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# Enhancing Mathematical Metacognition and Self-Efficacy in Third-Graders in Elementary School: Integrating Problem-Posing Activities within the Self-Regulated Learning Cycle

Yen-Hua Chiu and Hsi-Hsun Yang*

Department of Digital Media Design, College of Design, National Yunlin University of Science and Technology, Douliu City, Taiwan
Email: m111035025@yuntech.edu.tw (Y.-H.C.); jimmy@yuntech.edu.tw (H.-H.Y.)
*Corresponding author

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***Abstract*—This study examines how incorporating problem-posing tasks within a self-regulated learning cycle instructional model affects third-grade students' mathematical metacognition and self-efficacy. While existing research often highlights the learning outcomes of problem-posing in math, the link between these activities and students' metacognitive abilities in math still needs to be explored—additionally, the integration of self-regulated learning strategies with problem-posing tasks warrants further investigation. Employing a one-group pretest-posttest design, this research uses quantitative methods to measure the instructional approach's impact on students' math achievement, metacognitive skills, and self-efficacy in their abilities. The research engaged 21 students in a six-week intervention of problem-posing tasks within a self-regulated learning framework. Data was analyzed using SPSS 27, revealing substantial improvements in learning outcomes, metacognitive abilities, and self-efficacy post-intervention. Students excelled in evaluative skills over metacognitive knowledge and planning and monitoring. The findings endorse the effectiveness of problem-posing activities in the self-regulated learning cycle instructional model, which can enhance mathematical outcomes and metacognition. Additionally, students may develop better self-efficacy through problem-posing activities.**

***Keywords*—mathematical metacognition, problem-posing, four cyclical patterns, self-efficacy, self-directed learning, self-regulated learning**

## I. INTRODUCTION

### *A. Research Background*

The onset of the COVID-19 pandemic in 2020 has drastically reshaped educational paradigms across the globe. Di Pietro's study [1] indicated that the pandemic's disruption has had a detrimental effect on learning, particularly in mathematics and science, more than in other disciplines. Mastery of basic math concepts is pivotal for advancing learning [2–6]. In response to these educational setbacks, an increased effort from educators and learners is essential to recover lost mathematical proficiency and avert enduring adverse effects.

Mathematics is critical not merely as a subject but as a cornerstone for developing logical and problem-solving skills across various domains [7, 8]. However, many students experience challenges and disinterest in math [9], leading researchers to investigate methods to enhance math learning outcomes and engage student interest. The instructional strategy is a vital determinant of success in math education [10, 11]. When teaching interactions are sufficiently engaging, students will likely perceive the content as more diverse [12, 13]. Focusing solely on calculation and problem-solving techniques alone could lead to insufficient conceptual understanding among students, potentially impacting students' mathematical motivation [11].

Researchers advocate for problem-posing as a dynamic instructional strategy in mathematics [14, 15]. This approach triggers active engagement by encouraging learners to formulate questions, fostering a participatory education environment that heightens their willingness to learn and improves outcomes [15]. Moreover, problem-posing is recognized for enhancing deep analytical thinking. As students pose questions, they must think critically, analyze, and apply what they know, enriching and deepening their cognitive processes [16]. Such activities sharpen critical thinking and creativity and bolster problem-solving skills [17]. Furthermore, problem-posing stimulates collaborative dialogue and idea-sharing, strengthening peer communication and teamwork [18].

In Taiwan, the Ministry of Education's "Technology-Supported Self-Regulated Learning Program" [19] endorses using the self-regulated learning cycle instructional model. However, the literature still lacks comprehensive studies on this model's practical effects in academic settings. This research endeavors to fill that gap by examining the concrete support and transformation the self-regulated learning cycle instructional model brings to education.

Students' varying abilities play a pivotal role in their mathematical education, with metacognitive skills significantly influencing their ability to grasp math concepts [20–22]. Tu [23] delves into how students employ metacognition in math, encompassing the cognitive processes and regulatory skills essential for understanding and strategizing math [24]. This encompasses problem-solving and analytical skills and the capacity for self-monitoring and strategy adjustment. Developing metacognitive faculties is vital for mathematical proficiency [25, 26]. Through metacognitive development, learners gain a deeper comprehension of mathematical concepts and acquire effective strategies for problem-solving [27, 28].

