to renewable energy. These experiences allowed students to connect classroom learning with real-life environmental issues. The module also encouraged students to examine environmental problems within their own surroundings and discuss possible solutions using computational thinking processes. This appears to have strengthened both conceptual understanding and environmental sensitivity. Rather than memorising information about renewable energy, students were required to analyse situations, identify problems, and think critically about sustainable practices. The findings align with constructivist perspectives, particularly Piaget's view that meaningful learning occurs when students actively construct knowledge through direct experiences and interaction with their environment. Previous study by Kumar et al. (2023) aligns with this notion where primary level students presented strong climate change literacy when classroom activities are aligned with their cognitive development level. Another quasi-experimental study by Lapawi and Husnin (2020) also reported significant improvements in environmental science achievement among primary students using structured learning modules. Students in the treatment group were consistently involved in activities that required inquiry, reflection, and collaborative learning. These experiences may have contributed to the stronger levels of awareness and responsibility observed among students following the intervention. The findings are also in line with earlier studies on sustainability and environmental education, which reported that learning modules and interactive science activities can positively influence students' environmental literacy and climate awareness. In the present study, the integration of sustainability topics within computational thinking activities appears to have created a more meaningful and engaging learning experience for students.

The interview findings further strengthened the quantitative results. Students from the treatment group frequently reported higher engagement during lessons, better understanding of renewable energy concepts, and greater confidence when solving problems systematically. Taken together, these findings suggest that the CT-Module not only improved students' academic achievement, but also positively influenced their motivation, participation, environmental awareness, and overall learning experience. Similarly, Saldivar (2025) explained that reflective learning and self-construction of knowledge help students understand environmental issues more deeply. The CT Module extends these findings by integrating computational thinking with renewable energy education in a practical and engaging manner.

Therefore, the findings suggest that CT-Module provides a meaningful approach for increasing sustainability awareness among primary level students. Based on the findings and supporting evidence, hypothesis 2 (H_2) is supported.

CONCLUSION

This study demonstrated that the Computational Thinking–Integrated Module (CT-Module) was effective in improving both computational thinking skills and renewable energy awareness among Year 4 primary school students in Sabah, Malaysia. Students who participated in the intervention consistently achieved higher scores compared to students who received conventional science instruction. The findings from both quantitative and qualitative analyses point to the same conclusion: integrating computational thinking into science learning can produce meaningful educational benefits at the primary school level.

The study also shows that computational thinking can be integrated effectively within sustainability education through structured, student-centred, and activity-based learning experiences. The combination of plugged and unplugged activities, collaborative inquiry, environmental problem-solving, and experiential learning created a classroom environment that encouraged active participation and deeper understanding among students.

More importantly, the findings suggest that computational thinking and sustainability education should not be treated as separate domains. When integrated meaningfully, both areas can complement one another in supporting 21st-century learning skills, critical thinking, and environmental awareness among young learners. As schools continue to strengthen STEM education and Education for Sustainable Development (ESD), this study provides practical evidence that interdisciplinary approaches can be implemented successfully within primary science classrooms.

Implications for Theory

This study contributes to the existing literature by extending the application of constructivist learning theory and the Computational Theory of Mind within primary science education. The findings provide further evidence that computational thinking development is not dependent solely on programming instruction. Instead, computational thinking skills can also be developed through carefully designed learning experiences that involve inquiry, collaboration, reflection, and real-world problem-solving activities. The study also contributes to the growing body of research on interdisciplinary computational thinking integration. Specifically, the findings demonstrate how computational thinking components such as decomposition, abstraction, pattern recognition, and algorithmic thinking can be embedded meaningfully within renewable energy and sustainability learning contexts. In addition, the findings support constructivist perspectives which emphasise active participation and experiential learning as important processes in cognitive development. The study further suggests that computational thinking can function not only as a cognitive tool for problem-solving, but also as a reflective framework that supports environmental understanding and sustainability awareness.

Implications for Practice

From a practical perspective, the findings suggest that CT-integrated science modules can be implemented effectively in primary school classrooms to support both computational thinking development and renewable energy awareness. The study highlights the importance of designing learning activities that are interactive, student-centred, and appropriate to students' cognitive and technological backgrounds. The use of both plugged and unplugged activities was particularly valuable in this study because it allowed students with varying levels of digital access to participate meaningfully in classroom activities. This is especially relevant in contexts where technological resources may not be equally available across schools or communities. The findings also have implications for curriculum development and teacher professional practice. Science teachers may integrate computational thinking elements into lessons without relying entirely on coding-based instruction. Inquiry-based learning, collaborative problem-solving, environmental investigations, and experiential classroom activities can all serve as practical approaches for embedding computational thinking within science education. In addition, the study supports the broader goals outlined in the Malaysia Education Blueprint 2013–2025, particularly those related to higher-order thinking skills, STEM education, and Education for Sustainable Development in primary schools.

Limitations Of Study

Several limitations should be considered when interpreting the findings of this study. First, the study involved a relatively small sample drawn from only one primary school in Sabah, Malaysia. As a result, the findings may not fully represent the experiences of students from other educational settings or regions.Second, the study employed a quasi-experimental design using existing classroom groups rather than random assignment. Although both groups were selected based on comparable academic backgrounds, the absence of full randomisation may limit the generalisability of the findings. Third, the intervention was conducted over a relatively short period. While the study demonstrated positive short-term improvements and retention effects, the long-term impact of the CT-Integrated Module was not examined extensively.

Suggestions For Future Research

Future studies should involve larger samples across multiple schools and different educational settings, including rural, suburban, and urban contexts. This would provide a broader understanding of how CT-integrated renewable energy instruction functions across diverse student populations and learning environments.

Future research could also adopt longitudinal or multi-site designs to examine the long-term effectiveness and scalability of computational thinking integration within sustainability education. Such studies would help determine whether the positive learning outcomes observed in this study can be sustained over longer periods of time.

In addition, future studies may investigate the effects of individual computational thinking components separately, such as decomposition, abstraction, pattern recognition, and algorithmic thinking. This may provide deeper insight into how specific computational thinking processes contribute to students' learning, reasoning, and environmental understanding.

Ethical Considerations

Ethical approval and permission were obtained from the relevant educational authorities and the school administration before the study was conducted. Participants and their guardians were informed about the purpose of the study, the voluntary nature of participation, the confidentiality of responses, and their right to withdraw from the study at any time without consequences. All participant information was anonymised, and the collected data were used strictly for academic and research purposes only.

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Declaration On AI Usage

Artificial intelligence (AI)-assisted tools were used during the preparation of this manuscript to support language editing, improve readability, and enhance grammatical accuracy. All content was carefully reviewed and revised by the authors, who take full responsibility for the accuracy, interpretation, and final version of the article.

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