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Enhancing Digital-Age Metacognition: A Framework for Cognitive Innovation in Thai Secondary Education

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Abstract

Background/purpose. The increasing prevalence of digital tools in education necessitates models that enhance students' metacognitive skills. Despite this need, limited research exists on structured pedagogical approaches to foster metacognition within digital learning contexts. This study aimed to develop and evaluate the Cognitive Innovation Model to Enhance Metacognitive Skills in the Digital Age (CIMEMSDA) for Thai secondary students, addressing this gap in contemporary education.

Materials/methods. A quasi-experimental design was employed to assess the efficacy of CIMEMSDA, which follows a four-stage structured approach: (I) introduction and recalling, (ii) reviewing and planning, (iii) investigating and applying knowledge, and (iv) summary and evaluation. Rooted in constructivist and metacognitive principles, the model was validated by nine experts for utility, feasibility, suitability, and accuracy. The study involved 80 Grade 8 students in 2024, divided equally into experimental and traditional groups. The experimental group used CIMEMSDA with modules on computational thinking and Python programming, while the traditional group received standard instruction.

Results. The experimental group demonstrated significantly higher metacognitive skills and academic performance than the traditional group. The MAPS Model significantly improved students' digital technology competencies, with post-learning DTS scores exceeding the benchmark by 8.07%. This demonstrates the model's ability to surpass foundational expectations and foster advanced technological skills. Students maintained their academic achievement and digital technology skills for 14 days post-learning without significant decline, illustrating the model's effectiveness in ensuring durable and long-lasting learning outcomes.

Conclusion. CIMEMSDA shows strong potential as an educational tool for enhancing metacognitive skills in the digital age. Its structured, stage-based approach aligns well with contemporary educational practices, addressing critical gaps and offering a feasible framework for integrating metacognitive skill development into secondary education.

1. Introduction

The shift from teacher-centered to learner-centered educational theories has redefined learning from a one-way transfer of knowledge to a dynamic process where students actively construct their understanding (Oyelana et al., 2022). This approach aligns with constructivism, which emphasizes systematic thinking and learning mechanisms to foster self-initiated knowledge construction (Alam, 2023; Boser et al., 2017; Hokor & Sedofia, 2021; Zhu & Burrow, 2023).

Metacognition, or "thinking about thinking," plays a vital role in this paradigm by enabling self-regulation of cognitive processes (Kavousi et al., 2020). It involves awareness and control over one's thoughts, including evaluating learning strategies, recognizing strengths, and reflecting on thinking activities (Padmanabha, 2020; Sato, 2022). Research underscores the growing importance of metacognition in preparing students to thrive in an information-rich society, emphasizing process-oriented teaching to enhance student achievement.

Cognitive learning theory complements this by focusing on how students process, interpret, and organize information (Maringanti & Sahu, 2024). In modern education, integrating technology into teaching practices mirrors threads weaving into a cohesive fabric, creating enriched, functional learning experiences. The effectiveness of technology in education depends on how teachers design and implement it as an instructional tool, requiring a nuanced understanding of students' needs and capacities.

Recent studies highlight the interplay between metacognition and educational technology. Li et al. (2024) demonstrated the effectiveness of a metacognitive-regulation-based Collaborative Programming System (MR-CPS) in enhancing junior high school students' computational thinking (CT), learning achievements, and metacognitive skills. Similarly, Wang et al. (2024) explored the use of metacognitive scaffolding in project-based programming instruction, showing improvements in CT, learning outcomes, and self-regulatory capacities among elementary students. These findings affirm the critical role of metacognitive strategies in programming education and underscore the need to integrate metacognitive components into educational frameworks for enhanced learning efficiency and cognitive development.

Cognitive innovation (CI) represents another educational frontier, bridging cognitive science, creativity, and organizational theory. CI fosters new thinking methods to address complex challenges, emphasizing the restructuring of cognitive processes and generating innovative ideas. For instance, Williams et al. (2020) examined how cognitive flexibility (CF) influences responses to trust violations in workplace settings, revealing how nuanced thought processes enable victims to move beyond retaliation toward cooperative solutions. This research illustrates how CI can reshape approaches to problem-solving and organizational dynamics.