Investigating how mathematical metacognition affects the

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incorporation of problem-posing in the self-regulated learning cycle instructional model can inform strategies to improve mathematical outcomes and shift student attitudes toward math.

### *B. Research Motivation*

Xue *et al.* [29] found a notable link between students' learning attitudes, outcomes, and mathematical metacognition. This study aims to enrich students' mathematical outcomes and experiences, helping them utilize metacognitive skills to navigate math challenges effectively by employing problem-posing methods. The goal is to ignite a passion for math and enhance their learning drive.

Problem-posing engages students in active learning, advancing cognitive growth and cultivating a zest for learning through problem-solving and critical analysis. Ye *et al.* [18] saw improved results by integrating problem-posing in a flipped natural science classroom, using an interactive technique that outperformed traditional teaching, bolstering both outcomes and self-efficacy. This emphasizes blending problem-posing with conventional instruction to augment classroom learning. However, Chang *et al.* [14] noted that younger students needed help to create questions, leading to fatigue and reduced learning efficacy. Moreover, when problem-posing is limited to teacher-set questions, it can diminish students' drive due to monotony. Researchers recommend combining question creation with engaging activities, like games, to maintain high student motivation.

This research seeks to boost student involvement and interactive education by meshing problem-posing with digital gaming in math learning tasks. Students can gain a deeper understanding of mathematical concepts through independent thinking and collaborative problem-solving. The introduction of digital games is designed to invigorate students' enthusiasm and motivation for math.

### *C. Research Purpose*

This research examines how embedding problem-posing tasks within math lessons, aligned with a self-regulated learning cycle instructional model, affects student math learning. Students are encouraged to connect prior knowledge with classroom learning by engaging in these tasks, aiding content organization and comprehension. The study further assesses the impact on student self-efficacy and metacognitive skills, exploring how this instructional approach influences math learning outcomes, metacognition, and self-confidence in their academic abilities. Additionally, it investigates the role of problem-posing in deepening students' grasp and practical application of math concepts.

### *D. Research Questions*

Informed by the research context, objectives, and the current state of related studies, this investigation poses two main questions:

1) Does integrating problem-posing tasks into the third-grade math curriculum and a self-regulated learning cycle instructional model affect students' self-efficacy?
2) Can students' metacognitive abilities be enhanced by including problem-posing exercises within third-grade math instruction using the self-regulated learning cycle instructional model?

### *E. Limitations of the Study*

This study focused on investigating third-grade mathematics subjects, and the findings may not be applicable to different age groups or subjects. Additionally, it is important to note that the sample size for this study is too small to draw meaningful conclusions, potentially limiting the generalizability of the results.

## II. LITERATURE REVIEW

### *A. Self-Regulated Learning Cycle Instructional Model*

The Taiwan Ministry of Education [19] outlines in its Technology-Supported Self-Regulated Learning Program that the self-regulated learning instructional model is rooted in self-regulation concepts. This model's four learning phases aim to bolster students' self-regulation skills. Moreover, the model's stages support the broader teaching cycle within the classroom. The process is illustrated in Fig. 1.

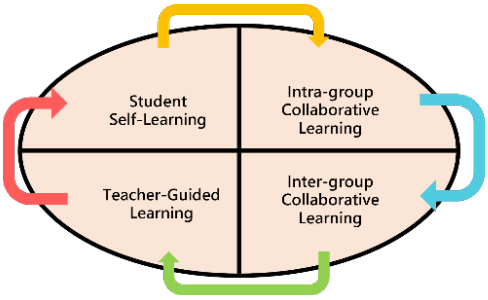

Fig. 1. Flowchart of the self-regulated learning cycle instructional model [19].

The Self-Regulated Learning Cycle Instructional Model encompasses four stages: Student Self-Learning, Intra-group Collaborative Learning, Inter-group Collaborative Learning, and Teacher-Guided Learning. Teachers can tailor the order and length of these stages to match the pace of their instruction. Each phase has distinct objectives, with students primarily engaging in self-learning at home and the rest conducted in school. This model facilitates the integration of at-home learning with classroom discussion. Collaborative learning, both within (inter) and between (intra) groups, helps to enhance students' comprehension through discussion.

