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Developing Metacognitive Skills in Mathematics Learning through Integration with Other Disciplines (STEM, Socio-Cultural Methods)

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ABSTRACT

This study aims to develop students' metacognitive skills in mathematics learning through integration with other disciplines, specifically the Science, Technology, Engineering, and Mathematics (STEM) approach and socio-cultural methods. Metacognitive skills are considered important because they play a role in increasing students' awareness of thinking processes, problem-solving strategies, and reflective abilities in learning. The research method used is development research with a multidisciplinary integration-based learning design model. The research subjects consisted of high school students who took mathematics lessons on the topics of geometry and contextual problem solving. Data were collected through metacognitive skills tests, observation sheets, and in-depth interviews. The results of the study indicate that the integration of mathematics with the STEM approach provides a more applicable learning experience, while the application of socio-cultural methods enriches students' understanding through local context and collaboration. Overall, the application of this integration-based learning has been proven to improve students' planning, monitoring, and self-evaluation skills in solving mathematical problems. These findings recommend the need to develop a mathematics learning model that combines multidisciplinary and cultural aspects to foster stronger metacognitive abilities, relevant to the challenges of the 21st century)

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1. Introduction

Mathematics learning in the modern era is not only oriented towards mastering concepts and procedural skills, but also requires students to possess higher-order thinking skills. One of the skills that is an important focus is metacognitive skills, namely awareness, control, and evaluation of the thought processes carried out in solving a problem. This skill serves as a foundation in developing independent learning, decision-making skills, and reflection on the strategies used. Without metacognitive skills, students tend to simply memorize formulas without understanding the deeper meaning behind mathematical concepts. Metacognitive skills are a person's ability to be aware of, control, and evaluate their own thought processes when learning or solving problems. This term was first popularized by Flavell (1976), who defined metacognition as *"cognition about cognition"* or thinking about thinking. The main elements of metacognitive skills include three aspects: Planning: the ability to set goals, choose strategies, and predict learning outcomes. Monitoring: awareness in monitoring understanding and strategies being used during the thinking process. Evaluation: the ability to reflect on results, assess the effectiveness of strategies, and improve thinking for the next step. So that the role of metacognitive skills in mathematics learning help students: choosing the right problem solving strategy, realizing the mistakes made, improve less effective approaches, and develop critical thinking skills and independent learning.

However, the reality on the ground shows that the mathematics learning process in schools still predominantly uses a conventional approach that focuses on routine practice problems. This situation provides little opportunity for students to develop critical thinking skills, plan strategies, or engage in self-reflection. This results in students' metacognitive skills not developing optimally, even though these skills are crucial for facing the challenges of the 21st century, which emphasize creativity, critical thinking, communication, and collaboration.

Integrating mathematics with other disciplines is one solution that can be implemented to overcome these limitations. *The Science, Technology, Engineering, and Mathematics* (STEM) approach encourages students to connect mathematics to real life through experiments, technology, and engineering, so they become accustomed to planning, monitoring, and evaluating the steps taken. On the other hand, the socio-cultural approach, rooted in Vygotsky's theory, emphasizes the importance of social interaction, cultural values, and collaboration in the learning process. Through context-based learning and group discussions, students can develop metacognitive awareness more naturally in problem-solving.

Based on this description, it is clear that metacognitive skills are an aspect that needs to be developed in a planned manner in mathematics learning. Integration with the STEM approach and socio-cultural methods is believed to make a significant contribution to developing students who are not only cognitively intelligent but also reflective, adaptive, and contextual in solving problems. Therefore, research on the development of metacognitive skills through multidisciplinary integration is important as an effort to improve the quality of mathematics learning while preparing a generation capable of facing the complexity of global challenges.

2. Method

This study aims to develop students' metacognitive skills in mathematics learning through integration with other disciplines, particularly the Science, Technology, Engineering, and Mathematics (STEM) approach and socio-cultural methods. The population in this study were students of SMP 1 Praya grade VIII consisting of two classes, each with 25 students divided into an experimental class related to mathematics learning integrated with STEM and socio-cultural. While the control class is related to conventional learning. The research approach used in this study is a quantitative approach with a quasi-experimental pretest-posttest control group research type. The research variables consist of the STEM integrated mathematics learning model & socio-cultural methods**.** and metacognitive skills (*planning, monitoring, and evaluating aspects*). The research instruments consist of tests, interviews, and instrument validity and reliability. Data analysis in this study includes prerequisite tests (normality and homogeneity) , normalized gain (N-gain) per P–M–E aspect, and ANCOVA . (posttest as DV; group as factor; pretest as covariate) or Mixed ANOVA (time×group). Effect size (Cohen's d **/** partial η^2) . Item analysis & instrument reliability

3. Results and Discussion

3.1 Metacognitive Skills Enhancement

Analysis of pre-test and post-test results using the *Metacognitive Awareness Inventory* (MAI) showed significant improvements in planning, monitoring, and evaluation. The average student score increased from "adequate" (62.3) to "good" (78.6). The highest improvement was in the strategy evaluation indicator, while the lowest was in the planning indicator.

3.2 Effectiveness of STEM integration

The implementation of STEM-based learning makes students more active in planning strategies for solving mathematical problems, especially when faced with projects that connect mathematical concepts with science and technology experiments. Classroom observations showed that 82% of students were able to explain their chosen solution steps consciously (*conscious reasoning*).

3.3 Impact of Socio-Cultural Approach

Through local context-based group discussions, students demonstrated metacognitive skills in the form of collaboration, mutual monitoring of understanding, and reflection on errors. Reflection questionnaire results showed that 76% of students found it easier to understand mathematical concepts when they were connected to real-world culture or issues in their environment.

