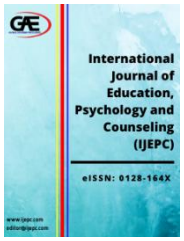
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COMPUTATIONAL THINKING AS A COGNITIVE MEDIATOR FOR RENEWABLE ENERGY AWARENESS IN PRIMARY SCIENCE EDUCATION

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Abstract:

The study investigates the role of computational thinking (CT) as a mediator in increasing renewable energy awareness among primary level students in Sabah. While CT is widely conceptualised as learning outcome, this study restructures it as a mechanism through which sustainability learning occurs. This is a quasi-experimental design which involved 78 year 4 students parted into treatment and control groups. The treatment group received CT module intervention while control group followed conventional teaching. Researcher used Renewable Energy Awareness (REA) test and computational thinking pre-post-test to examine computational thinking and renewable energy awareness. PROCESS Model 4 by Andrew F. Hayes (2018) were used to analyse mediation analysis. Finding revealed CT-Module significantly improved computational thinking (B=25.00, p <.001), and computational thinking significantly predicted renewable energy awareness (B = 0.54, p <.001). The direct effect of the intervention for increasing renewable energy awareness was not significant (B = 1.95, p <.373) when CT was included in the model. However, the indirect effect was significant with (effect = 13.56, 95% CI [9.41,17.43]), proving full mediation. The findings highlights that computational thinking fully mediates relationship between module intervention and renewable energy awareness, suggest that the effectiveness of CT-Module depends on its ability to develop students' cognitive processes than mere content delivery. The study contributes to sustainability education by reframing CT as cognitive mediator that supports high order thinking and complex concept understanding. The study brings in light the importance of integrating computational thinking in complex science concept among young learners to provide better understanding and increased awareness

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about environment besides highlights constructivist approach that lays strong foundation for cognitive learning and behavioural change.

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Computational Thinking; Constructivism; Cognitive Mechanism; Module Intervention; Sustainability Education

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Introduction

Integrated STEM education is very important in interdisciplinary work and in our energy literacy curriculum, as real-world energy problems tend to take place across various fields. Programs that integrate SDG 7 (Affordable and Clean Energy) into STEM curricula will facilitate students' ability to apply their knowledge in energy and are therefore able to apply it in a manner that is relevant to energy (Maidatsi et al., 2022). Renewable energy education is a core part of ESD (Education for Sustainable Development). But at the primary school level, renewable energy is often presented as facts, which leaves students with a superficial knowledge of renewable energy and a lack of capability to utilize it to get to the heart of the problem. Climate change, pollution, the increasing energy demand of the world, and renewable energy are all at crossroads for our youth, and we need to get them involved in it as well. Concerning energy literacy in Malaysia, these integrated STEM methods contribute to the change in student attitude towards the whole system from one point of view to the whole world. Recent research has suggested that students require specific cognitive tools for reasoning about complex systems. In this context, Computational Thinking (CT) can also play a pivotal role as a cognitive mediator to help students understand and solve energy issues, moving them from passive consumers of technology to active producers of sustainability.

Based on CT, in order for students to engage in energy problems and to respond to the global problems of 21st-century society, the researchers and practitioners of Computational Thinking (CT) have proposed a domain-general framework for thinking in many domains. CT has been widely introduced and implemented in Malaysia, but there is little research on its role as a cognitive mediator to introduce younger students to renewable energy concepts and how they can apply them. Existing studies are mainly focused on programming-based CT interventions or secondary-level learners and are not yet able to provide an understanding of how CT may be applied to younger students to develop a deeper understanding of energy concepts. In order

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to address these gaps, this study aims to examine how a CT-based science module affects primary school students' awareness of renewable energy and to explore the role of CT processes in sustainability learning.

Theoretical Background

This study is grounded in primary level science learning and sustainability education theories that conceptualise learning as an active, cognitive, and contextually situated process. Rather than positioning computational thinking as merely a set of programming skills, the framework adopted in this study conceptualises CT as a cognitive scaffolding method that harnesses learners' reasoning about complex sustainability-related scientific processes, particularly renewable energy concepts. The theoretical grounding comprises Education for Sustainable Development (ESD), constructivist learning theory, and experiential learning to explain how CT-oriented learning mediates renewable energy awareness among primary students.