While Taiwan's education system specifically implements the Self-Regulated Learning Cycle Instructional Model, a literature review indicates its widespread use in promoting self-directed learning skills. Lai and Hwang [30] found that a self-regulated flipped classroom model, which reverses traditional in-class and homework roles, increases in-class activity engagement. Their findings show that this model boosts academic achievement and elevates student self-efficacy, highlighting the flipped classroom's effectiveness in improving engagement and educational outcomes.

Suratno *et al.* [31] developed the Synectic Model to foster students' creative thinking and metacognitive abilities. This model employs a range of techniques, including substantial input, direct analogies, the analysis and explanation of those analogies, personal analogy creation, exploration, and the generation of novel analogies. Employing this method in ecosystem science education aimed to enhance student metacognition and creativity. The model stimulates a dynamic exchange of ideas, promoting reflective thinking within ecological studies. Such educational strategies are instrumental in advancing students' metacognitive application, underscoring the necessity for continual innovation in teaching methodologies.

### *B. Application of Problem-Posing in Mathematics Education*

In 1987, Kilpatrick [32] highlighted problem-posing as a crucial adjunct to fostering students' problem-solving skills. He noted that real-world problems often need to be identified and defined by the problem-solvers themselves. Thus, problem-posing warrants attention as a pedagogical strategy. Researchers like Cai, El Saye, and Li [33–35] concur that problem-posing significantly influences mathematical learning. El Sayed [34], along with Kul and Celik [36], points out the importance of context in crafting mathematical problems linking everyday life with mathematical concepts. They argue that problem statements often lack complete information, prompting solvers to draw on relevant knowledge and constraints [32], a skill crucial for developing mathematical thought. However, Kilpatrick [32, 37] and Martin-Diaz *et al.* note that students typically need help from teachers, textbooks, or external sources. At the same time, the most influential mathematical challenges may emerge from the students. Contrasting with conventional classrooms focused on content transmission and repetitive exercises [38], Christidamayani and Kristanto [39] investigated problem-posing as a teaching tool in math education, noting its positive effects on student engagement and confidence. This aligns with what many researchers have noticed: a lack of positive classroom atmosphere is one of the reasons for generally deficient performance in students' mathematical performance [33, 37].

Research into the use of problem-posing across various academic domains is still emerging. Wang and Hwang [40] employed problem-posing techniques to improve team-based programming skills among university students. Chang *et al.* [14] tackled the challenge of student fatigue in math problem-posing by integrating it with varied activities to preserve student motivation. These approaches yielded improvements in self-perception, specifically in areas like self-efficacy and flow. Existing studies primarily highlight problem-posing within STEM disciplines, particularly to monitor student self-awareness shifts due to these strategies [14, 15, 18, 41].

The collective findings underscore the significance of problem-posing in math education, pointing to its role in fostering students' ability to adjust and adapt within the learning process.

### *C. Metacognitive Abilities*

The concept of Metacognitive Abilities was first introduced by Perkin and Swartz [42] in "Teaching Thinking: Issues and Approaches," prompting a surge in related research. Sperling *et al.* [28] examined how these abilities vary by gender and age in children, developing a measurement scale for ages 3 to 9. Veenman *et al.* [26] researched the presence of Metacognitive Skills across different learning disciplines of novice learner and their relevance to specific subjects. Ngan Hoe *et al.* [21] observed the impact of Metacognition on the mathematical progression of students struggling academically, noting marked improvements with the application of Metacognitive Strategies over a 12-week instructional period. Xue *et al.* [29] investigated the relationship between Academic Attitudes, Academic Procrastination, Metacognitive Abilities, and math grades among 614 Chinese primary school students, uncovering significant links between Mathematical Attitudes, Academic Procrastination, Mathematical Metacognition, and their math performance.

