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Analysis of the Application of the M-Apos Learning Model to the Improvement of Prospective Teachers' Computational Thinking Skills

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ABSTRACT

This study aims to analyze the effectiveness of the M-APOS learning model (a modification of Action, Process, Object, and Schema) in improving the computational thinking skills of prospective mathematics teachers. The study employed a mixed-methods approach with an explanatory sequential design that combines quantitative and qualitative data. The research subjects consisted of 44 third-semester students divided into an experimental group (n = 22) and a control group (n = 22). The research instruments included an essay-based computational thinking test, learning activity observation sheets, and interview guidelines. Quantitative data were analyzed using a t-test and Cohen's d effect size calculation, while qualitative data were analyzed thematically to strengthen the quantitative findings. The results indicate that the M-APOS model significantly improves students' computational thinking skills, as shown by a Cohen's d value of 1.57, which represents a very large effect. In addition, observation results show a consistent increase in students' learning activities, particularly in the indicators of decomposition, pattern recognition, abstraction, and algorithmic thinking. High levels of learning activity support concept internalization through the Action–Process–Object–Schema stages. These findings confirm that the M-APOS model has a substantial impact on students' computational thinking skills.

Keywords: *M-APOS, computational thinking skills, innovative learning, prospective teacher.*

ABSTRAK

Penelitian ini bertujuan untuk menganalisis efektivitas model pembelajaran M-APOS (modifikasi dari Action, Process, Object, dan Schema) dalam meningkatkan kemampuan berpikir komputasional mahasiswa calon guru matematika. Penelitian ini menggunakan pendekatan *mixed methods* dengan desain *explanatory sequential* yang mengombinasikan data kuantitatif dan kualitatif. Subjek penelitian terdiri atas 44 mahasiswa semester tiga yang terbagi ke dalam kelompok eksperimen (n = 22) dan kontrol (n = 22). Instrumen penelitian meliputi tes kemampuan berpikir komputasional berbentuk esai, lembar observasi aktivitas pembelajaran, dan pedoman wawancara. Analisis data kuantitatif dilakukan menggunakan uji-t dan perhitungan *effect size* Cohen's d, sedangkan data kualitatif dianalisis secara tematik untuk memperkuat temuan kuantitatif. Hasil penelitian menunjukkan bahwa model M-APOS secara signifikan meningkatkan kemampuan berpikir komputasional mahasiswa dengan nilai Cohen's d sebesar 1,57 yang tergolong efek sangat besar. Selain itu, lembar observasi menunjukkan peningkatan aktivitas pembelajaran mahasiswa secara konsisten, khususnya pada indikator dekomposisi, pengenalan pola, abstraksi, dan berpikir algoritmik. Aktivitas belajar yang tinggi mendukung internalisasi konsep melalui tahapan *Action–Process–Object–Schema*. Temuan ini menegaskan bahwa model M-APOS memberikan dampak substansial terhadap kemampuan berpikir komputasional mahasiswa.

Kata Kunci: M-APOS, kemampuan *computational thinking*, pembelajaran inovatif, calon guru.

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INTRODUCTION

The quality of human resources (HR) in a country is directly influenced by the quality of its education. As education serves as the key foundation in shaping human potential to adapt to the rapid development of the modern era, it must align with societal changes and future demands (Rusmini, 2017). According to Law No. 20 of 2003, the national education system aims to develop students' potential to become knowledgeable, capable, creative, independent, and responsible citizens (Depdiknas, 2003). Mathematics, being one of the core subjects at all levels of education, plays a vital role in the development of critical, computational, and structured thinking skills. Carl Friedrich Gauss once referred to mathematics as the "queen of sciences" due to its foundational nature in supporting other scientific disciplines (Wahyudi, Suyitno, & Waluya, 2018). Therefore, mathematics education is expected to foster computational thinkingA, problem-solving abilities, and deep conceptual understanding (Depdiknas, 2003; NCTM, 2000).

As said before, computational thinking, particularly in mathematics, is one of the essential 21st-century skills that mathematics education must foster. It helps prospective teachers break down complex problems into manageable parts, recognize patterns, and develop logical solutions. It encourages systematic problem-solving, promotes understanding of algorithms, and enhances their ability to approach mathematical challenges efficiently. Ultimately, computational thinking supports deeper learning and application of mathematical concepts to analyze problems, construct arguments, and draw conclusions based on valid reasoning (Mendrofa, 2024).

