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Comparative Effectiveness of ICT-Based APOS and M-APOS Learning Models on Students' Self-Efficacy Viewed from Initial Mathematical Ability

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Abstract

Statistics is an essential course in the curriculum of the Informatics Engineering Study Program, as it plays a crucial role in equipping students with skills in data analysis, information processing, and data-driven decision-making. However, various studies have reported that students often experience low self-efficacy in statistics, which can hinder their academic performance and engagement. This study aims to compare the effectiveness of the ICT-based APOS model and the M-APOS model on students' self-efficacy, taking into account their Initial Mathematical Ability (IMA). The APOS theory provides the foundation for the instructional models used, while Bandura's theory of self-efficacy underpins the construct being measured. A quasi-experimental method was employed using a 2 × 2 factorial design (treatment by level). The data analyzed were students' scores on a validated and reliable self-efficacy questionnaire, and a two-way ANOVA was used as the analytical technique. Prerequisite tests included the Lilliefors test for normality and Levene's test for homogeneity. The rationale for selecting the ICT-based APOS and M-APOS models lies in their potential to address cognitive and metacognitive learning challenges in mathematical thinking. The results showed that, overall, students taught using the ICT-based APOS model demonstrated higher self-efficacy than those taught with the M-APOS model. A significant interaction was found between the learning model and IMA on students' self-efficacy. Students with high IMA who received instruction through the ICT-based APOS model exhibited greater self-efficacy than those who experienced the M-APOS model. Among students with low IMA, there was no significant difference. These findings suggest that integrating technology into constructivist learning models such as APOS can enhance students' confidence in learning statistics, particularly for those with a strong mathematical foundation, and inform future innovations in adaptive, ability-sensitive instructional design.

Keywords: APOS Learning Model based on ICT, M-APOS, Self Efficacy, Student Initial Ability

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INTRODUCTION

In the era of digital transformation and the Fourth Industrial Revolution, data literacy has become a critical global competency across various fields, including informatics engineering. Higher education institutions, therefore, must ensure that graduates are not only technically proficient but also capable of interpreting and utilizing data effectively in decision-making processes. Within this context, the Statistics course holds a central role in the Informatics Engineering curriculum, particularly at Universitas Pamulang, as it equips students with essential skills in data analysis, information processing, and evidence-based problem-solving (Shi et al., 2017). However, the increasing complexity of statistical content and the rapid integration of data technologies demand learning approaches that go beyond conventional lectures.

Current challenges also include students' limited data reasoning and confidence, which are foundational elements of data literacy. Despite the course's importance, field observations and institutional records reveal that many students still struggle with low self-efficacy when learning statistics. This is consistent with empirical findings that link low confidence in mathematical reasoning to high anxiety, avoidance behavior, and underperformance (Ma et al., 2008). Therefore, enhancing students' self-efficacy in statistics is not only an academic necessity but also a strategic imperative for fostering data-literate graduates. Statistics not only help students understand data and conduct analysis, but also become the basis for data-driven decision-making in the field of information technology (Simbolon & Koeswanti, 2020). Students who have a good understanding of statistics are expected to be able to use the concepts obtained practically in their daily activities, especially in formulating systematic solutions to various problems (Handayani & Noviana, 2021).

Despite its importance, many students in the Informatics Engineering Study Program at Universitas Pamulang still show low levels of self-efficacy in statistics. Based on internal academic reports and observational data from lecturers, a significant proportion of students display hesitation and anxiety when solving data-related problems. Several studies corroborate this finding, highlighting that statistics anxiety and low confidence are persistent obstacles in learning environments where abstract reasoning and quantitative analysis are emphasized (Husnul & Nurullah, 2020). These challenges are often rooted in traditional lecture-based approaches that limit students' opportunities to engage in active knowledge construction, a key process in building confidence. Moreover, low self-efficacy has been associated with reduced motivation, higher stress levels, and poor academic outcomes. Difficulties in understanding statistics courses are still a challenge for many students, one of the main causes of which is low confidence in one's own abilities or *self-efficacy* in understanding the material (Handayani & Noviana, 2021).

The novelty of this study lies in its specific focus on comparing the effectiveness of the ICT-based APOS model and the M-APOS model in improving students' self-efficacy, particularly when analyzed in relation to students' Initial Mathematical Ability (IMA). While both structured worksheets and statistical software have been widely used in previous studies, the integration of ICT tools within the APOS framework—targeted at students with varying levels of IMA—remains underexplored in the existing literature. Moreover, comparative studies that investigate how different instructional models perform across low and high IMA groups are still limited, especially in the Indonesian higher education context. This research seeks to fill that gap by providing empirical evidence on the interaction effect between learning models and IMA levels on self-efficacy outcomes in a statistics course. By doing so, this study contributes to a more nuanced understanding of how instructional strategies can be adapted to students' prior knowledge profiles, which is essential for fostering inclusive and data-literate learning environments in the digital era.