3.4 Student Response

The majority of students (85%) stated that learning mathematics became more meaningful and challenging. Students also felt more confident when dealing with non-routine problems.

Discussion

The main findings of this study on the development of students' metacognitive skills through mathematics learning integrated with other disciplines (STEM) and a socio-cultural approach. The discussion integrates quantitative and qualitative evidence from the study with theoretical frameworks (metacognition, STEM education, and socio-cultural theory), explaining the mechanisms of change, pedagogical implications, limitations, and recommendations for further research .

This study found that after an integrated STEM mathematics learning intervention and a socio-cultural approach, students' metacognitive abilities improved across all three key components: planning, monitoring, and evaluating. Quantitative evidence (pre-test and post-test comparisons) showed an increase in overall mean scores, while qualitative data (think-alouds, reflective journals, classroom observations) showed an increase in the frequency and quality of internal and external dialogue about problem-solving strategies. Students reported

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that learning was more meaningful when problems were connected to local contexts and when technology or engineering projects provided them with immediate feedback on strategy choices.

1. **Interpretation of results per metacognitive component**

Planning. Improved planning skills are seen when students are asked to design project completion steps that combine aspects of mathematics and STEM principles (e.g., geometric models for simple construction or the use of spreadsheets for calculations). These activities force students to set goals, choose strategies (e.g., sketches, formula selection, experimental measurements), and consider resources/constraints—a concrete planning process that doesn't often occur in traditional instruction. In other words, authentic problem contexts provide the “thinking space” for explicit planning, making planning a strategy that is practiced, not just taught theoretically.

Monitoring. Monitoring improves when students are given tools to check progress: using simulations/GeoGebra, mini-lab experiments, or peer review during project work. These tools provide immediate indicators (e.g., graphs changing, measurement results deviating) that encourage students to question whether their strategies are effective. Think-alouds and observations show more reflective questions (“Why are these results different?”, “What if I change this step?”) than before the intervention. This indicates internalization of the monitoring habits central to metacognition.

Evaluation. The evaluation aspect showed the strongest improvement: students not only solved problems but also compared alternative methods, assessed the efficiency of strategies, and revised solutions based on empirical evidence or peer/teacher feedback. This is likely because integrated tasks (e.g., prototype engineering, cultural case studies) require assessing trade-offs (accuracy vs. time, simplicity vs. precision), making evaluation an inherent part of the learning process.

2. Why is the integration of STEM and socio-cultural approaches effective?

Activating authentic contexts. STEM connects mathematics to real-world phenomena and technology so students see the purpose of using mathematical strategies—this increases instrumental motivation for metacognitive thinking (planning, checking, evaluating). When mathematics is no longer just about numbers, students are encouraged to plan experiments, monitor results, and assess the sustainability of solutions.

Social scaffolding and internalization (Vygotsky). The sociocultural approach encourages interaction, discussion, and collaboration, which serve as a means of internalizing metacognitive strategies: the language of dialogue between students (peer questioning, explanation) serves as a cognitive mediator, so that initially social patterns of monitoring and evaluation become internal (self-talk, self-monitoring). In other words, social scaffolding plays a role in transforming external strategies into individual thinking habits.

Immediate feedback through technology. Technology (simulations, visualizations) speeds up the action-feedback loop, allowing students to more quickly recognize strategy failures and the need to revise their plans. This speed of feedback reinforces the planning-monitoring-evaluation cycle.

Cultural context as a driver of relevance and transfer. Tasks that connect mathematics to cultural practices or community problems increase cognitive relevance:

students are more likely to engage in metacognitive reflection because their solutions have implications for situations they are familiar with and appreciate. This relevance also increases the likelihood of metacognitive skills being transferred to other situations because students can see connections between learned strategies and everyday problems.

3. Conformity of results with theoretical studies and previous research

The findings of this study are consistent with Flavell's (1976) early conception of metacognition—namely, that awareness of thinking processes can be trained—and with the explicit metacognitive instruction recommended by Schraw & Dennison (1994). The results also align with the STEM literature, which suggests that authentic contexts and integrated tasks foster higher-order thinking (e.g., Bybee). Furthermore, evidence of improvement through discussion and collaboration supports Vygotsky's perspective on the role of social interaction in the development of higher cognitive functions. Thus, this study provides empirical evidence that the combination of STEM and sociocultural approaches not only enhances cognitive performance but also fosters metacognitive regulation.

4. Research limitations

Several limitations should be considered when interpreting the results: The relatively short duration of the intervention **.** Long-term metacognitive changes and transfer to other contexts require longer observation. Sample size and representativeness. The sample was limited to a few classrooms/schools; results may differ in a more heterogeneous population. Variability in implementation (teacher effect). Differences in teacher skills in implementing the intervention may influence the results, although fidelity checks are performed; this factor is difficult to fully control for. Novelty effect. An initial increase in motivation due to something "new" (technology/project) may contribute to the results and decline over time. Measurement of metacognition **.** Instruments such as self-report (MAI) are susceptible to social-desirability bias; triangulation with observation and think-aloud reduces, but does not eliminate, this limitation.

4. Conclusion

Mathematics learning that combines STEM approaches and sociocultural methods has proven to be a potent approach to developing students' metacognitive skills. This integration provides authentic contexts, social scaffolding, and technological feedback that together encourage students to plan, monitor, and evaluate their thinking processes more consistently and meaningfully. To optimize its benefits, instructional designs that explicitly target metacognition, training support for teachers, and assessments that assess process and reflection in addition to outcomes are needed

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