Dewey (as cited in Arifin, 2020) emphasized reflective thinking as a systematic approach to solving problems, involving careful analysis, fairness, and evidence-based reasoning. However, studies and field observations indicate that prospective teachers, particularly those in mathematics education programs, still struggle with computational thinking. They often rely on rote memorization and face difficulties in constructing computational justifications or solving analytical tasks (Purwaningsih & Supriyono, 2020; Sari, Suhendra, & Nurlaelah, 2024). This situation contrasts with the expectations that mathematics education should help prospective teacher think computationally, critically, systematically, and creatively. Mathematics education would be more meaningful if related to real-life contexts, allowing prospective teacher to understand concepts concretely.

In this context, the role of teachers is crucial in designing learning experiences that not only focus on the teacher but also provide opportunities for prospective teacher to experience and build their own knowledge. This issue is exacerbated by conventional and abstract teaching methods that lack contextual relevance, leading to a gap between mathematical theory and real-life applications (Depdiknas, 2003; Malik, 2016). As a result, there is a pressing need for innovative learning, fostering active engagement in prospective teachers and their computational thinking abilities.

One promising approach is the M-APOS learning model, a modified version of the APOS theory (Action, Process, Object, Schema), which is grounded in constructivist learning principles. This model enables prospective teacher to build mathematical understanding through structured cognitive stages and collaborative learning (Arnon et al., 2014; Asiala et al., 1996; Dubinsky & McDonald n.d.). The implementation of M-APOS through the ADL cycle (Activities, Discussions, and Exercises) provides an interactive learning environment where prospective teacher construct, internalize, and apply mathematical concepts meaningfully (Nurlaelah, 2015). Arnon et al., (2014) added that the APOS theory is useful in analyzing how mathematical understanding is formed and developed. Implementing the APOS theory in mathematics education can help prospective teacher achieve a deep understanding of concepts by involving various stages of thinking (Cahyani, 2018). Aisyah (2018) stated that the APOS approach enhances conceptual understanding and students' higher order thinking abilities, also stated that this approach encourages meaningful learning and forms strong cognitive structures. Additionally, Budiarti, Purwanto, & Hendriana, (2019) showed that the APOS approach positively impacts students' mathematical concept skills. Therefore, this study explicitly focuses on developing prospective mathematics teachers' computational thinking skills as one of the main learning objectives, enabling them to internalize and apply computational ways of thinking in their teaching and learning practices.

The M-APOS learning model (Modification of Action, Process, Object, Schema) was developed as an innovative approach. This model is based on constructivist theory and designed to enhance prospective teachers' computational thinking abilities through a learning cycle that includes activities, class discussions, and exercises. Recent research by (Yerizon, Sukestiyarn, & Arnellis (2024)) showed that M-APOS-based learning tools are effective in improving prospective teacher' mathematical reasoning abilities, where the APOS approach not only enhances conceptual understanding but also supports achieving the Pancasila student profile, which is adaptive and reflective in facing the challenges of 21st-century learning. Furthermore, studies by Asiala et al., (1996) emphasized the importance of using interactive software during the activity phase to facilitate prospective teachers' construction of mathematical knowledge. However, infrastructure limitations often hinder the implementation of such technology. Therefore, adapting the M-APOS model with task sheets (LKT) based on applications such as Excel and SPSS becomes a practical and effective alternative. Thus, the application of the M-APOS learning model is expected to be a solution in enhancing the computational thinking abilities of mathematics education prospective teachers, ultimately contributing to the improvement of education quality and human resources in Indonesia.

METHODS

This study employs a mixed-methods approach (quantitative and qualitative) with an explanatory sequential design (Sugiyono, 2019). Quantitative data were collected through pre-tests and post-tests to measure changes in prospective teacher's computational thinking abilities before and after the implementation of the M-APOS learning model. The pre-test functioned to assess students' baseline computational thinking skills prior to the intervention, while the post-test was used to evaluate students' improvement after learning. Both tests used the same set of essay questions, but their roles were different: the pre-test established initial ability levels, and the post-test measured learning gains attributable to the intervention.

Each question of the computational test (pre and posttest) was constructed to assess four main indicators of computational thinking: decomposition, pattern recognition, abstraction, and algorithmic thinking. The content validity of the test was established through expert judgment involving two mathematics education experts, who evaluated the alignment between each item and the intended indicators. In addition, construct validity was confirmed through a pilot test with 20 students who were not part of the main sample. The pilot data were analyzed using internal consistency analysis (Cronbach's alpha), resulting in a reliability coefficient above 0.7, which indicates acceptable reliability.