A number of studies show that students, both at the undergraduate and postgraduate levels, often experience anxiety when attending statistics lectures due to a lack of confidence in solving problems related to data analysis (Stella & Glory N., 2018). *Self-efficacy* itself refers to an individual's belief and expectations of his or her ability to complete learning tasks (Masri et al., 2018). Moreover *self-efficacy* also affects learning motivation, perseverance in facing challenges, and academic achievement (Damayanti & Alwi, 2024). Low level *self-efficacy* It is known to reduce motivation, increase stress, and trigger anxiety during the lecture process (Risyiani, 2016). On the other hand, students who have *self-efficacy* are more motivated, have great fighting power, and are able to overcome academic obstacles more effectively (Muchtar, 2014). Motivation is essential to improve the process of conceptual change, critical thinking, learning strategies, and student achievement (Siagian et al., 2024). This is in line with (Afiqah et al., 2023), student learning motivation is an internal drive that triggers students to achieve optimal learning outcomes.

In the context of mathematics and statistics learning, the APOS (Action, Process, Object, Schema) model and its modification, MAPOS (Modified-APOS), have been shown to be effective in increasing student self-efficacy (Arnon et al., 2014; Dubinsky & McDonald, 2001). To address this, educational models grounded in constructivist theory—such as the APOS (Action, Process, Object, Schema) model and its derivative, the M-APOS model—offer promising pedagogical alternatives. The APOS model, particularly when integrated with ICT tools like statistical software, encourages students to actively construct knowledge through interactive exploration, which can enhance understanding and self-efficacy. Learning procedures that offer students to understand the material independently before discussion or completion of complex tasks have proven to be effective in increasing confidence and self-efficacy (Nst et al., 2023). In addition, research by (Budiarti et al., 2019) also supports the findings, where the M-APOS model contributes significantly to improving students' understanding of mathematical concepts.

Although the main focus of her research is on understanding concepts, increasing such understanding can have positive implications for students' self-efficacy, as better understanding can increase students' confidence in doing assignments. The ICT-based APOS model allows students to construct knowledge through technology-based activities, such as the use of statistical software so that it can increase student self-efficacy (Handayani & Noviana, 2021). Meanwhile, MAPOS offers a more structured approach through the provision of worksheets, which help students understand concepts systematically (Lestari, 2014). Research (Sani & Arianingrum, 2024) stated that learning that involves students to play an active role in understanding and constructing a concept can increase self-efficacy compared to lecture learning. In addition, research that has been carried out (Ningrum et al., 2019) stated that learning using ICT can improve students' mathematical connections and self-efficacy.

In addition to the learning model, students' initial abilities are also an important factor that affects the level of *self-efficacy* in the learning process. Students who already have an initial understanding of a topic tend to show higher confidence in completing challenging academic tasks, as they are able to relate new concepts to pre-existing concepts (Handayani, 2019). This ability not only smoothens the learning process, but also strengthens students' self-confidence in dealing with complex material. Recent research supports this view, with students with high initial knowledge known to have *self-efficacy* who are stronger than those whose initial knowledge is low (Choo et al., 2024). In line with that, (de Bruin & van Merriënboer, 2017) stating that students who have higher initial knowledge and a lighter cognitive load are more likely to seek instrumental help effectively, which ultimately positively impacts the quality of their involvement in the learning process. Based on this, initial knowledge is influential in forming self-confidence related to their ability to do academic tasks.

The study by (Arnon et al., 2014) introduced the APOS Theory as a constructivist-based instructional model that is effective in developing mathematical understanding. (Budiarti et al., 2019) xamined the contribution of the M-APOS model in enhancing students’ conceptual understanding of mathematics. The findings showed that M-APOS can improve conceptual comprehension; however, it was not directly compared to the ICT-based APOS model, nor did it address differences in students’ proficiency levels. The study by (Handayani & Noviana, 2020) investigated the effects of both the ICT-based APOS model and the M-APOS model on students’ self-efficacy.

However, none of these three studies specifically compared the APOS and M-APOS models in the context of different proficiency levels. Seeing the importance of developing *students' self-efficacy* in the learning process, an in-depth study is needed related to the effectiveness of the implementation of the ICT and M-APOS-based APOS learning models, especially in the context of learning the Statistics course at the Informatics Engineering Study Program, University of Pamulang. This research is relevant to review the extent to which the two models can contribute to shaping students' self-confidence in understanding and mastering statistical material more optimally.

METHOD

This study employs a quantitative approach using a 2×2 factorial quasi-experimental design, aimed at examining the effects of two instructional models—ICT-based APOS and M-APOS—as well as their interaction with students' Initial Mathematical Ability (IMA) on self-efficacy in statistics learning.