Advances in neuroscience further enrich our understanding of learning processes. Neuroscience integrates multiple disciplines to analyze brain functions, offering insights into cognitive mechanisms underlying intelligence, memory, and creativity (Goldberg, 2022; Hackman & Kraemer, 2020). Studies highlight how neural signaling and synaptic connections shape learning, underscoring the importance of teaching strategies that align with brain function to optimize educational outcomes (McTighe & Willis, 2019).

In summary, effective education necessitates understanding learning objectives, educational philosophy, and diverse learning theories. Teachers should design process-oriented, student-centered activities tailored to content, the school environment, and student potential. This research, therefore, aims to develop cognitive innovations that enhance metacognitive skills, preparing secondary students for the digital age.

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2. Literature Review

2. 1. Cognitive Innovation

Cognitive innovation refers to the processes and pedagogical strategies that enhance students' creative thinking, problem-solving, and adaptability. In secondary education, cognitive innovation integrates teaching methodologies, technological tools, and psychological insights to foster intellectual growth and innovative capacities. It emphasizes active engagement, interdisciplinary learning, and real-world problem-solving, preparing students to meet complex challenges.

In secondary schools, fostering cognitive innovation involves creating environments that encourage creativity, critical thinking, and collaboration. This is consistent with Kocabaşoğlu & Şahin (2021), who analyzed cognitive innovation among gifted secondary school students, identifying strong correlations between innovative thinking and cognitive adaptability. Moreover, the development of innovation education as a distinct discipline highlights the importance of equipping students with skills such as design thinking (Honra & Monterola, 2024; Kavousi et al., 2020; Verganti et al., 2021), higher-order reasoning (Kwangmuang et al., 2021), and entrepreneurial attitudes (Altinay et al., 2022). Gero and Milovanovic (2020) also evaluated the impact of design education on the creative cognition of high school students, concluding that structured design-thinking curricula significantly improve problem-solving abilities. Additional studies also reveal that innovative teaching practices enhance students' engagement, improve their cognitive flexibility (Honra & Monterola, 2024), and increase their interest in various subjects.

2. 2. Metacognition

Metacognition, or the awareness and regulation of one's thinking processes (Abdelrahman, 2020), plays a critical role in the academic success of secondary school students (Akcaoğlu et al., 2023). It involves two core aspects: metacognitive knowledge (awareness of cognitive processes) and metacognitive regulation (control over learning activities) (Padmanabha, 2020). Metacognitive skills, such as planning, monitoring, and evaluating one's learning, enable students to become independent learners and adapt to complex tasks.

In secondary education, integrating metacognitive practices improves outcomes in critical thinking (Li et al., 2023; Rivas et al., 2022), problem-solving, and academic achievement. Educational strategies such as problem-based learning, self-regulated learning frameworks, and targeted metacognitive prompts are particularly effective. Additionally, infusing metacognition into STEM, language education, and cultural intelligence (Basman & Bayram, 2024) promotes deeper understanding and proficiency. Teachers' roles in modeling metacognitive strategies further enhance student engagement and skill acquisition.

2. 3. Cognitive Learning Theory

Cognitive learning theory emphasizes understanding how the brain processes, stores, and retrieves information (Nückles et al., 2020). This theory focuses on mental processes such as perception, memory, and problem-solving, aiming to help students build meaningful connections between new knowledge and their existing knowledge base. In secondary schools, applying cognitive learning principles enhances students' ability to process and retain complex concepts, fostering creative and critical thinking and adaptability (Rubenstein et al., 2018).

Key practices include integrating problem-based learning, using scaffolded instructional approaches, and leveraging metacognitive strategies to promote independent learning. Incorporating cognitive learning frameworks into secondary education also addresses diverse learning needs, enabling students to master advanced skills while maintaining engagement.

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2. 4. Research Objectives (ROs)

RO1: To develop the Cognitive Innovation Model to Enhance Metacognitive Skills in the Digital Age (CIMEMSDA) to foster advanced metacognitive abilities in secondary school students.

RO2: To implement and evaluate CIMEMSDA by:

RO2a: Comparing metacognitive skill levels and academic achievement between students instructed with CIMEMSDA and those taught through conventional methods.