The sample consisted of 44 mathematics education prospective teachers selected through purposive sampling. The selection was based on the following criteria: participants were third-semester prospective teachers who were scheduled to take the *Introduction to Statistics* course, and the class structure could not be reorganized due to institutional regulations. Therefore, the existing class distribution was maintained, resulting in two intact groups: an experimental group (n = 22) that received instruction using the M-APOS model, and a control group (n = 22) that received conventional instruction. Quantitative data were analyzed using statistical tests to determine significant differences and effect sizes, while qualitative data were analyzed thematically (Arikunto, 2019; Cohen, 1988; Sugiyono, 2020).

To assess changes and the improvement in prospective teacher's computational thinking skills, normalized gain (N-Gain) scores were calculated based on the results of pre-tests and post-tests. These N-Gain scores were then compared between the experimental group (using the M-APOS learning model) and the control group (using conventional learning). A significant difference test of N-gain was conducted to determine the statistical differences improvement between the groups, and a Dunnett test was used to evaluate the effect size of the M-APOS model on prospective teachers' computational thinking improvements. Additionally, qualitative data were gathered through interviews and classroom observations to explore prospective teachers' experiences during the learning process and provide a deeper understanding of the results found in the quantitative data. The qualitative data analysis followed a thematic analysis approach. Transcripts and observation notes were coded to identify recurring patterns and categories, focusing on students' engagement, problem-solving behaviors, and cognitive strategies during learning. Data triangulation—through test scores, observation records, and interview findings—was conducted to enhance validity and credibility. Data triangulation was used to enhance the validity of the study, and reliability was ensured through instrument pre-testing and member checking. This methodology is expected to provide a comprehensive understanding of the effectiveness of the M-APOS model in improving prospective teachers' computational thinking abilities.

RESULT AND DISCUSSION

RESULT

Pre-Test Analysis: Baseline Comparison

This section presents the results of the pretest analysis, which was conducted to examine the equivalence of experimental and control groups before the learning intervention. The data were obtained from tests measuring students' computational thinking abilities, administered prior to the intervention in both groups. An equality of means test was conducted using an independent samples t-test to compare the pre-test results between the control and experimental groups. Since the assumptions for the test were met, the t-test was applied to determine whether there was a significant difference in students' computational thinking abilities at the outset. The results of the equality of means test are presented below:

Table 1. Results of the Pretest Equality of Means Test

t-test for equality of means			Criteria	Conclusion	Remarks
t	*Df*	Sig.(2-tailed)			
-0,034	51	0,973	0,973>0,05	H_0 accepted	There is no significant difference

Based on Table 1 of t-test results, the significance value of 0.973 is greater than the significance level of 0.05. This indicates that there is no significant difference in the computational mathematical thinking abilities between the two groups before the intervention. Therefore, it can be concluded that the initial computational mathematical thinking abilities of the students in both the control and experimental groups were equivalent. Since there is no significant difference, the implementation of the M-APOS teaching model can proceed to assess whether it leads to an improvement in the computational mathematical thinking abilities of the students in the Tadris Mathematics program.

Post-Test and N-Gain Analysis

Following the pre-test, the M-APOS teaching model was implemented in the experimental group, while the control group continued to receive conventional instruction as usually practiced in the course. The intervention was carried out over the course of seven sessions, focusing on topics in basic statistics. After the instructional period, both groups were given a post-test to measure their computational thinking performance after the learning process. To analyze the improvement in students' abilities, normalized gain (N-Gain) scores were calculated for each group. The results were then compared using appropriate statistical tests to determine whether there was a significant difference in the improvement of computational thinking skills between the two groups.

The discussion that follows highlights these differences and provides insights into the effectiveness of the M-APOS model in enhancing students' computational thinking in the context of higher education. A prerequisite test for normality and homogeneity was carried out before performing the t-test for equality of means. Because the homogeneity assumption was not met, a t-test for unequal variances (t') was used to test whether there was a significant difference between the improvement in computational mathematical thinking abilities of the students in the control and experimental groups after the implementation of the M-APOS model. The results are presented in Table 2 below:

Table 2. Results of the N-gain Equality of Means Test for Computational Mathematical Thinking Ability

t-test for equality of means	**Criteria**	**Conclusion**	**Remarks**
t	Df	Sig. (2-tailed)	
-5.299	31.872	0.000	0.000 < 0.05

The results from Table 2 of the T-test show a significant value of 0.000, which is less than 0.05. Therefore, H_0 is rejected, and it can be concluded that there was a significant improvement in the computational mathematical thinking abilities of students who received the M-APOS teaching model, compared to those who received the lecture-based teaching in the Control group. This leads to the conclusion that the M-APOS teaching model can be used as an effective alternative to improve the computational mathematical thinking abilities of students.