Education for Sustainable Development

ESD includes Education for Sustainable Development (ESD), constructivist learning theory, and experiential learning to show that CT-oriented learning promotes renewable energy knowledge in primary students. ESD teaches the ability to learn to address complex environmental problems through analysis of alternative solutions and make informed decisions that are based on environmental, social, and economic factors. ESD is not limited to technical knowledge but also systems thinking, critical thinking, and responsible choice making. Because renewable energy is a core component of ESD, students must reason about energy production, environmental issues, and sustainability. However, in primary level science education, ESD concepts are presented as factual information without hands-on learning, and students are limited in their capacity to think critically (Aryabkina et al., 2021). ESD requires pedagogical practices with cognitive bases that provide a basis for the young to analyze sustainability. CT skills are generally taught either as programming subjects or out-of-school activities (coding, STEM clubs) which are aimed at developing future technologists and, of course, in direct opposition to CT (Román-González et al., 2017; Xu et al., 2022) in which spatial ability, reasoning, problem-solving, and creative thinking are developed in conjunction. The concurrent promotion of CT and environmental awareness in early childhood is currently under-studied, especially in Malaysian science education systems, and there is a lack of scoping reviews and evidence-based studies of how these skills are shared by children. Therefore, CT is one such foundation that can be used to implement ESD strategies in primary science education at a higher level in renewable energy awareness.

Constructivist and Experiential Learning Perspectives

Constructivism and experiential learning are two theories with the greatest connection to learning and are the main drivers of Renewable Energy Awareness (REA) through processes of mental processes such as computational thinking. These models, such as Piaget's, are ones where students are the main creators of knowledge, but they also teach children about assimilation and accommodation so that children develop mental processes through interaction (Purnadewi & Widana, 2023). Experiential learning brings abstract ideas into practice through hands-on skills like projects and modules and provides students with immediate, tangible feedback on how to solve problems and how they are doing. According to constructivist theory (Bruner, 1966), learners are actively learning things (learning with a computational mind),

which offers the same kind of scaffolded problem-solving experience. This is consistent with Piaget's cognitive development theory, which focuses on progressive abstraction. Therefore, the role of CT in learning modules is more than a technical skill but rather an important mediator in thinking. It helps students form mental representations of non-observable phenomena like sunlight becoming electricity, wind turning into electricity, and learning about alternative energy. For example, in the EPCIA project, we used unplugged games to push students to use algorithmic thinking to solve environmental problems like finding the shortest route to recycling plants (Moreno-León et al., 2025). Research by Munasinghe et al. (2023) has shown that students who learn computational thinking by doing unplugged activities before using computers develop their mental processes more efficiently. Even though previous research has shown the positive impact of unplugged activities and modules, the students who were involved were those from kindergarten or secondary school, leaving primary school learners behind. Primary level students need to be introduced to abstract processes and concepts through computational thinking to prepare for knowledge application in secondary school. Kindergarten-level children are introduced to computational thinking with games; primary level learners can benefit from unplugged modules that teachers are involved in teaching them, where they can become facilitators and share their own knowledge through the use of hands-on activities and learn how to model their own thinking. Therefore, this study aims to combine constructivism and experiential learning through computational thinking to increase the level of renewable energy awareness of primary level students.

Literature Review

In the competitive digital world, Computational Thinking (CT) has emerged from being a specialised skill encompassing only coding and programming for computer scientists into a fundamental literacy significant for all individuals to thrive in this technological era. Initially redefined by Jeannette Wing as a systematic approach to problem solving, CT comprises fundamental computer science concepts such as abstraction, decomposition, pattern recognition, and algorithmic thinking to understand human behaviour and build complex systems (Falloon, 2024). Simultaneously, global environmental issues and the urgent need for clean energy transition have situated energy literacy and renewable energy awareness as critical foundations for cultivating responsible citizenship among youth. This section explores the role of CT as a cognitive mediator that facilitates a deeper understanding of renewable energy systems and environmental stewardship.