RO2b: Assessing changes in academic achievement within the experimental group before and after learning with CIMEMSDA.

2. 5. Research Questions (RQs)

RQ1: How does implementing CIMEMSDA affect students' metacognitive skills compared to traditional teaching methods?

RQ2: What is the impact of CIMEMSDA on students' academic achievement relative to conventional instruction?

RQ3: How does academic achievement differ before and after applying CIMEMSDA within the experimental group?

RQ4: To what extent do students perceive the CIMEMSDA model as valuable and applicable in enhancing their learning and problem-solving abilities in the digital age?

3. Methodology

3. 1. The CIMEMSDA Model Development

The development of the Cognitive Innovation Model to Enhance Metacognitive Skills in the Digital Age (CIMEMSDA) followed a systematic process, ensuring a robust foundation based on literature and expert evaluation. This process was carried out in two key steps:

3. 1. 1. Step 1: Synthesizing the model

The synthesis involved a comprehensive review of relevant literature and research on cognitive innovation, covering ten years from 2014 to 2024. Data sources included academic books, peer-reviewed journals, and domestic and international databases. Using document analysis and synthesis forms, the collected materials were consolidated through content analysis techniques to extract essential elements that informed the initial design of the CIMEMSDA model.

3. 1. 2. Step 2: Developing and evaluating the model's quality

The proposed model underwent a thorough quality evaluation by nine purposively selected experts specializing in computer studies, instructional model development, curriculum and instruction, and assessment and evaluation. The experts rated the model's utility, feasibility, suitability, and accuracy using a structured quality assessment form based on a 5-point Likert scale adapted from frameworks by Stufflebeam and Yarbrough et al. (2010). The evaluation included 18 items and achieved a perfect Index of Congruence (IOC) score of 1.00. Feedback from focus group discussions conducted via Zoom complemented the assessment. After obtaining informed consent from all participants, the evaluation results were analyzed to determine the mean and standard deviation (SD), ensuring a rigorous validation process.

3. 2. The CIMEMSDA Model Implementation

The implementation phase of the CIMEMSDA model aimed to test its effectiveness in fostering metacognitive skills and academic achievement among Grade 8 students.

3. 2. 1. Study population and sampling

The study involved 570 students enrolled in 15 Grade 8 classes at Sakonrajwitthayanukul School during the first semester of the 2024 academic year. Using cluster random sampling, two classrooms were selected, comprising 80 students divided into an experimental group (40 students) and a control group (40 students).

3. 2. 2. Research instruments

- **Instructional Tool:** The experimental group received instruction using the CIMEMSDA model.
- **Measurement Tools:** A Metacognitive Skills Scale (MDA) assessed students' metacognitive knowledge and experience using a 5-point Likert scale (Table 1) containing three dimensions and 12 indicators. Students were asked to mark (?) in the "Performance Level" column that best corresponds to their behavior. The meaning of each column was as follows: 5: Always perform, 4: Frequently perform, 3: Sometimes perform, 2: Rarely perform, and 1: Hardly ever perform. The scale had an IOC of 1.00 and a reliability score of 0.98.

Table 1. Metacognitive Skills Scale (MDA) Assessment.

Assessment Items	Performance Level				
	5	4	3	2	1
Planning					
The student sets goals or objectives.					
The student selects methods and organizes the steps of learning or practice.					
The student predicts or anticipates answers in advance.					
The student gathers or outlines various approaches to achieve learning outcomes.					
Monitoring					
The student reviews activities and exchanges knowledge with peers to gather information.					
The student ensures that their tasks align with the required steps.					
The student defines their own objectives and fulfills tasks assigned by the group.					
The student explains the thought process used to solve problems and identify errors in learning, along with methods for resolving them.					
Evaluation					
The student summarizes the knowledge gained.					
The student interprets or derives meaning from the summary, identifying ways to apply it effectively in the future.					
The student evaluates success based on the objectives.					
The student prioritizes problems and errors encountered, eliminating unsuitable methods.					

An achievement test evaluated computational thinking and Python problem-solving, aligned with Bloom's cognitive taxonomy. The test's IOC ranged from 0.60 to 1.00, with item difficulty between 0.40 and 0.80, discrimination power from 0.35 to 0.75, and a reliability score of 0.76.