Effect Size and Practical Interpretation

To assess the strength of the intervention of the M-APOS learning model Cohen's *d* was calculated. The results as shown in Table 3 below:

Table 3. Cohen d Effect Size

		Standardizer[a]	Point Estimate	95% Confidence Interval	
				Lower	Upper
Computational Thinking	Cohen's d	1.57	.094	-.405	.592

a. The denominator used in estimating the effect sizes.
Cohen's d uses the pooled standard deviation.
Hedges' correction uses the pooled standard deviation, plus a correction factor.
Glass's delta uses the sample standard deviation of the control group.

The Cohen's d test, which yielded a value of d = 1.57, indicates a very large effect size, suggesting that the M-APOS teaching model has a substantial and meaningful impact on improving students' computational mathematical thinking abilities. According to Cohen's conventions, a d-value of 0.8 or higher is considered a large effect, and in this case, the value of 1.57 indicates an even stronger impact.

DISCUSSION

This study clearly demonstrates that the implementation of the M-APOS teaching model contributes significantly to the improvement of students' computational mathematical thinking abilities in the Tadris Mathematics program. The model includes steps such as recitation tasks, class discussions, and practice exercises, which have proven to be effective in enhancing computational mathematical thinking through structured learning activities. In the recitation task stage, students initially faced difficulties when confronted with complex problems. Many of them found these problems challenging, leading them to give up at first. However, with encouragement and motivation from the instructor, students were urged to attempt the recitation problems before the class discussion. At this stage, the indicator of decomposition was clear, where students learned to break down complex problems into smaller, more manageable parts. Over subsequent meetings, students' performance in the recitation tasks significantly improved. They became more meticulous, able to construct better computational arguments, and were able to develop more accurate solutions based on the assumptions used to reach conclusions.

This aligns with the National Council of Teachers of Mathematics (NCTM), which states that pre-learning tasks provide positive stimulation for students, thereby increasing their engagement and motivation (NCTM, 2000). This finding is consistent with the research by Ilmi et al., (2022) which demonstrated that the online-based M-APOS model significantly improved students' mathematical problem-solving abilities, indicating a very strong effect in the context of distance learning. The implementation of the M-APOS model resulted in a significant improvement in students' abilities, can be attributed to its structured approach, which is rooted in the cognitive processes of learning and problem-solving. The M-APOS model integrates the four key components: Action, Process, Object, and Schema, which guide students through different stages of understanding a concept by each stage.

In the recitation task stage, some students initially faced difficulties when confronted with complex problems. Many of them found these problems challenging, leading them to give up at first. However, with encouragement and motivation from the instructor, students were urged to attempt the recitation problems before the class discussion. At this stage, the indicator of decomposition was clear, where students learned to break down complex problems into smaller, more manageable parts.

Over subsequent meetings, students' performance in the recitation tasks significantly improved. They became more meticulous, able to construct better computational arguments, and were able to develop more accurate solutions based on the assumptions used to reach conclusions. This finding is further supported by a bibliometric study conducted by Öztürk et al., (2024), which identifies the APOS theory as one of the most widely used pedagogical approaches in the development of students' mathematical skills and abilities in international literature. The study highlights the effectiveness of the APOS theory in enhancing students' understanding and problem-solving skills, making it a valuable framework in educational settings. By utilizing this approach, educators can better support students in building deeper cognitive connections and improving their ability to think critically and solve mathematical problems which can improve computational thinking skills.