CT as a Cognitive Mediator and Metacognitive Process

CT has evolved from programming to a cognitive process governed by metacognitive practices (Allsop, 2018). CT is a "full set of mental tools" of high value to solve complex human problems, and the integration of those tools is based on metacognition (the thinking about one's own thinking). CT is a mediator between students and their problems that helps them to create mental representations of the ill-structured problems, develop strategies, and track their progress. An exploratory study by Allsop (2018) reported how young London-based students were able to solve complex problems in games like Scratch and Alice 2.4. We also found some innovative modules to bridge the gap between abstract CT and environmental problems. For example, an energy teaching kit from Maharani et al. (2025) was able to conclude that modules are effective in elevating cognitive processes in primary students as a moderate N-gain of 52.76% was achieved through science learning. Also, the findings from the research (Arık, M., & Topçu, M. S. 2022; Küçükaydın, M., & Çite. 2024; Tsarava, K., et al. 2022; Waterman, K.

P., et al. 2020) present CT as a mediator in environmental education, but in the Malaysian context, the issue remains under investigated. Hence, this study investigates the role of CT as a mediator in Malaysian primary level science education. Constructive learning environments (games, projects, modules) helped students to develop and work through their learning path and can influence the learning of other students. Cognitive mediation is also essential because students are confronted with complex scientific phenomena that are not visible to the eye, e.g., energy transfer and climate change. Although efforts to mediate renewable energy with CT have been taken on a wide scale, in Malaysia they are not integrated for primary level science education. This can be seen in the Malaysia Education Blueprint 2013-2025, which is currently in its third wave (2020-2025). It is the blueprint that emphasizes digital transformation and the integration of digital skills in all academic fields, yet the implementation of computational thinking skills is not done directly to students in the classroom, though it is important for young students to start with the basics and to practice what they know and then use the knowledge in daily life. This is because of the high number of studies that utilize secondary level students in Malaysia (Bharathi et al., 2022; Jaya et al., 2025; Lapawi & Husnin, 2020), but primary level students are not that often included in CT mediated studies. The main reason that secondary level students are being included in most of the research in Malaysia is because they have the ability to distinguish between concrete and abstract ideas and thus to address complex problems. But it is important to provide young students with the basic concepts of computational thinking as a way to prepare them for the complex problems in the future. Thus, the basic introduction of computational thinking concepts (decomposition, pattern recognition, algorithms and abstraction) to renewable energy literacy in Year 4 students has a positive impact on the knowledge of computational thinking, application and awareness of renewable energy.

Renewable Energy Awareness in the Malaysia Context

The National Philosophy of Education outlines the holistic development of individuals, which is achieved through integrated learning that emphasizes intellectual and spiritual growth, focusing on students' ability to contribute to societal betterment. Furthermore, 'MyDIGITAL' and the Malaysian Economic Blueprint 2021 underscore the commitment to preparing a future-ready workforce endowed with computational capabilities to drive a digital economy. Local research demonstrates successful implementation of CT into sustainability education. For instance, integrating STEM approaches across primary education has been shown 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 the 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 Hydroponic Module, which was implemented to connect STEM elements in parallel with SDG 7 (Affordable and Clean Energy) and SDG 13 (Climate Action), embedded the use of microcontrollers, environmental sensors, solar energy components, and cloud-based monitoring platforms to create an accessible agricultural solution. This had a positive impact on students, with 90% of overall students rating their experiences as "excellent" or "good," and their technical skills and positive attitudes towards the environment increased drastically (Maizahtulakma et al., 2025). Furthermore, Zakaria et al. (2024) in their empirical research supported the notion that interactive mobile applications are effective, with over 98% of 9-year-old students improving their understanding and awareness of renewable energy. Despite the successes of these modules, projects, and applications, students, particularly at the primary level, still struggle with the synthesis of conceptual energy

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IJEPC
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knowledge and algorithmic thinking in high-complexity scenarios. The concurrent cultivation of CT and environmental awareness is scarcely investigated, with a critical lack of empirical evidence on how these two domains grow together. Hence, this study aims to address this gap by combining CT and renewable energy into a simple introductory module for 10-year-old students, whose syllabus contains an energy topic comprising energy transfer, renewable energy, how energy is created, and sustainable energy. The module serves as an induction for CT concepts through energy literacy for students before they seek deeper knowledge in the coming years. This is significant because CT is not taught as a standalone subject or concept in the Malaysian Primary Education Syllabus; rather, it is embedded in multidisciplinary subjects. By learning basic CT concepts, students will be more prepared and able to understand abstract concepts systematically.