The 2×2 factorial design was chosen to analyze both main effects and interaction effects between two independent variables (instructional model and IMA) on a single dependent variable (self-efficacy). This design is widely applied in educational research to assess the effectiveness of teaching strategies while accounting for learner characteristics (Sukendro et al., 2020). The structure of the design is illustrated in Table 1.

Table 1. Factorial Research Design

	High IMA	**Low IMA**
ICT-based APOS	Group A (n = 20)	Group B (n = 20)
M-APOS	Group C (n = 20)	Group D (n = 20)

The population of this study includes all students in the Informatics Engineering Study Program at Universitas Pamulang during the 2024/2025 academic year. A total of 80 students were selected using a multistage sampling technique. The process involved three stages: (1) purposive sampling to select intact classes within the same academic year to control for curricular variation; (2) grouping students into high and low IMA based on a standardized mathematics ability test; and (3) random assignment of students within each IMA category into one of the two instructional model groups. This sampling method ensures representation and experimental control (Siregar & Nababan, 2021).

The primary instrument was a self-efficacy scale developed based on Bandura's theoretical framework and adapted for the context of statistics education. The scale consisted of 25 items measuring students' confidence, motivation, and persistence, using a 5-point Likert scale ranging from "strongly disagree" to "strongly agree." The content validity of the instrument was evaluated by three education experts, and the internal consistency reliability yielded a Cronbach's alpha coefficient of 0.87, indicating high reliability (Fitriani et al., 2022). The IMA variable was measured using a researcher-developed mathematics test validated by two subject matter experts.

The data analysis was conducted in several stages. Prior to hypothesis testing, assumption tests were carried out, including normality and homogeneity tests. Normality was assessed using two methods—the Shapiro–Wilk test and the Lilliefors test—to ensure accuracy, given that each subgroup consisted of n = 20 students. Levene's test was employed to assess the equality of variances (homogeneity). Once the assumptions were met, a two-way ANOVA was performed to examine both the main effects and interaction effects of the independent variables on students' self-efficacy scores.

RESULTS AND DISCUSSION

The self-efficacy scores of students who received instruction through the ICT-based APOS model and the M-APOS model are presented in the Table 2. A summary of the measures of central tendency and the distribution of students' self-efficacy scores based on initial mathematical ability (IMA) and the learning model is presented in Table 1. The average self-efficacy score of students with high IMA taught using the ICT-based APOS model was 128.20, which was higher than that of students taught using the M-APOS model, whose average score was 111.60. Similarly, for students with low IMA, the average self-efficacy score of those taught using the ICT-based APOS model was 103.70, compared to 101.20 for those taught using the M-APOS model.

Table 2. Self-Efficacy Scores of the Control and Experimental Groups

Learning	IMA	n	Min	Max	$\bar{X}$
APOS-based ICT	High	20	107	149	128.20
	Low	20	90	143	103.70
MAPOS	High	20	73	147	111.60
	Low	20	78	130	101.20

Analytical Prerequisite Testing

The self-efficacy scores were analyzed by considering the learning model used as well as the students' initial level of mathematical ability. The data were obtained from the results of a post-test administered after the learning implementation, involving 80 students divided into two groups: 40 students in the first experimental class and 40 students in the second experimental class. Before entering the data analysis stage, prerequisite tests were conducted to ensure that the data met the assumptions required for statistical analysis. These tests included a normality test using the Lilliefors method and a homogeneity test using Bartlett's test.

Normality Test of Students' Self-Efficacy Scores Treated with the ICT-Based APOS and M-APOS Learning Models

Normality tests need to be carried out to ensure that the self-efficacy value data of students who receive treatment through the ICT-based APOS model and the M-APOS model are distributed normally. The results of the analysis of both value data groups are presented in Table 3.

Table 3. Normality Test of Self-efficacy Score Based on Learning Model

	Learning Model	Kolmogorov-Smirnova			Information
		Statistics	Df	Sig.	
Self Efficacy	ICT-based APOS	0.090	40	0.200*	H0 Accepted
	M-APOS	0.113	40	0.200*	H0 Accepted

Referring to Table 3, the results of the analysis show that the *self-efficacy* value of classes treated with ICT-based APOS and M-APOS models each has a Sig. of $0.200 > \alpha = 0.05$, meaning that the *self-efficacy* value in ICT-based APOS and M-APOS classes is normally distributed.

Normality Test of Self-Efficacy Scores for the APOS-IMA High, APOS-IMA Low, MAPOS-IMA High, and MAPOS-IMA Low Groups

To ensure that the data on student self-efficacy scores is distributed normally, a normality test was carried out on four groups formed based on a combination of learning models and IMA, namely APOS IMA H, APOS IMA L, MAPOS IMA H, and MAPOS IMA L. This test aims to see whether each group meets the assumption of normal distribution as a condition for further analysis. In this test, decisions are made based on significance values (Sig.), where the data is considered to be normally distributed if the Sig. value is greater than $\alpha = 0.05$.