3. 2. 3. Data collection procedure

The study spanned four weeks in May 2024, during which both groups underwent instructional sessions. The experimental group was taught computational thinking and Python problem-solving through the CIMEMSDA framework, while the control group received conventional teaching methods. Pre-tests were administered before the intervention to measure baseline academic achievement. After completing the instructional phase (eight hours over four weeks), post-tests were conducted to evaluate both groups' academic progress and metacognitive skill development.

3. 2. 4. Data analysis

Data analysis was performed to assess the CIMEMSDA model's effectiveness:

1. **Between-Group Comparisons:** Post-learning outcomes, including metacognitive skills and academic achievement, were compared between the experimental and control groups using an independent samples t-test.
2. **Within-Group Comparisons:** Pre- and post-instruction academic achievement scores were analyzed using a dependent samples t-test for the experimental group.

This multi-faceted analysis ensured a detailed understanding of the CIMEMSDA model's impact, providing evidence of its potential as an innovative instructional framework for digital-age education.

4. Results

4. 1. The CIMEMSDA Model Development Results

The CIMEMSDA model includes four structured stages: Introduction and Recalling, Reviewing and Planning, Investigating and Applying knowledge, and Summary and Evaluation (Figure 1). According to expert feedback, CIMEMSDA received high ratings across utility, feasibility, suitability, and accuracy (Ayoo et al., 2024; Stufflebeam; Yarbrough et al., 2010). The high ratings indicate that the CIMEMSDA model meets essential educational criteria, reflecting its practicality and relevance for enhancing metacognitive skills.

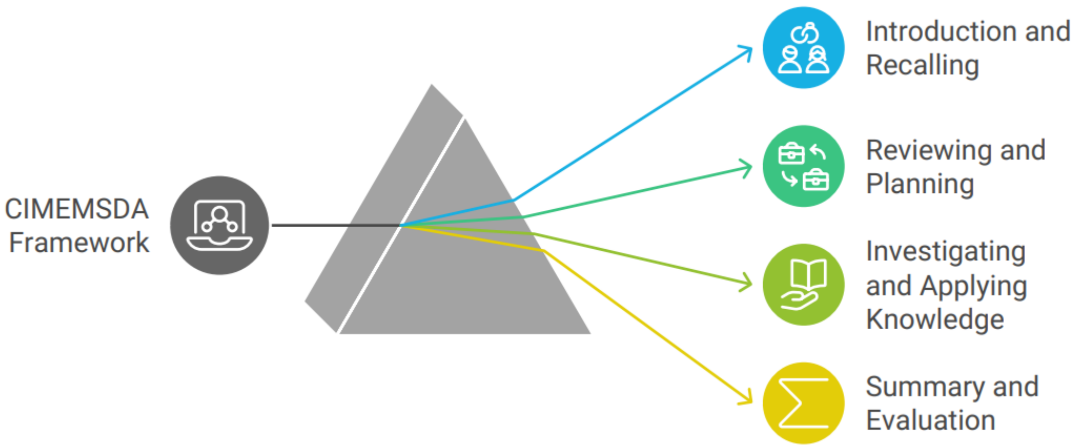

Figure 1. The CIMEMSDA Framework's Four Steps

4. 2. CIMEMSDA Model Quality Based on Expert Evaluations

Table 1 provides a detailed summary of these ratings by the expert panel. The evaluation of the CIMEMSDA model focused on assessing its quality and effectiveness in enhancing digital-age metacognitive skills among secondary students. Using a structured quality assessment model, nine subject matter experts participated in focus group discussions to evaluate the CIMEMSDA framework across multiple dimensions. The assessment was based on a 5-point Likert scale, measuring key criteria such as utility, feasibility, suitability, and accuracy (Ayoo et al., 2024), following guidelines established by Stufflebeam (2015) and the Joint Committee on Standards for Educational Evaluation (JCSEE) (Yarbrough et al., 2010).

This meta-evaluation approach involved gathering descriptive and judgmental data about the model's overall quality, ensuring that each dimension was assessed comprehensively. Mean and SD were used to analyze the experts' ratings. Following a structured interpretive framework, the mean scores were categorized as follows:

4.50 – 5.00: Reflecting the highest level of agreement or effectiveness.