Developing structured, contextually aligned modules is crucial for solving the current lack of CT skills among students. By framing CT as a cognitive mediator through which sustainability is presented as a 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 skills involving sustainable education. By embedding technical competencies within real-world environmental challenges, this module allows CT to serve as a cognitive mediator, enabling students to understand complex energy systems and environmental issues.

Conceptual Framework

The conceptual framework guiding this study proposes that computational thinking mediates the relationship between instructional intervention and renewable energy awareness. The framework posits that CT-oriented instructional activities foster specific CT processes, which in turn support systems and sustainability reasoning, leading to enhanced renewable energy awareness.

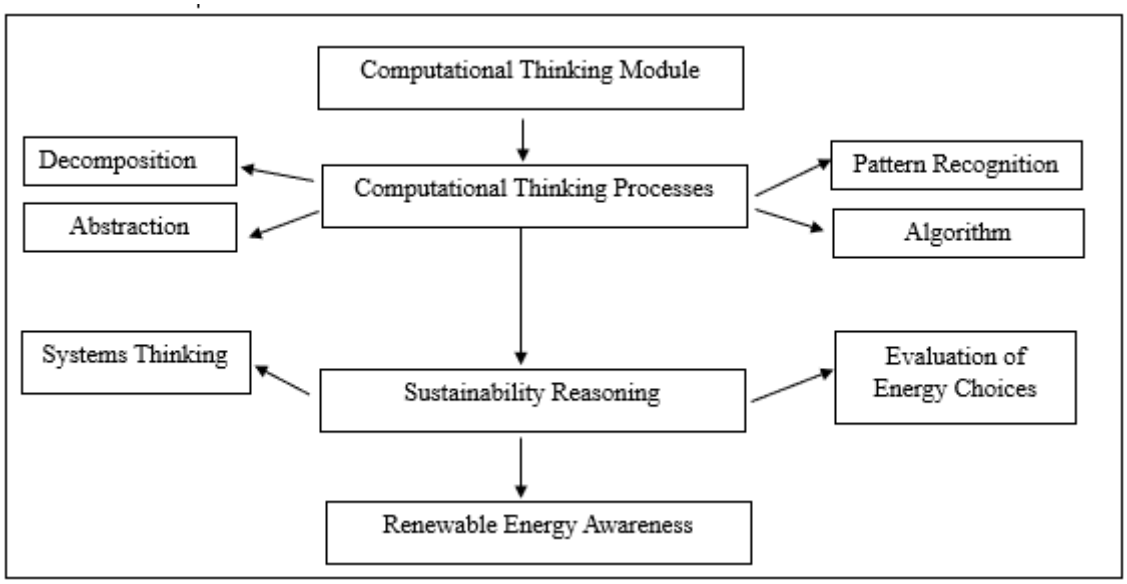


Figure 1: Conceptual Framework

Source: Author's Own Work

International Journal of Education, Psychology and Counseling
IJEPC
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Figure 1 describes the conceptual framework of this study by which computational thinking acts as a mediating mechanism between teaching in CT Module and renewable energy awareness in primary level students. The CT integrated module helps students learn more about decomposition, abstraction, pattern recognition and algorithmic thinking. As a result, these processes can better support sustainability thinking in relation to systems thinking and energy choice and eventually leads to more renewable energy. The framework therefore views CT as a cognitive mediating mechanism for sustainability learning.

Methodology

This study employed a quasi-experimental design involving a treatment group and a control group. The treatment group received learning instruction through the Computational Thinking Module, while the control group followed conventional teaching methods.