The test results are shown in Table 4 that all groups, both those using the ICT-based APOS learning model and the M-APOS learning model, at high and low initial ability levels, had a significance value above the limit of 0.05. So it was concluded that the self-efficacy value of the four groups met the assumption of normality.

Table 4. Normality Test of Group Self-efficacy Value

	Group	Kolmogorov-Smirnova			Information
		Statistics	Df	Sig.	
Self Efficacy	APOS IMA H	0.119	20	0.200*	H0 Accepted
	APOS IMA L	0.162	20	0.178	H0 Accepted
	M-APOS IMA H	0.128	20	0.200*	H0 Accepted
	M-APOS IMA L	0.165	20	0.159	H0 Accepted

Homogeneity Test

Test of Homogeneity of Student Self-efficacy Scores with ICT and M-APOS Based APOS Model Treatment

The homogeneity test was carried out to test whether the variance of student self-efficacy score data with the ICT-based APOS learning model and the M-APOS learning model has a homogeneous nature. The results of the analysis of self-efficacy values based on the learning model are presented in Table 5.

Table 5. Homogeneity Test of Self-efficacy Value Based on Learning Model

LifeStatistic	df1	df2	Sig.	Information
3.357	1	78	0.071	H0 Accepted

The results of the analysis *of students' self-efficacy* scores with the ICT-based APOS learning model and with the M-APOS learning model have Sig. = 0.071 > α = 0.05, meaning that the class is homogeneous.

Homogeneity Test of Self Efficacy Scores of APOS IMA H, APOS IMA L, MAPOS IMA H, and MAPOS IMA L

The homogeneity test was carried out to test whether the variance of the data of the self-efficacy value of each group of students who were treated with APOS IMA Tinggi, APOS IMA Low, M-APOS IMA High and M-APOS IMA Low was normally distributed. The results of the analysis of the data group are presented in Table 6.

Table 6. Group Self-efficacy Score Homogeneity Test

LifeStatistic	df1	df2	Sig.	Information
0.091	3	76	0.965	H0 Accepted

The results of the analysis of the self-efficacy value of the APOS IMA High, APOS IMA Low, M-APOS IMA High and M-APOS IMA Low groups at Sig. = 0.965 > α = 0.05, mean that the group is homogeneous.

Hypothesis Test

The *self-efficacy score data to be used* for hypothesis testing is normally distributed and has the same variance. With these conditions met, hypothesis testing can be resumed using two-way variance analysis (ANAVA). If the results of two-way ANAVA show an interaction, then a follow-up analysis is carried out, namely the t-test.

Differences in Self efficacy between Learning Models

The analysis of *self-efficacy scores* was carried out to evaluate the difference in the level of *self-efficacy* between students with ICT-based APOS learning and M-APOS learning. This analysis process is carried out thoroughly using the two-path ANAVA approach. The results of the analysis with the help of SPSS software version 21 are shown in Table 7, a significance value of 0.003 was obtained for the learning model variable. This value is below the significance threshold of 0.05, so the analysis results express a rejection of the null hypothesis (H_0). This shows that there is a significant difference between the two learning models in influencing the level of *student self-efficacy*.

Table 7. Two-Way ANOVA: The Effect of Learning Model and Initial Mathematical Ability (IMA) and Their Interaction on Students' Self-Efficacy

Data Source	Number of Squares	Df	Average Number of Squares	F	Sig.	Partial eta squared
Model	1824.050	1	1824.050	9.379	.003	.077
IMA	6090.050	1	6090.050	31.313	.000	
Model * IMA	994.050	1	994.050	5.111	.027	
Error	14781.400	76	194.492			
Total	1012480.000	80				
Corrected Total	23689.550	79				

Based on Table 8**,** the effect of the Model has an η^2 value of 0.077 and a Cohen's f of 0.289, indicating a medium effect. This means that the Model provides a meaningful contribution in explaining the variation in the data. The effect of IMA with an η^2 value of 0.257 and a Cohen's f of 0.589 shows a large effect. This indicates that IMA is the most dominant factor influencing the results in this model. The interaction between Model * IMA, with an η^2 value of 0.0420 and a Cohen's f of 0.209, indicates a small to medium effect. This means that the influence of the Model on the dependent variable may vary depending on the condition of IMA, but the effect is not substantial.

Table 8. Effect Interpretation

Faktor	Eta Squared (η^2)	Cohen's f	Effect Interpretation
Model	.077	.289	Medium
IMA	.257	.589	Large
Model * IMA	.042	.209	Small-medium

The difference in *self-efficacy* of students who are treated with the ICT-based APOS model and the overall M-APOS model can be further tested with a t-test. The results of the calculation can be presented in Table 9.