In 1994, Schraw and Dennison [27] created the Metacognitive Awareness Inventory (MAI) to quantify Metacognitive Abilities. This inventory, utilizing a binary scoring system, comprises 62 items across two main categories: Metacognitive Knowledge with subdivisions of Declarative, Procedural, and Conditional Knowledge, and Metacognitive Skills, encompassing Planning, Information Management Strategies, Comprehensive Monitoring, Adaptation Strategies, and Evaluation. Yildiz *et al.* [43] devised a tool tailored for measuring Metacognitive Abilities in younger learners, featuring eight facets: Declarative, Procedural, and Conditional Knowledge, along with Planning, Monitoring, Controlling, Cognitive Strategies, and Evaluation, through 30 distinct items. Addressing gaps in prior validity assessments [27, 28], Tu [23] introduced a metric for evaluating Metacognitive Abilities in math among primary and secondary students, concentrating on Metacognitive Knowledge, Planning and Monitoring, and Evaluation.

Metacognitive Abilities aid students in identifying their academic weaknesses and applying various strategies to bolster their mathematical reasoning, computation, and comprehension skills. Kuzle [25] introduced a Metacognitive Framework tailored for solving mathematical problems, which involves the Multimethod Interview Approach (MMI approach) to observe and evaluate students' metacognitive functions and behaviors during problem-solving. Metacognition serves a beneficial role in enabling students to understand and ascertain their learning progress.

### *D. Literature Summary*

While a robust body of work connects problem-posing activities with mathematical metacognitive skills, research exploring their integration with the self-regulated learning cycle instructional model needs to be more extensive. Modern math instruction is evolving from traditional lectures to active learning methods, incorporating techniques like problem-posing and self-regulated learning cycle instructional model. These methods are known to boost student involvement and motivation, thereby enriching their comprehension of math concepts. Leveraging mathematical metacognition in teaching problem-posing, particularly within the self-regulated learning framework, can yield important insights for math education. This knowledge can guide teachers and policymakers in refining the mathematical learning process, ultimately improving student outcomes.

## III. RESEARCH METHODS

This research examines how incorporating problem-posing activities within the self-regulated learning cycle instructional model in mathematics affects students' learning achievement, metacognition, and self-efficacy. The study seeks to lessen the cognitive load during intricate problem-posing exercises by integrating innovative teaching methods with digital tools. The self-regulated learning model's four-phase cycle promotes active learning, boosting metacognitive skill use and collective self-efficacy. The ultimate objective is to enhance students' mathematical performance, in line with the goals of this educational model.

Employing a one-group pretest-posttest design, the study utilizes questionnaires for quantitative data gathering to explore students' experiences with problem-posing and the evolution of their metacognitive abilities. The analysis aims to pinpoint the critical factors influencing students' metacognition and assess the effect of problem-posing on their learning journey, providing insights into the instructional method's influence on educational outcomes and experiences.

### *A. Research Framework*

In this study, the primary independent variable is the incorporation of problem-posing activities into self-regulated learning cycle instruction. The dependent variables are students' mathematical learning outcomes, metacognition, and individual and collective self-efficacy. Control variables include instruction content, the duration of teaching sessions, and the educator involved.

### *B. Research Participants*

This study's participants comprised third-grade students from a selected elementary school, aged between 8 and 9 years. Of the 23 students who participated in the study, 21 provided valid data for analysis. The cohort included 12 boys and 9 girls, all with prior experience using tablets as a learning tool.

### *C. Data Collection Process*

The primary mode of data collection in this study was through quantitative questionnaires. These were administered as pretests and post-tests at the beginning of the first week and after the sixth week, respectively. To accommodate the third-grade participants, the class teacher read each questionnaire item aloud to mitigate any cognitive discrepancies or missed responses. Researchers gathered the pretest data at the end of the first week, and the post-test data was collected before the completion of the sixth week.

### *D. Experimental Procedure*

The experimental and teaching process of this study is illustrated in Fig. 2.

The instructional experiment encompassed 16 sessions, each lasting 40 minutes. These sessions included standard self-regulated learning cycles and periods dedicated to problem-posing development, editing, and gaming activities. The problem-posing components were structured into three phases, collaboratively crafted by the research team and the math teacher. Fig. 3 illustrates these activities biweekly, spanning two class periods per session for 80 minutes—one for problem-posing editing and one for problem-posing activities. Each session also functioned as a recapitulation as the instructional unit neared completion, with the scheduling of activities being a collaborative decision between the teacher and the researcher.