Participants

78 Year 4 students from a primary school in a semi-urban area participated. Purposive random sampling was used with defined criteria as follows:

1) Learning Science in Malay
2) Achievement criteria in Year 3 classroom-based assessment (band 3-6).
3) Being able to work together in groups.

The eligible participants were then assigned to the treatment group (n = 39) and the control group (n = 39) based on matched pair sampling.

Computational Thinking Module

A CT module was designed and developed by the researcher using the ADDIE model, with renewable energy as the main theme. The module followed the five phases of the model and was divided into five sections (renewable and non-renewable energy, clean energy, introduction to computational thinking, and mini project. The module was evaluated by five experts from teaching institutions, a university, and a school. Content validation indicated satisfactory agreement among experts, with all evaluated aspects achieving a Content Validity Index (CVI) above the recommended threshold of 0.79 and content validity performance exceeding 70%, presenting acceptable content validity. Face validation demonstrated positive evaluations, with an overall agreement percentage at 84%.

Instruments

The researcher used two instruments to evaluate the mediating factor of CT: a renewable energy awareness test and a computational thinking skills pre-post-test. Both instruments were validated by experts and pilot tested to ensure reliability. The face validation of both instruments received good feedback, and an overall agreement percentage was 81%. A pilot study involving 10 year 4 students was conducted to assess the reliability of the instruments. The Computational Thinking Skills Test showed sufficient internal consistency (Cronbach's α = .752), and the Renewable Energy Awareness Test had excellent internal consistency (Cronbach's α = .964). Minor revisions were subsequently made based on expert and pilot study feedback to improve item clarity and instrument usability.

International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
Volume 11 Issue 63 (June 2026) PP. 702-716

Procedure

The researcher ensured that parents provided consent on behalf of their children to take part in the study. An evaluation of the module's usability was given to a facilitator. Both groups completed pre-tests before the intervention. Post-tests were administered to evaluate learning outcomes and retention. The intervention was conducted over 8 weeks. The initial week involved briefing and pre-test conduction. From week 2 to 6, CT module intervention was performed in the treatment group and conventional teaching in the control group, followed by post-tests conducted in weeks 7 to 8.

Data Analysis

To examine whether computational thinking mediated the relationship between CT Module intervention and renewable energy awareness, a simple mediation analysis was conducted using IBM SPSS Statistics with PROCESS Macro Version 4.2, Model 4 (Hayes, 2018). Statistical significance of the indirect effect was determined using 5000 bootstrap samples to generate 95% confidence intervals.