Table 9. Self-Efficacy Comparison Between Experimental Class 1 and Experimental Class 2

Learning Model	t-test for Equality of Means			Information
	T	Df	Sig. (2-tailed)	
APOS Based on ICT >< MAPOS	2.551	78	0.013	H0 Rejected

Based on the results of the calculation in Table 9, it can be seen that t_{count} = 2.551 and t_{table} = 1.664, because t_{count} = 2.551 > t_{table} = 1.664, then H_0 is rejected. This means that the *self-efficacy* of students who are treated with the ICT-based APOS model is higher than the *self-efficacy* of students who are treated with the M-APOS model.

The Interaction Between the Learning Model and Early Mathematical Ability on Self-Efficacy

Results in Table 7 showed a significant interaction between the learning model and early math ability on students' self-efficacy (Sig = 0.027 < 0.05). This indicates that these two variables simultaneously contribute to the increase in self-efficacy. Visualization in Figure 1. shows that the ICT-based APOS model provides higher self-efficacy results than the M-APOS model, both in students with high and low initial ability. Thus, the ICT-based APOS model is more effective in improving self-efficacy overall than the M-APOS model.

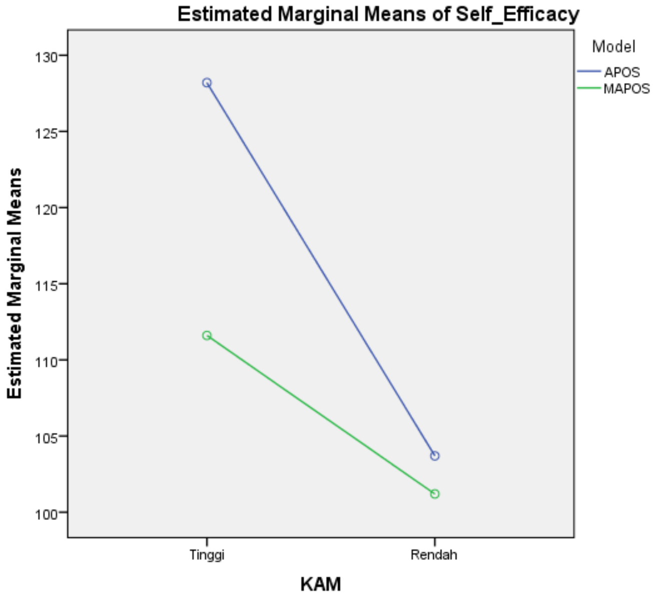

Figure 1. Interaction of Learning Models with IMA

In Figure 1, it can be observed that the ICT-based APOS model leads to higher self-efficacy scores compared to the M-APOS model for both high and low IMA groups. However, the difference in the slope of the lines suggests a variation in the effect pattern. Specifically, the increase in self-efficacy among students with high IMA is steeper in the ICT-based APOS group than in the M-APOS group. For students with low IMA, although both models show a positive trend, the difference between the two is less pronounced. This indicates that the ICT-based APOS model is more effective for students with high initial mathematical ability, although it still yields benefits for those with lower abilities. Thus, the interaction is not only statistically significant but also conceptually meaningful, highlighting that alignment between instructional models and students' initial profiles (in this case, IMA) plays a critical role in optimizing self-efficacy outcomes. This finding aligns with the differentiated instruction approach, which emphasizes tailoring teaching strategies to match learners' prior knowledge and readiness levels (Tomlinson, 2017).

Self-Efficacy Among Student Groups with High Initial Mathematical Ability (IMA)

Based on Table 6 and Figure 1, it can be seen that there is an interaction between the learning model and IMA on self-efficacy. In order to identify groups that showed significant differences, a t-test was performed. The test results showed a significance value of 0.001 < 0.05, so H0 was rejected. This means that there is a significant difference in self-efficacy between students with high IMA using the ICT-based APOS model and those using M-APOS. Details of the test results can be seen in Table 10.

Table 10. *Self-efficacy* test test for students with high IMA

Learning Model	t-test for Equality of Means			Information
	T	**Df**	**Sig. (2-tailed)**	
APOS Based on ICT >< MAPOS	3.675	38	0.001	H0 Rejected

Based on the results of the statistical test, it was obtained that the calculated t value of 3,675 exceeded$_{\text{the table}}$ t value of 1,664. Based on the decision-making criteria, this condition indicates a rejection of the null hypothesis (H_0). Thus, there is a significant difference in the level of self-efficacy between students with high IMA who participate in learning using the

ICT-based APOS model and those who follow M-APOS. These findings lead to the conclusion that the ICT-based APOS model is more effective in increasing self efficacy in the student group with high CAM.

Self-Efficacy of Students with Low Initial Mathematical Ability

Based on the results of the analysis listed in Table 11, a significance value of 0.0564 > 0.05 was obtained, so that H_0 was accepted. This means that there is no significant difference in the level of self-efficacy between students with low IMA who participate in learning using the ICT-based APOS model and those who follow M-APOS. Thus, the application of the ICT-based APOS learning model does not show significant advantages compared to the M-APOS model in increasing *self-efficacy* in students with low initial mathematics skills.