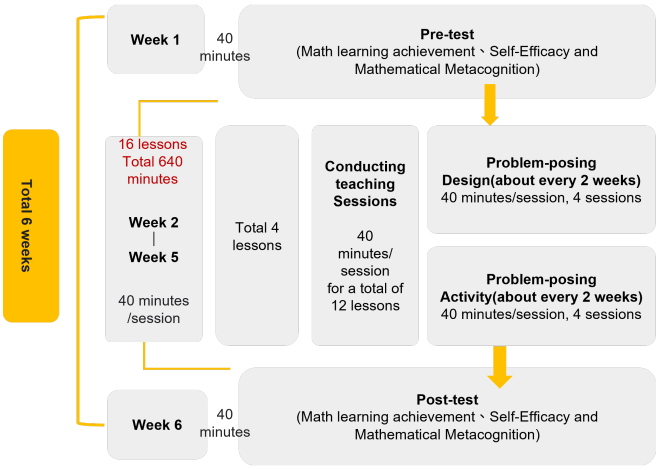

Fig. 2. Experimental and instructional process diagram.

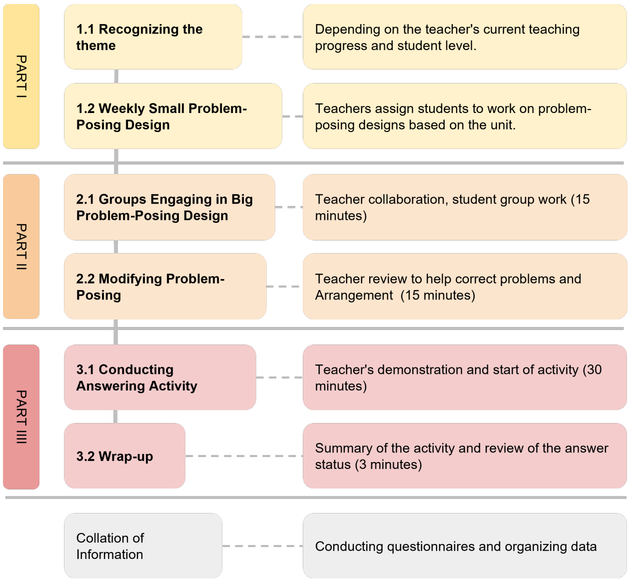

Fig. 3.Comprehensive process diagram for big and small problem-posing design, editing, and problem-posing activities.

The process of the problem-posing activity consists of three parts:

The initial phase consists of weekly discussions between the researcher and the instructor to review teaching progress and identify students' misunderstandings. Each week, the teacher crafts tailored problem-posing exercises focusing on areas where students show less proficiency or frequently make mistakes, deploying these tasks on the learning platform aligned with the curriculum. The second phase sees the teacher orchestrating a more comprehensive problem-posing activity, building on the weekly exercises. In the third phase, students engage in solving the problems posed.

The second stage of the initial phase featured mini problem-posing design activities, as depicted in Fig. 4. These exercises allowed students to refine their understanding of common question types through iterative problem-posing. By engaging in intra-group and inter-group collaborative learning phases within the self-regulated learning cycle instructional model, students actively contributed to group discussions. They gained insights from the problem-solving methods of their peers. The fundamental goal was to deepen students' familiarity with problem-posing in each practice session.

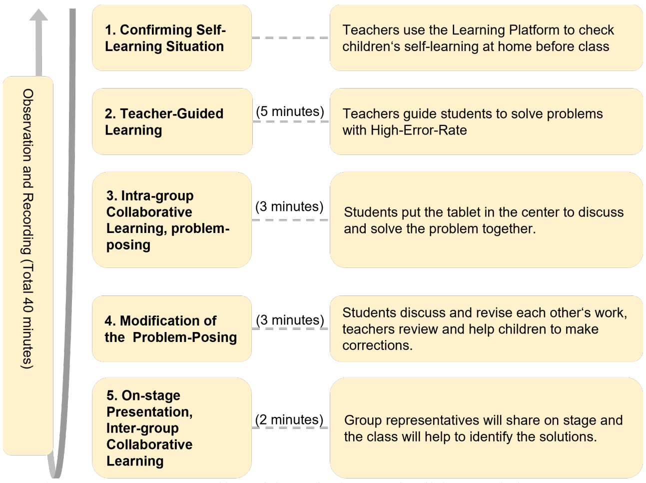

Fig. 4. Part one - small problem design and editing activity process.