Result

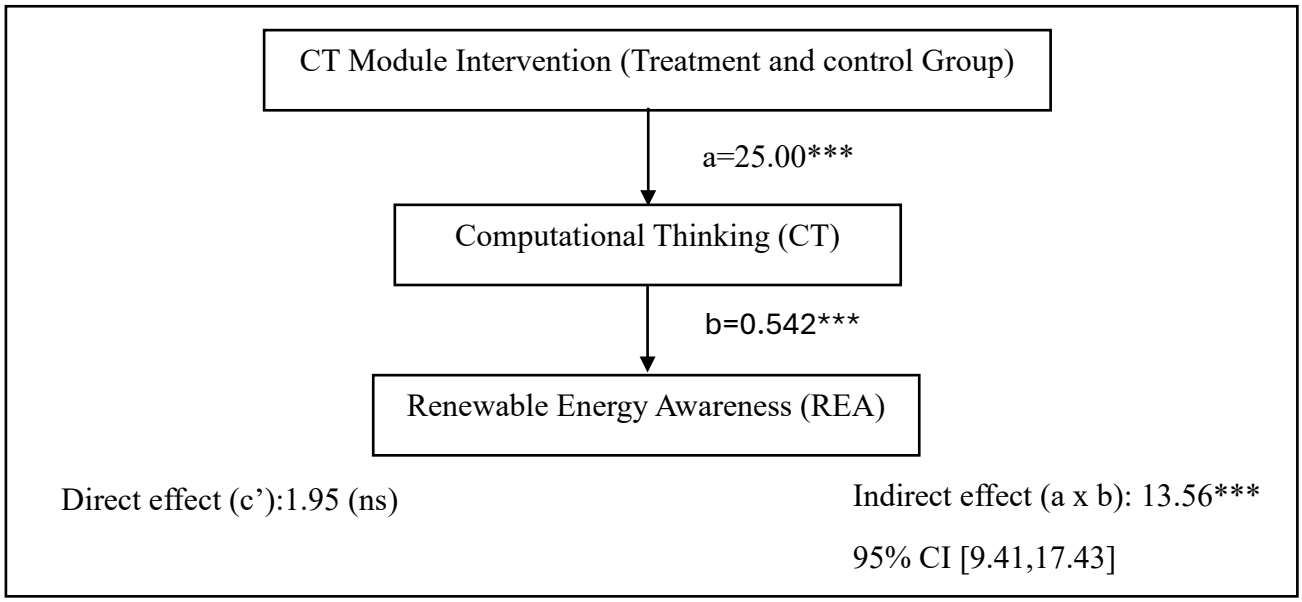


Figure 2: Mediation Analysis Model

Source: Author's Own Work

Figure 2 shows mediation analysis model using regression-based approach outlined by PROCESS macro (Model 4) in SPSS. The mediation model tested four paths:

1. The effect of the module intervention on computational thinking (path a)
2. The effect of computational thinking on renewable energy awareness (path b)
3. The direct effect of module intervention on Renewable Energy Awareness (path c).
4. The Indirect Effect of Module Intervention on Renewable Energy Awareness (path d)

International Journal of Education, Psychology and Counseling
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Path a: CT Increase

A simple linear regression was conducted to investigate the effect of module intervention on computational thinking pre-post test scores. The intervention significantly predicted CT scores, B = 25.00, p < .001, indicating that students in the treatment group demonstrated higher CT skills than those in the control group. This finding suggests that the module intervention is effective in developing CT, which is consistent with earlier findings on CT integrated instructional approaches (Grover & Pea, 2018; Hsu et al., 2022).

Path b: CT effect on Renewable Energy Awareness

Computational thinking was a significant predictor of renewable energy awareness (B = 0.5424, p < .001), demonstrating that higher CT skills were associated with higher renewable energy awareness. This supports the notion that CT is a key cognitive factor driving learning outcomes and demonstrates that students with higher levels of computational thinking abilities possess a deeper understanding of renewable energy concepts. This finding supports previous evidence that CT supports higher-order cognitive processes, including abstraction, systems reasoning, and analytical thinking, which are paramount for understanding complex scientific phenomena (Weintrop et al., 2021; Tang et al., 2023).

Path c: Direct Effect

The module has no significant effect on renewable energy awareness (B = 1.95, p = .373). This result indicates that the intervention does not directly improve REA.

Path d: Indirect Effect

Based on the PROCESS mediation analysis, the CT module had a statistically significant indirect effect on REA (effect size = 13.56). The 95% confidence interval [9.41, 17.43] does not include zero, confirming that the intervention improves REA through computational thinking. The findings are consistent with a full mediation pattern, explaining that the CT module intervention does not directly improve renewable energy awareness but influences REA primarily through computational thinking. This explains how computational thinking functions as a mechanism between the CT module and REA.

Overall Model Interpretation

The overall results presented a significant explanatory power, accounting for a substantial proportion of variance in renewable energy awareness (R^2 = .8959, 89.6%). The model explained 89.6% of the variance in the renewable energy awareness. In addition to elevating awareness about sustainability, the proposed framework is robust in capturing the cognitive processes underlying sustainability education.

The observed mediation pattern has significant theoretical implications. First, it indicates that the effectiveness of the CT module depends on its ability to harness students' computational thinking skills. In short, the CT module does not directly improve renewable energy awareness; instead, it facilitates the cognitive processes that increase student awareness and understanding of renewable energy, environmental issues, and sustainability.