Table 11. Self *efficacy* test test for students with low IMA

	t-test for Equality of Means			Information
Learning Model	**T**	**Df**	**Sig. (2-tailed)**	
APOS Based on ICT >< MAPOS	0.581	38	0.0564	H0 Rejected

The Influence of the ICT-Based APOS Learning Model on Self-Efficacy Viewed from Initial Mathematical Ability (IMA)

The second hypothesis test, conducted using SPSS version 21, revealed a significant difference in students' self-efficacy based on the learning model applied. The ICT-based APOS model was found to be more effective than the M-APOS model in enhancing students' self-efficacy. Furthermore, the analysis results indicated an interaction effect between the learning model and students' initial mathematical ability (IMA) on self-efficacy. The following section provides a detailed discussion of these research findings:

Differences in Student Self-Efficacy Based on Learning Models

The results of the descriptive analysis and statistical tests revealed a significant difference in self-efficacy and initial mathematical ability (IMA) between students who engaged with the ICT-based APOS model and those who followed the M-APOS model. These findings indicate that students learning through the ICT-based APOS model tend to demonstrate higher levels of self-efficacy. This outcome can be theoretically grounded in Bandura's theory of self-efficacy, which emphasizes that self-efficacy is shaped by four sources: mastery experiences, vicarious experiences, social persuasion, and physiological states. The ICT-based APOS model likely enhances students' mastery experiences by enabling immediate feedback through digital tools, allowing students to verify their calculations and develop confidence in their problem-solving capabilities. In contrast, the M-APOS group, which relied solely on manual computations, lacked this feedback loop, leading to uncertainty and reduced confidence in their performance—key components that, according to Bandura, directly influence perceived self-efficacy.

The ICT-based APOS model and M-APOS consist of four stages, namely action, process, object and scheme. The ICT-based APOS model and M-APOS are also carried out by way of group discussions. Students get experience from their friends during group discussions (Williamson & Paulsen - Becejac, 2018). In addition to gaining experience from their friends, students can also assess their performance in solving problems as a contribution to group discussions (Chambers & Harkins Monaco, 2023). Personal experiences when solving a problem can also be presented during group discussions. Students will receive awards both from lecturers and from their friends when the presentation of the results is very appropriate.

In the ICT-based APOS model, students have confidence in their performance before the results of their performance are discussed with their friends. Students with the ICT-based

APOS model can compare the results obtained from the analysis *Ms. Excel* with SPSS. Students with the APOS model combined with information and communication technology (ICT) have proven to be able to build student confidence, especially in presentation activities and the delivery of learning results. This model not only strengthens conceptual understanding through collaborative activities and the use of digital media, but also encourages students' active participation in the learning process and increases their courage in expressing ideas and analysis results openly in front of peers (Hanifah, 2017). In line with the results of the study, one intriguing approach for investigation is the implementation of project-based collaborative learning methods, where students with physical disabilities can work alongside their peers in groups to complete tasks related to marketing management (Husnul, NRIH & Rusnaini, 2024).

From a constructivist perspective, the learning process in the APOS model—particularly when supported by ICT—aligns with the principles of active, student-centered learning. Learners are not passive recipients of knowledge but are instead engaged in constructing understanding through the stages of action, process, object, and schema. The ICT-based APOS model fosters collaborative learning environments, encourages peer interaction, and supports the co-construction of knowledge, which are core features of Vygotsky's social constructivism. Students involved in the ICT-enhanced APOS setting showed higher levels of participation and communication, suggesting that the model not only supports cognitive engagement but also creates a socio-affective climate conducive to learning. Therefore, the observed differences in self-efficacy between the two models are not merely statistical in nature but are underpinned by strong theoretical foundations explaining how digital scaffolding and collaborative learning environments foster students' belief in their academic competence.

Students showed a higher level of activeness and communication skills when participating in learning with the ICT-based APOS model compared to the M-APOS model. In line with (Ghavifekr & Rosdy, 2015), the use of information and communication technology in the learning process encourages students to participate more actively and be deeply involved in learning activities. Studi (Longe & Maharaj, 2023) menggunakan kerangka APOS untuk menganalisis perubahan pemahaman konsep fungsi, dan menunjukkan bahwa representasi grafis dan teknologi (seperti perangkat lunak) memperkuat tahap mental "Proses" dan "Objek" dalam APOS.