3.50 – 4.49: Indicating a substantial level of agreement or effectiveness.

2.50 – 3.49: Denoting a moderate level of agreement or effectiveness.

1.50 – 2.49: Indicating a minimal level of agreement or effectiveness.

1.00 – 1.49: Representing the lowest level of agreement or effectiveness.

The experts' evaluations of the CIMEMSDA model produced high mean scores across all criteria, as shown in Table 2, indicating strong support for its practical application in educational settings. This systematic and quantitative approach to evaluation facilitated a clear understanding of CIMEMSDA's quality, enabling precise interpretations of its effectiveness in fostering metacognitive skills.

Table 2. Quality of the CIMEMSDA Framework Based on Expert Evaluations

Aspect	Experts (*n*=9)		Level	Rank
	Mean	SD		
Utility	4.47	0.61	High	2
Feasibility	4.61	0.56	Highest	1
Suitability	4.33	0.64	High	3
Accuracy	4.22	0.73	High	4
Average	4.41	0.64	High	-

4. 3. CIMEMSDA Implementation Results

After verifying assumptions with a One-way MANOVA (Okoye & Hosseini, 2024), results revealed that students taught through the CIMEMSDA framework achieved significantly higher scores in metacognitive skills and academic performance than those taught by traditional methods. Comparative mean scores are presented in Tables 2 and 3.

4. 4. Experimental Group Data Collection Procedures

Introduction to the CIMEMSDA Instructional Plan: The researcher introduced an innovative learning plan grounded in cognitive science designed to enhance students' metacognitive skills. Instruction centered on computational thinking and Python-based problem-solving within the computing science curriculum.

Pre-Test Administration: Students took a pre-test to establish a baseline for academic achievement. Scores were documented for future comparison.

Execution of CIMEMSDA Learning Activities: Guided by the CIMEMSDA framework, students engaged in structured learning activities targeting metacognitive development, following the specific activities outlined in the innovative instructional plan.

Post-Test Administration: At the end of the instructional period, a post-test was administered to assess academic achievement and metacognitive skills. The results were recorded and later analyzed alongside the pre-test scores.

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4. 5. Traditional Group Procedures

Introduction to the Traditional Instructional Plan: In the control group, students followed a standard instructional plan, covering the same topics in computational thinking and Python-based problem-solving but without the metacognitive focus of CIMEMSDA.

Pre-Test Administration: As in the experimental group, a pre-test was conducted to assess initial academic achievement, and scores were documented for later analysis.

Execution of Traditional Learning Activities: Students participated in traditional learning activities based on the standard instructional plan, with no additional emphasis on metacognitive skill enhancement. The findings in Table 3 demonstrate a statistically significant advantage for the CIMEMSDA group in metacognitive skill development compared to the traditional group.

Table 3. Comparison of Metacognitive Skills Between CIMEMSDA and Traditional Groups.

Metacognitive Skills	Students	Total Score	Mean	SD	t-value	Sig.
Experimental	40	60	49.53	1.69	6.09**	0.00
Traditional	40		44.25	5.21		

**sig.< 0.01

This result highlights the CIMEMSDA model's efficacy in fostering students' ability to self-regulate and monitor their cognitive processes effectively.

Similarly, Table 4 shows that students in the CIMEMSDA group significantly outperformed their counterparts in academic achievement. The mean score for academic achievement (AA) in the experimental group (Mean = 20.00, SD = 2.35) is notably higher than that of the control group (Mean = 15.98, SD = 3.03). The lower standard deviation in the experimental group suggests more consistent performance among students who followed the CIMEMSDA model. The higher standard deviation in the control group indicates more significant variability in student outcomes.

Table 4. Comparison of AA Between CIMEMSDA and Traditional Groups.

Academic achievement (AA)	Students	Total Score	Mean	SD	t-value	Sig.
Experimental	40	30	20.00	2.35	6.63**	0.00
Control	40		15.98	3.03		

**sig.< 0.01

The t-value of 6.63 indicates a large effect size, further affirming the meaningful difference between the two groups. The p-value (Sig. = 0.00) confirms that this difference is statistically significant at the 0.01 level, suggesting that the observed improvement in academic achievement is unlikely due to chance. These results highlight the CIMEMSDA model's effectiveness in enhancing students' computational thinking and problem-solving abilities.