International Journal of Education, Psychology and Counseling
IJEPC
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This finding supports existing literature by positioning computational thinking as a cognitive mediator rather than merely a learning outcome. While previous studies have presented CT as improving engagement and problem-solving (Grover & Pea, 2018), this study demonstrates CT as a mechanism through which awareness occurs via various student-centered activities. This aligns with constructivist perspectives, which highlight that mediated cognitive processes enable learners to actively construct meaning (Bruner, 1966).

Conclusion

We have demonstrated the role of computational thinking as a cognitive mediator in promoting renewable energy awareness in the Year 4 primary level students. Our results and findings show strong empirical evidence that the module intervention significantly improved students' computational thinking skills, which in turn raised students' awareness of renewable energy. On the other hand, the intervention effect on renewable energy awareness was not significant when computational thinking was addressed in the model, meaning that renewable energy awareness is mediated through CT. Thus, we are able to conclude that the effectiveness of the CT module is not only about its content but related to its integration with CT, as CT is an important cognitive mechanism to develop structured cognitive processes for students to enhance renewable energy awareness. The role of CT as a cognitive mediator in decomposition, pattern recognition, abstraction, and algorithm design is also highlighted in these studies. The research therefore complements and adds to the growing field of research on sustainability education by presenting CT as a mediating process rather than simply a module intervention outcome. This reconceptualization emphasizes how cognitive skills and development in science have to be embedded in learning and that even young students need to have such a sense of sustainability. Overall, the findings have supported the existence of CT modules in module learning in the context of deeper conceptual and environmental awareness of these students. In this sense, the study is a proof-of-concept of CT modules as a mediating mechanism for environmental learning, and one of the models for innovation and technology development in the field of the environment at the learning level.

Implication

Computational Thinking Mechanism Contribution

This work contributes to the growing body of computational thinking (CT) literature by reframing CT away from the technical skill or learning outcome in the traditional sense as a technical skill or learning outcome. Rather than thinking of CT as a matter of coding, programming, and robotics or digital problem solving from a technical perspective, this study treats CT as a cognitive mechanism that mediates sustainability learning in primary school students.

The mediation findings have great relevance to existing CT discussions. The results of the CT-integrated module did not directly enhance renewable energy awareness, but indirectly enhanced computational thinking processes. This reduces CT from being an additional teaching tool to a key mechanism through which conceptual understanding and sustainability awareness are acquired.

International Journal of Education, Psychology and Counseling
IJEPC
EISSN : 0128-164X
Volume 11 Issue 63 (June 2026) PP. 702-716

The study also expands present knowledge of decomposition, abstraction, pattern recognition, and algorithmic thinking and frames them as interrelated reasoning processes that can help young people organise and interpret abstract environmental concepts. Students are therefore more sophisticated when working to simplify complex concepts, identify relationships within systems, and structure concepts of environmental reasoning. CT can be viewed as a cognitive framework that enables systems thinking, causal thinking, and informed environmental decision-making.

Another significant contribution lies in the Malaysian primary education context, which remains relatively underexplored in CT mediation research. Much of the existing literature focuses on secondary school learners or programming-based environments. In contrast, this study demonstrates that primary-level students can engage meaningfully with CT processes within sustainability-oriented science learning. The findings therefore broaden current assumptions regarding the developmental applicability of computational thinking among younger learners.

Cognitive Theory Contribution

This study adds to constructivist and cognitive learning theories by empirically demonstrating the role of computational thinking as a cognitive scaffold in complex science learning. CT supports learners in developing meaning through active reasoning processes rather than passive reception of scientific information, we found.

The study extends constructivist ideas from Jerome Bruner and cognitive developmental principles from Jean Piaget. Students also developed a better understanding of renewable energy when they undertook structured cognitive activities that involved analysis, simplification, and problem-solving. This supports the idea that learning is a process internalised in the person's mind that involves assimilation, accommodation, abstraction, and experiential meaning-making.

More importantly, the study introduces a cognitive mediation perspective within sustainability education. The findings indicate that computational thinking functions as an intermediary cognitive layer connecting instructional experiences with conceptual awareness. Rather than treating awareness as a direct outcome of teaching, the study suggests that awareness emerges through mediated cognitive engagement involving systematic reasoning, mental organisation, and problem decomposition. This provides a more nuanced explanation of how sustainability learning develops among young learners.