Despite the strengths of this study in employing a factorial quasi-experimental design and addressing the interaction between learning models and students' initial mathematical ability, several limitations must be acknowledged. First, the sample was relatively homogeneous, consisting solely of students from a single study program at one university, which limits the generalizability of the findings to broader or more diverse student populations. Second, the possibility of a Hawthorne effect cannot be ruled out, as participants may have altered their behavior simply due to their awareness of being involved in an experimental study. Third, the study employed a posttest-only design without any longitudinal follow-up, which restricts the ability to assess the sustainability of the observed improvements in self-efficacy over time. Future research should consider a more diverse sample, implement strategies to control for participant reactivity, and incorporate delayed posttests to evaluate long-term effects.

The Interaction between Learning Models and Early Mathematics Abilities on Self Efficacy

Data analysis indicates that there is an interactive relationship between the type of learning model and early mathematics ability (IMA) on the level of student self-efficacy, as visualized in Figure 1. These findings indicate that the ICT-based APOS model is suitable as an alternative to mathematics learning strategies, especially for students with high IMA. Powered by (A. K. Tsafe, 2024), ICT-based APOS learning effectively improves mathematical problem-solving skills. The group that used the APOS model showed better results than the group that studied with the traditional method, so this model is suitable as an alternative, especially for students with high initial math skills. This conclusion is reinforced by the data in Figure 2. In addition, the analysis shows that there is a difference in values *self-efficacy* between students with the ICT-based APOS learning model and M-APOS, both in groups with high and low IMA. This difference is at a 95% confidence level, which identifies that variations in learning models have a real impact on the level of *self-efficacy* student. Overall, these results confirm that the choice of learning model contributes significantly to the strengthening of *self-efficacy*, depending on the level of initial ability that the student has.

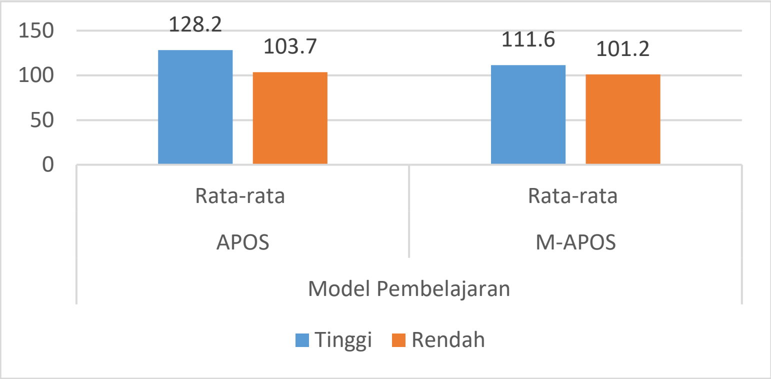

Figure 2. Average Self Efficacy Score Based on Learning Model and IMA

In light of these findings, the integration of ICT tools within the APOS learning framework not only enhances conceptual understanding but also promotes students' confidence in tackling statistical tasks independently. This pedagogical innovation provides dynamic, interactive, and student-centered experiences that are essential for fostering self-efficacy—particularly among learners with higher cognitive readiness. Moreover, the structured scaffolding offered by both APOS and M-APOS enables learners to progress through the stages of abstraction and generalization more effectively. Thus, beyond its statistical significance, this research highlights the pedagogical value of aligning instructional models with learners' prior knowledge levels, as a means to optimize affective and cognitive learning outcomes in data-intensive disciplines such as statistics.

Differences in Self Efficacy Based on Learning Models and IMA

The findings of the data analysis revealed that students with high IMA received an increase in *self-efficacy* which is more significant when participating in learning using the ICT-based APOS model compared to the M-APOS model. These findings illustrate that the ICT-based APOS model is more effective in supporting the development of students' self-confidence in the group. Students with high initial abilities generally show characteristics such as strong confidence, perseverance in learning, and high motivation to explore and understand new concepts (Chan et al., 2024). Students tend to be very interested and want to learn more and the drive to solve academic challenges independently. The ability to relate previous knowledge to new material makes them better able to build a deep understanding, so that learning becomes more meaningful and has a positive impact on *self-efficacy* they.

Theoretically, these findings are supported by Bandura’s (1997) Self-Efficacy Theory, which states that mastery experiences and positive feedback from the use of technological tools can strengthen an individual’s belief in their capabilities. In addition, Vygotsky’s (1978) Social Constructivist Theory explains that social interaction within a technological context can expand students’ zone of proximal development, enabling them to learn more optimally through guidance from instructors and technological assistance. Sweller’s (1988) Cognitive Load Theory is also relevant, as technology helps reduce cognitive load by providing automated visualizations and simulations, which can enhance students’ mental capacity in understanding complex statistical concepts.

Models APOS ICT-based provide opportunities for students to behave and act positively towards statistics courses. Students with high initial mathematics skills will be very enthusiastic about the APOS model of ICT-based learning. Alternative learning that is suspected to affect student confidence is ICT-based learning (Al-Fraihat et al., 2020). Students who have high IMA prefer to learn with various experiences and in various ways. Students who are given the APOS model ICT-based will have high confidence, because students can know that the results that have been obtained can be said to be correct if the results are the same as the results of the SPSS analysis. Students with high initial math skills will also be confident in explaining the results of their performance.