4. 6. Academic Achievement (AA) Testing Results

An analysis of pre-test and post-test scores within the experimental group reveals a statistically significant improvement in AA following the implementation of the CIMEMSDA framework. The findings in Table 5 further validate the effectiveness of CIMEMSDA by demonstrating notable gains in students' post-test scores. This improvement reflects enhanced comprehension and application of computational thinking and problem-solving skills.

Table 5. Comparison Of AA Before and After CIMEMSDA Implementation in the Experimental Group

Academic Achievement (AA)	Full Score	Students (*n*=40)		t-value	Sig.
		Mean	SD		
Post-test	30	20.00	2.35	15.23**	0.00
Pre-test		11.78	2.36		

**sig.< 0.01

These findings collectively underscore the critical role of the CIMEMSDA model in advancing both metacognitive skills and academic achievement, emphasizing its potential as a practical instructional approach for computational thinking and problem-solving education.

5. Discussion

The findings of this study demonstrate the efficacy of the CIMEMSDA framework in fostering metacognitive skills and improving academic achievement among Thai secondary school students. The discussion integrates the results with insights from prior research, emphasizing the broader implications of this innovative educational framework.

5. 1. Model Development and Quality Evaluation

A synthesis of contemporary literature and expert feedback guided the development of CIMEMSDA. The four structured stages—Introduction and Recalling, Reviewing and Planning, Investigating and Applying Knowledge, and Summary and Evaluation—align well with established cognitive science principles (Raković et al., 2022). Experts' high ratings across utility, feasibility, suitability, and accuracy highlight the model's practical relevance and adaptability to secondary education contexts (Wongrugsa et al., 2022). These findings are consistent with prior research emphasizing the importance of structured, multi-phase instructional approaches in enhancing cognitive and metacognitive engagement (Ayoo et al., 2024; Stufflebeam, 2015).

Furthermore, the high mean ratings across dimensions (Table 1) strongly align with the criteria for effective educational models. Similar evaluations in prior studies (Montuori et al., 2023; Zhang et al., 2024) have underlined the significance of incorporating feedback loops and expert validation in instructional design.

5. 2. Implementation Outcomes: Metacognitive Skills (MS) and Academic Achievement (AA)

The implementation phase revealed that students taught using the CIMEMSDA model outperformed their peers across both MS and AA in the traditional group. Comparative analyses (Tables 2 and 3) showed statistically significant differences in favor of the experimental group, confirming the model's effectiveness in achieving its intended outcomes. This aligns with Okoye and Hosseini's (2024) findings, which highlighted the benefits of cognitive innovation frameworks in fostering higher-order thinking.

The results also suggest that CIMEMSDA's emphasis on structured planning, active engagement, and self-reflection contributes significantly to students' ability to monitor and regulate their learning processes. These outcomes resonate with Bandura's social cognitive theory, which posits that metacognitive skill development is closely linked to deliberate practice and guided instruction (Bandura, 1986; Zhang et al., 2024).

5. 3. Enhanced AA using CIMEMSDA

A substantial improvement in AA was observed within the experimental group, as indicated by a significant mean difference between pre-test and post-test scores (Table 4). This finding underscores the effectiveness of integrating metacognitive-focused instruction with computational thinking and Python programming. Prior studies (Montuori et al., 2023; Widodo et al., 2018) reported enhanced problem-solving abilities and knowledge application when instructional models emphasized self-regulated learning.

These results highlight CIMEMSDA's role in bridging theoretical and practical aspects of learning, particularly in computational subjects. Python programming was chosen as the subject focus due to its simplicity, flexibility, and widespread application in real-world problem-solving. As a programming language, Python promotes creativity, computational thinking, and problem-solving skills, which align closely with metacognitive development goals. Its accessibility and the availability of diverse libraries and frameworks make it an excellent tool for fostering cognitive engagement, enabling students to connect abstract concepts with practical applications. This aligns with the model's objective of cultivating metacognitive skills and enhancing student performance in complex learning environments.