Quantitative questionnaires were employed for data collection, administered as pretests and post-tests during the first and sixth weeks. Since participants were third-grade elementary students, the teacher read each questionnaire aloud to mitigate cognitive bias or missing responses. Researchers collected the pretest data at the end of week one, and the post-test data were gathered before week six concluded.

### E. *Research Tools*

The research tools employed for collecting experimental data include the following items:

#### 1) *Mathematical metacognition scale*

The mathematical metacognition ability questionnaire used in this study is derived from Tu's [23] Mathematical Metacognition Scale (MMS), designed for primary and middle school students. This scale features three dimensions—metacognitive knowledge with five items, planning and monitoring with four, and evaluation with three—resulting in 12 items. Each dimension demonstrates high internal consistency, evidenced by Cronbach's alpha coefficients of .87, .81, and .80. The scale has been validated by three experts, earning it expert validity confirmation. Utilizing a five-point Likert scale for responses, the questionnaire is presented to the students by the class teacher, who reads each item aloud.

#### 2) *Self-efficacy perceived scale*

The Self-Efficacy Perceived Scale measures individual self-efficacy [44] and collective efficacy [44, 45] across 19 items, using a five-point Likert scale for responses.

## IV. RESULT AND DISCUSSION

### A. *Data Analysis Process*

Data analysis in this study was performed using SPSS 27, with questionnaires as the primary data collection tool. The Shapiro-Wilk test, a normality assessment, was applied. The pre-test for mathematical learning showed a p-value greater than 0.05, suggesting a normal distribution of scores. In contrast, the post-test scores, with a p-value less than 0.05, deviated from normal distribution. Consequently, for the valid sample size of 21 students, nonparametric methods—specifically, the Wilcoxon signed-rank test—were employed to evaluate shifts in mathematical metacognition and learning achievement.

### B. *Data Analysis Results*

The Wilcoxon signed-rank test results indicate a substantial improvement in students' mathematical learning achievement scores between the pre-test and post-test after introducing problem-posing into the self-regulated learning cycle instructional model. *Notably*, the post-test scores surpassed the pre-test scores. A similar trend was noted in the domain of mathematical metacognition. Detailed analysis, as presented in Table 1, shows significant enhancement across all aspects of mathematical metacognition, including metacognitive knowledge, planning and monitoring, and evaluation, following the integration of problem-posing activities within the instructional model.

Table 1. Wilcoxon signed-rank test statistics for mathematical metacognition ability

| | **Pre-test** | | **Post-test** | | | |
|---|---|---|---|---|---|---|
| Dimension | *M* | *SD* | *M* | *SD* | Z | *p* |
| Mathematical Metacognition: Overall | 35.76 | 0.714 | 43.67 | 6.522 | $-2.766^{**}$ | 0.006 |
| Mathematical Metacognition: Metacognitive Knowledge | 15.67 | 5.053 | 18.95 | 2.729 | $-2.490^{*}$ | 0.013 |
| Mathematical Metacognition: Planning and Monitoring | 11.52 | 3.970 | 13.86 | 3.103 | $-2.139^{*}$ | 0.032 |
| Mathematical Metacognition: Evaluation | 8.57 | 3.010 | 10.86 | 2.220 | $-2.584^{**}$ | 0.010 |

$^{*}p < 0.05$ $^{**}p < 0.01$

In terms of self-efficacy, individual and collective self-efficacy also exhibit significant differences before and after the instructional intervention, as presented in Table 2.

Table 2. Wilcoxon signed-rank test statistics for perceived self-efficacy

| | **Pre-test** | | **Post-test** | | | |
|---|---|---|---|---|---|---|
| | *M* | *SD* | *M* | *SD* | Z | *p* |
| Self-Efficacy: Overall | 65.38 | 15.299 | 73.81 | 11.188 | $-2.625^{**}$ | 0.009 |
| Self-Efficacy | 37.52 | 9.179 | 41.86 | 6.770 | $-2.384^{*}$ | 0.017 |
| Collective Efficacy | 27.86 | 6.575 | 31.95 | 5.113 | $-2.539^{*}$ | 0.011 |

$^{*}p < 0.05$ $^{**}p < 0.01$

The findings show that incorporating problem-posing activities within the self-regulated learning cycle instructional model significantly boosts students' mathematical metacognition, including metacognitive knowledge, planning and monitoring, and evaluation. Additionally, there's a marked improvement in both individual and collective self-efficacy. This integration of problem-posing with the self-regulated learning cycle instructional model positively influences third graders' math learning, enhancing their independent learning skills before instruction and their self-awareness post-learning.