The study also contributes to discussions surrounding cognitive load and mental representation. Renewable energy concepts are often abstract, interconnected, and difficult for young learners to visualise. The findings suggest that CT processes help reduce this conceptual complexity by enabling students to organise information into structured reasoning pathways. Through decomposition, abstraction, and algorithmic thinking, learners are able to mentally simulate and interpret complex environmental systems more effectively. As a result, CT appears to support the development of deeper conceptual schemas and transferable reasoning abilities within primary science learning.

International Journal of Education, Psychology and Counseling
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Taken together, the findings strengthen the theoretical integration between computational cognition, experiential learning, and sustainability education. The study demonstrates how cognitive mediation processes shape environmental understanding and supports meaningful conceptual learning among children.

This study also suggest that module interventions should prioritise integration of computational thinking particularly in complex science concepts. As CT is known for its multidisciplinary nature, teachers can engage CT in any subjects to help students gain better understanding. The strong indirect effect observed in this research demonstrates teaching strategies that focuses decomposition, abstraction, algorithm and pattern recognition. This supports the notion that effective science education should go across content delivery and emphasize student centred learning that highlights development of cognitive skills which can enable deeper understanding.

Pedagogical Contribution

The study from a pedagogical perspective provides a practical basis for incorporating computational thinking in sustainability-focused primary science education. CT-oriented module interventions can improve students' conceptual understanding and renewable energy awareness when learning experiences are centred on active reasoning rather than conventional content transmission.

By placing computational thinking as a multi-disciplinary cognitive process rather than a computer science one, the research also suggests an important pedagogical shift. This is in line with current educational reforms that advocate interdisciplinary STEM integration and the Ministry of Education Malaysia efforts related to digital learning and STEM education. Moreover, the findings show that unplugged and module-based CT activities can be useful for primary level learners. This is a challenge to the common assumption that computational thinking instruction is based on technologies and advanced programming environments. Instead, the study demonstrates that structured experiential activities based on decomposition, abstraction, pattern recognition and algorithmic reasoning are enough to help develop higher-order thinking skills of the young learners.

The study also offers a transferable instructional model that integrates CT processes with renewable energy literacy. The model provides practical guidance for teachers, curriculum developers, and instructional designers to develop cognitively engaging science lessons that foster environmental awareness, systems thinking, and responsible decision-making.

Finally, the findings highlight the importance of teacher facilitation within constructivist learning environments. Meaningful sustainability learning appears to emerge when students are actively involved in inquiry, collaborative problem-solving, experiential engagement, and guided cognitive reflection. In this regard, the study reinforces the pedagogical value of cognitive scaffolding approaches that encourage deeper understanding and long-term environmental awareness among primary school learners.

Limitation and Suggestion

The study has several limitations that should be taken into account. First, the study was done with a small sample size from one school and so the results may not be generalizable for more

generalised populations. Research of students from other backgrounds can be considered for future work to have more external validity. Second, the study relied on quantitative measurements to find out the computational thinking and renewable energy awareness. Hence, future research may include richer qualitative data to further our understanding of sustainability in young learners.

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Ethics Statement: This study was conducted in accordance with ethical research standards. All procedures involving human participants were reviewed and approved by the Ministry of Education (ERAS) approval number KPM.600-3/2/3-eras (23601). Informed consent was obtained from all participants prior to data collection. Participation was voluntary, and respondents were assured of confidentiality and anonymity. The data collected were used solely for academic purposes.

Author Contribution Statement: All authors contributed significantly to the development of this manuscript. Heerashini Subramaniam was responsible for the conceptualization, methodology, and overall supervision of the study, handled data collection, analysis, and interpretation of results. Dennis Andrew Lajium contributed to the literature review, drafting, and critical revision of the manuscript. All authors read and approved the final version of the manuscript prior to submission.

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Appendix

CT Module Link
https://docs.google.com/presentation/d/1tRsIToI5AmEWTkgN7ledpYsxgGeHAev2/edit?usp=sharing&ouid=116997549295888219822&rtpof=true&sd=true