6. Conclusion

The Cognitive Innovation Model to Enhance Metacognitive Skills in the Digital Age (CIMEMSDA) demonstrates effectiveness in developing metacognitive skills and boosting academic performance. The four stages are Introduction and Recalling, Reviewing and Planning, Investigating and Applying Knowledge, and Summary and Evaluation. CIMEMSDA encourages students to become self-regulated, adaptive learners. The model was rated highly by experts and shown through empirical testing to significantly enhance metacognitive and academic outcomes compared to traditional methods. CIEMDA holds promise for improving student engagement and skill development in educational settings that require digital adaptability.

7. Implications and Limitations

7. 1. Practical Implications

The study's results suggest that the CIMEMSDA model is not only practical but also adaptable to a variety of educational contexts. The structured stages and focus on metacognition make it particularly suitable for modern classrooms that aim to integrate digital tools and cognitive innovation. Its computational thinking and problem-solving success also imply potential applicability to other STEM disciplines.

Effective implementation of CIMEMSDA, however, requires targeted teacher training to ensure educators can guide students through its stages effectively. Professional development programs focusing on metacognitive strategies, computational thinking, and leveraging digital tools for engagement would enhance the model's impact. Furthermore, the adaptability of CIMEMSDA to remote or hybrid learning environments should be explored, incorporating tools for virtual collaboration and asynchronous learning to maintain its efficacy across diverse teaching contexts.

7. 2. Limitations and Future Research Implications

Future research could examine the long-term impact of CIMEMSDA on metacognitive skills and academic performance across different grade levels and disciplines. Testing the CIMEMSDA in varied educational contexts (e.g., different countries, age groups, or subjects) would help evaluate its adaptability and effectiveness. Exploring how digital tools can enhance each CIMEMSDA stage could optimize the model for remote or hybrid learning environments, particularly in the context of digital-age learning and cognitive innovation. This combination of findings, limitations, and future directions suggests that CIMEMSDA can be a valuable tool for educators aiming to cultivate essential metacognitive skills and support students' adaptive learning capabilities.

Furthermore, aligning with insights from Fernández-Cézar et al. (2024), CIMEMSDA's adaptability to collaborative and international learning environments presents a promising avenue for future research. Investigating its application in intercultural educational settings could enhance its scalability and relevance in diverse contexts. Similarly, as highlighted by Papadakis (2022, 2024), integrating digital tools such as apps, AI, and neuroimaging into CIMEMSDA's framework may optimize its effectiveness and broaden its appeal in the era of cognitive and technological advancements.

While this study strongly supports CIMEMSDA's effectiveness, it is limited by its focus on a single school and Grade 8 students. This narrow sampling scope may restrict the generalizability of the findings to other educational settings or populations. Additionally, longitudinal research is needed to determine the sustained impact of CIMEMSDA on students' metacognitive skills and academic performance. Expanding the sample to include diverse schools and age groups in future studies would provide a more comprehensive understanding of the model's potential and limitations.

Declarations

Author Contributions. Conceptualization, software use, validation, investigation, resources, and writing—review and editing, and supervision. (TK): Conceptualization, software use, validation, formal analysis, investigation, resources, writing—original draft preparation, and writing—review and editing. (NT): Software use, validation, formal analysis, writing—original draft preparation, and writing—review and editing. (MC): Conceptualization, software use, validation, formal analysis, writing—original draft preparation, and writing—review and editing, and supervision (PP). All authors have read and agreed to the submitted version of the manuscript.

Conflicts of Interest. The authors explicitly state that this paper has no conflicts of interest.

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Informed Consent: The participants provided written informed consent to participate in this study.

Data Availability Statement. The data supporting this study's findings are available upon reasonable request from the corresponding author.

Ethical Approval. The Research Ethics Committee of King Mongkut's Institute of Technology Ladkrabang reviewed and granted an exemption to the study titled "Enhancing Digital-Age Metacognition: A Framework for Cognitive Innovation in Thai Secondary Education" (EC-KMITL_67_068). Thereafter, each participant gave their informed consent and was assured of their data's confidentiality.

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speaker working in collaboration with the authors. Therefore, the authors assert full responsibility for the final manuscript's accuracy, originality, and quality.

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