### C. *Discussion*

This study's results reveal that students' mathematical metacognition and self-efficacy have significantly improved after integrating problem-posing activities into the self-regulated learning cycle instructional model. Students improved their ability to evaluate their learning and problem-solving post-intervention. This was closely followed by advances in metacognitive knowledge, indicating a heightened ability among students to process and comprehend problems more effectively. Positive developments were observed across all metacognitive dimensions after the intervention.

Regarding self-efficacy, the post-instruction findings demonstrate a marked increase, particularly in collective self-efficacy. This suggests that students have gained greater confidence in their joint capabilities after engaging with the integrated problem-posing and self-regulated learning cycle instructional model.

An in-depth look at mathematical achievement data (refer to Table 3) shows marked improvements in areas such as addition and subtraction and interpreting sequential data from tables following the educational intervention. The data suggest that integrating problem-posing activities within the self-regulated learning cycle instructional model has effectively supported the practice of mathematical metacognitive skills. This notable shift in mathematical performance has also bolstered students' self-assurance and trust in collaborative efforts. Overall, including problem-posing tasks in the self-regulated learning framework has proven to be a significant asset in enhancing the math education of third graders.

Table 3. Wilcoxon signed-rank test statistics for mathematics unit achievement performance

| | Pre-test | | Post-test | | | |
|---|---|---|---|---|---|---|
| Unit | *M* | *SD* | *M* | *SD* | Z | *p* |
| Application of Multiplication and Division | 90.079 | 10.166 | 82.05 | 18.970 | $-2.254^{*}$ | 0.024 |
| Addition and Subtraction of Fractions | 95.634 | 7.273 | 99.24 | 2.406 | $-2.413^{*}$ | 0.016 |
| Decimal | 92.48 | 9.893 | 94.00 | 6.907 | −0.831 | 0.406 |
| Form comprehension | 91.190 | 8.947 | 96.38 | 4.599 | $-2.625^{**}$ | 0.009 |

$^{*}p < 0.05$ $^{**}p < 0.01$

This study's outcomes align with those of Tsai and Chen [46], who observed notable enhancements in self-regulation and math proficiency among third graders using the self-regulated learning cycle instructional model as a teaching method, augmented by a digital learning platform. The current study builds upon these results by integrating problem-posing with this self-regulated learning cycle instructional model, offering insights for future educators to consider and adapt in their teaching practices.

## V. CONCLUSION

This research investigated the integration of problem-posing activities with the self-regulated learning cycle instructional model in mathematics instruction. Post-intervention, students exhibited significant enhancements in utilizing mathematical metacognition. Specifically, their ability to evaluate their learning outperformed their metacognitive knowledge, planning, and monitoring skills. Gains in self-efficacy and mathematical prowess were also evident. These outcomes validate the effectiveness of this combined instructional approach in mathematics education and address gaps in existing research.

Regarding curricular guidance, the study advises educators to offer more targeted metacognitive prompts to boost students' metacognitive skill application. Additionally, embedding problem-posing exercises into various subjects could further aid teachers in developing comprehensive curricula.

In future research, it would be valuable to explore the applicability and effectiveness of similar intervention measures across various grades and disciplines. Understanding the subtle differences in implementing problem-posing activities in diverse educational settings can contribute to the development of tailored instructional strategies. Additionally, investigating the role of teacher training and support in the successful implementation of this instructional model can provide insights into scalability and sustainability.

## CONFLICT OF INTEREST

The authors declare no conflict of interest.

## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication; Y.H.C. collected the data and information; Y.H.C. analyzed the data and information; Y.H.C. calculated the data; Y.H.C. analyzed and visualized the result; Y.H.C. and H.H.Y. conceptualized the idea and contributed to study design; H.H.Y. reviewed and edited the paper; H.H.Y. supervised the research process. All authors had approved the final version.

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