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Inquiry-Based Online Learning Model Using Metacognitive Strategy to Enhance Mathematics Critical Thinking Ability

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ABSTRAK

Kemampuan berpikir kritis calon guru sangat menentukan perannya sebagai mentor dan fasilitator pendidikan. Untuk itu, diperlukan proses pembelajaran yang lebih fleksibel dan bersinergi dengan perkembangan zaman untuk mendorong eksplorasi dan keterlibatan. Oleh karena itu, penelitian ini bertujuan untuk menguji kemampuan berpikir kritis matematika menggunakan pembelajaran online berbasis inkuiri dengan strategi metakognitif. Penelitian ini melibatkan 60 orang siswa calon guru matematika, 30 orang dikelompokkan sebagai kelas eksperimen, dan 30 orang lainnya sebagai kelas kontrol. Masing-masing kelompok dibagi berdasarkan pengetahuan awal yaitu tinggi, sedang, dan rendah. Hasil penelitian menunjukkan bahwa siswa yang mendapat pembelajaran online berbasis inkuiri dengan strategi metakognitif menunjukkan peningkatan kemampuan berpikir kritis matematika yang lebih signifikan. Tren ini diamati di semua tingkat pengetahuan matematika awal. Secara keseluruhan, siswa yang mendapat pembelajaran online berbasis inkuiri dengan strategi metakognitif menunjukkan peningkatan kemampuan berpikir kritis matematika pada semua kategori.

Kata Kunci: Kemampuan Berpikir Kritis Matematis; Pembelajaran Inquiry Berbasis Online; Strategi Metajoignitif.

ABSTRACT

The critical thinking ability of prospective teacher is crucial to their role as mentors and educational facilitators. For this reason, a learning process is needed that is more flexible and synergistic with current developments to encourage exploration and involvement. Therefore, this study aimed to examine the critical thinking ability of mathematics using inquiry-based online learning with a metacognitive strategy. This research involved 60 prospective mathematics teacher students, 30 people were grouped as the experimental class, and 30 other people as the control class. Each group is divided according to initial knowledge, namely high, medium, and low. The results showed that students who received inquiry-based online learning with metacognitive strategy demonstrated more significant improvement in mathematics critical thinking ability. This trend was observed across all initial mathematics knowledge levels. Overall, students who received inquiry-based online learning with metacognitive strategy demonstrated improved mathematics critical thinking ability in all categories.

Keywords: Mathematics Critical Thinking Ability; Inquiry-Based Online Learning; Metacognitive Strategy.

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1. INTRODUCTION

The COVID-19 pandemic has resulted in a significant change in education patterns, with many academic institutions in 188 countries facing challenges related to the suspension of traditional face-to-face learning activities (Chertoff et al., 2020; Ferrel & Ryan, 2020; Toquero, 2020; Fadilah & Afriansyah, 2021). As a result, there is an urgent need for institutions to quickly transition to online or network-based learning because teachers and students must remain at home (Hakim, 2023). However, many educators are ill-prepared to handle the shift to online education (Toquero, 2020). This poses several obstacles in terms of planning, implementation, motivation, and other areas.

The global focus on online learning development in the post-pandemic era aims to prioritize literacy and prepare the world for future virus outbreaks (Toquero, 2020). In order to achieve this, various adaptive learning models have been designed, particularly in teacher education (Eltayar et al., 2020). However, criticism of these models has emerged, arguing that it does not align with the true function of preparing future teachers, as these are considered too theoretical and lacking in technology (Afdal, 2017). One promising adaptive learning model that maximizes online learning is the inquiry model. It can synergize with the development of the 21st century to fulfil educational needs and challenges (Jeffrey et al., 2014).

The inquiry model allows for the development of new techniques that open opportunities for investigating processes with the support of electronic learning environments (Pedaste et al., 2015; Suartama et al., 2020). Collaboration and technological advances can also significantly enhance the success of implementing the inquiry model (De Jong et al., 2014). In order to adapt to this approach for online implementation, an inquiry-based online learning model was developed. This model incorporates the principles of inquiry-based learning to create an adaptive online learning experience that maximizes the benefits of technology and collaboration.