In the class discussion stage, students worked in groups to discuss the Assignment Worksheet (AW) prepared by the instructor. During the first meeting, many students struggled to follow the provided learning scenarios due to insufficient prior knowledge. At this stage, the indicator of pattern recognition was clearly visible. The instructor played a crucial role as a facilitator, offering guidance and support to help students recognize patterns in the more complex problems. Although students initially struggled with completing the LKT, which was based on prerequisite knowledge from other courses, over time, they began to understand the concepts more effectively and could perform the tasks with greater efficiency. The group discussions became more productive as students helped one another when encountering difficulties, which, in turn, positively impacted their computational mathematical thinking abilities. This finding aligns with Slavin's (as cited in Rahman & Ahmar, 2016) assertion that cooperative learning offers both academic and social benefits, where students help each other solve problems and develop solidarity and concern for their group members. As a result, students not only improved their understanding of the material but also developed important social skills. This stage will improve students' critical thinking, problem-solving strategies which play a significant role in strengthening computational thinking and further developing students' mathematical abilities. This highlights the value of group discussions in encouraging reflective thinking, which, in turn, enhances computational thinking. By engaging in these discussions, students improve their ability to analyze and solve problems, which not only bolsters their computational thinking but also nurtures their broader mathematical skills

In the practice exercise stage, students were asked to solve problems individually. These exercises were designed to measure how well students understood the concepts taught and to provide an opportunity for them to apply the knowledge in a more structured context. At this stage, both the algorithmic and abstraction indicators were clear. Students were required to apply appropriate algorithms to solve problems and abstract the concepts they had learned into more generalized solutions. The practice exercises served as the central learning activity, where students could practice applying the concepts they had learned. The importance of practicing exercises in the learning process is to enhance understanding and computational mathematical thinking skills. These exercises provide an opportunity for students to develop systematic solutions through the application of appropriate algorithms and a deeper understanding of concepts (Lehtinen et al., 2017; Shapulatovich, 2019). This emphasizes the effectiveness of activities aimed at developing computational thinking, as they help students build critical cognitive skills. Through targeted exercises, students are able to strengthen their problem-solving strategies and improve their ability to think systematically, which are key components of computational thinking (Li & Oon, 2024).

Overall, the series of steps in the M-APOS model successfully improved students' computational mathematical thinking abilities, in line with the APOS theory (Action, Process, Object, Schema) proposed by Piaget and further developed in the context of mathematics education. The M-APOS model provides both a cognitive framework rooted in Piagetian theory and a pedagogical approach that actively involves learners in computational reasoning. Its focus on the construction of knowledge, from action to schema, aligns with the core processes of computational thinking, a fundamental skill for everyone, not just computer scientists, highlighting the importance of recursive and abstract thinking in problem-solving and decision-making. This theory demonstrates that the development of computational mathematical thinking can be achieved through an approach that involves a deep understanding of mathematical concepts, starting from action, process, object, and schema.

The M-APOS model effectively facilitates students in progressively constructing their understanding of mathematical concepts, which in turn enhances their computational thinking abilities. This study is consistent with findings from previous research, such as the study by Sari & Hoiriyah (2021), which showed that the implementation of the M-APOS teaching model at a university in Padangsidimpuan also resulted in a significant improvement in students' mathematical thinking abilities, with a high category of improvement. Additionally, Mitrayana (2024) findings indicate that the ACE learning model within the M-APOS framework positively influences the improvement of students' computational thinking abilities. The results showed that students who received ACE-based learning in the M-APOS framework achieved better improvements in computational thinking compared to students who received learning with a scientific approach. This influence was also observed in students with a high level of learning independence, where there was no significant difference between the two teaching models. However, for students with moderate learning independence, there was a significant difference in the improvement of computational thinking abilities between the two models. These findings further strengthen the argument that the

M-APOS teaching model is an effective approach to improving students' computational mathematical thinking abilities.

Therefore, the M-APOS learning model not only improves mathematical problem-solving but also lays a strong foundation for computational thinking by equipping students with structured, reflective, and schema-based ways of understanding problems. It provides an effective, scalable framework for mathematics education that integrates cognitive theory and 21st-century thinking skills. In future applications, the M-APOS model could be adapted across STEM disciplines and used to design learning interventions that aim to enhance computational thinking holistically—particularly in teacher education programs, where future educators are expected to integrate these skills into early-level teaching.

CONCLUSION

The implementation of the M-APOS learning model significantly improved students' computational thinking abilities compared to conventional instruction. This improvement was supported by a Cohen's d value of 1.57, indicating a very large effect size and demonstrating the strong effectiveness of the model. The structured stages of M-APOS (Action, Process, Object, Schema) effectively enhanced students' abilities in decomposition, pattern recognition, abstraction, and algorithmic thinking. Qualitative findings also showed higher engagement and more structured problem-solving strategies. Thus, M-APOS can be considered a highly effective pedagogical approach for developing computational thinking skills, particularly for prospective mathematics teachers.

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