Students do not have high confidence in the M-APOS model, they do not ensure that the performance results are appropriate or not. Students with the M-APOS model will have confidence after knowing from the experience of others, namely after a group has presented the results of a discussion. Students with high initial mathematics skills will feel bored with these lectures, because in the lectures they only teach manual calculations and do not practice with computers. This is because the students expect more complex challenges and practical applications that can maximize the understanding of concepts directly through simulations or learning support software (Rahma et al., 2024).

In contrast to the results obtained in the high initial ability group, students with low initial math ability did not show significant differences in levels *self-efficacy* between the use of the ICT-based APOS model and the M-APOS model. These findings show that the fourth hypothesis that predicts the advantages of ICT-based APOS models in improving *self-efficacy* in this group it is not empirically proven. Thus, it can be concluded that in students with low initial ability, both learning approaches have a comparable impact in influencing *self-efficacy*. Both the ICT-based APOS and M-APOS models are not significantly superior to each other in increasing students' self-confidence in statistical learning in this group. In line with (Afari et al., 2023) Students with varying levels of initial ability, both low and high, experience increased confidence in learning when they follow a learning process that utilizes information and communication technology (ICT).

The findings of this study, which demonstrate that the ICT-based APOS model more effectively enhances students’ self-efficacy than the M-APOS model, are consistent with the study by Handayani and Noviana (2021). Their research emphasized that technology-integrated instruction in statistics promotes more active knowledge construction and increases students’ confidence in solving numerical problems. This similarity can be explained by the use of statistical software, which provides immediate feedback, accelerates the validation process, and reduces anxiety associated with making errors. Furthermore, technology-enhanced learning environments tend to be more interactive and flexible, contributing to more positive learning experiences. These outcomes align with Bandura’s self-efficacy theory, which highlights the importance of mastery experiences in building learners’ confidence and belief in their own abilities.

However, the results of this study differ from those of Budiarti et al. (2019), who found that the M-APOS model was sufficiently effective in improving students’ conceptual understanding of mathematics, without distinguishing based on their initial mathematical ability. This discrepancy may be attributed to differences in evaluative focus. While Budiarti's research emphasized cognitive outcomes such as conceptual understanding, the present study examined affective outcomes—specifically self-efficacy—which are closely tied to an individual’s perception of their capability. Additionally, the integration of technology in the ICT-based APOS model offers more extensive support for visualization and independent exploration, which may be more effective in enhancing affective domains such as self-efficacy compared to the structured worksheet approach of M-APOS. Thus, contextual differences, instructional strategies, and the specific learning outcomes assessed are key factors in explaining the observed similarities and differences between the present study and previous research.

CONCLUSION

Based on the results of the study and the discussion on the influence of mathematical comprehension ability and self-efficacy between students taught using the ICT-based APOS model and those taught using the M-APOS model, as viewed from their initial mathematical ability, the following conclusions can be drawn: (1) The overall self-efficacy of students who received instruction using the ICT-based APOS model was higher than that of students who received instruction using the M-APOS model; (2) There is a significant interaction between the learning model and initial mathematical ability on students' self-efficacy; (3) Students with high initial mathematical ability who were taught using the ICT-based APOS model demonstrated higher self-efficacy than those taught using the M-APOS model; (4) There was no significant difference in self-efficacy between students with low initial mathematical ability taught using the ICT-based APOS model and those taught using the M-APOS model.

RECOMMENDATION

Based on the findings and conclusions presented earlier, the following recommendations are proposed: (1) The ICT-based APOS learning model should be considered a viable instructional alternative for statistics courses, particularly for improving student self-efficacy across varying levels of initial mathematical ability. This approach supports the development of data literacy skills, which are increasingly critical in the digital era. (2) Instructors planning to implement either the ICT-based APOS or M-APOS models should ensure thorough preparation of instructional materials and adopt strategic student grouping. Heterogeneous grouping is recommended to maximize peer learning benefits and foster collaborative knowledge construction. (3) Students must be adequately prepared to engage in adaptive and participatory learning environments. They should be encouraged to actively question, communicate their ideas, and synthesize discussion outcomes, while connecting new concepts with prior knowledge during group activities. (4) At the faculty level, curriculum development should include the integration of ICT-based pedagogy. This can be achieved through regular professional development programs, such as workshops and training sessions, aimed at equipping instructors with skills to utilize statistical software and digital learning tools effectively. (5) Future research should address current limitations—such as sample homogeneity and lack of long-term evaluation—by conducting multi-institutional, longitudinal studies. Additionally, researchers are encouraged to explore hybrid instructional approaches that combine constructivist models with emerging technologies to further enhance student self-efficacy and engagement.

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