The inquiry-based online learning model adapts its offline counterpart for use in digital learning environments, focusing on investigative activities (Duran & Dökme, 2016; Pedaste et al., 2015). This model stimulates inquiry by prompting learners to ask questions to comprehend the learning material and problem-solve (Lestari et al., 2021). In this model, the role of the instructor is similar to the motivator, thereby facilitating the primary source of learning (Suartama et al., 2020). As a result, the inquiry-based online learning model can foster an engaging and interactive learning environment that promotes prospective teacher students to participate actively in learning activities (Muhati et al., 2021; Pedaste et al., 2015). This approach can lead to meaningful learning experiences that provide opportunities for new discoveries and insights through investigation.

In this study, the inquiry-based online learning model was utilized to incorporate metacognitive strategy, which is known to enhance cognitive processes (Ahdhianto et al., 2020;

Halpern, 1998; Ku & Ho, 2010). This strategy supports the inquiry investigation process and has been found to positively impact mathematics achievement (Desoete & De Craene, 2019). The model comprises five stages, namely orientation, conceptualization, investigation, conclusion, and discussion (Joyce, 2011; Pedaste et al., 2015), which were implemented through an e-module as an effective means of addressing potential issues in online learning. E-module is digital version of printed textbook systematically designed to facilitate self-learning (Serevina & Sari, 2018; Setiyani et al., 2022; Sitorus et al., 2019; Utami et al., 2020). The design of e-module can incorporate various media formats, including audio, video, animation, and interactive worksheets, to create a dynamic, effective, and engaging learning experience that stimulates students' interest in learning (Supriadi et al., 2019; Irwansyah et al., 2017; Istuningsih et al., 2018; Seruni et al., 2020).

In this study, applying the inquiry-based online learning model through metacognitive strategy to improve critical thinking ability is crucial in mathematics education. Critical thinking is related to forming geometric concepts, a complex process (Dinuţă, 2015; Luritawaty, Herman, & Prabawanto, 2022; Rohmah dkk., 2023). This process cannot be completed in elementary school but continues as a major component of mathematics education. It develops observation skills in geometry needed to create, reproduce, and train thinking ability using various transformation methods in a useful and enjoyable way (Afriansyah, 2021; Nurhanifah, 2022). The focus on improving critical thinking ability helps to address challenges in developing geometric concepts (Brunheira & Ponte, 2019; Fujita et al., 2017; Vasilyeva et al., 2013).

2. METHOD

A quasi-experimental design was employed due to the inherent difficulty in fully controlling the independent variable. This approach looked into how variables could be manipulated to make sure the independent ones affected the dependent one (Lodico et al., 2006). This was consistent with the goal of evaluating the impact of a treatment using pre- and post-test. This study comprises of two classes, namely experimental group comprising mathematics students who underwent the inquiry-based online learning treatment with metacognitive strategy, and the control group, consisting of students who did not receive the same treatment.

The non-equivalent control group design was employed by Shadish et al. (2002) to compare the experimental and control classes. The difference between the two groups' capacities for critical thinking in mathematics was ascertained using this design.

Experiment Group : O X O

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Control Group : O O

Description:

O : Pre-test or post-test of mathematics critical thinking

X : Inquiry-based online learning with metacognitive strategy
– – – : There is no random grouping of subjects.

The sample consisted of 60 mathematics students from Garut, Indonesia, comprising 16 males and 44 females aged between 19 and 20 years. The participants were randomly assigned to either the experimental or control group, with each group comprising 30 individuals. The experimental group received instruction through the inquiry-based online learning model with metacognitive strategy, while the control group received instruction using the problem-based online learning model. All participants had similar social backgrounds and were from middle-class families. The learning process was led by one lecturer with more than 10 years of teaching experience and a graduate of a reputable university in Indonesia with a master's degree in mathematics education (M.Pd.). The lecturer was trained to use various learning models to avoid potential biases.

A test was used to evaluate first-year mathematics students' mathematics critical thinking ability in flat-sided spatial structures. The test was validated by three mathematics education experts and developed based on critical thinking aspect theory of Daniel & Auriac (2011), Ennis (2011), and Sanders (2016). These include proof, generalization, consideration of alternative answers, and problem-solving. Each aspect is evaluated using the FRISCO theory, which consists of focus, reason, inference, situation, clarity, and overview (Ennis, 1991; 1996). The FRISCO theory effectively demonstrates critical analysis and improves critical thinking ability (Ennis, 1996; Dominguez et al., 2015). The rubric for assessing mathematics critical thinking ability is provided in Table 1 and consists of evaluating the ability to identify the problem, provide logical reasons, follow up on the reasons to reach conclusions, compare with the actual situation, provide explanations about the terms used, as well as determine problem-solving and check the entire process.

Table 1. Rubric for evaluating mathematics critical thinking ability based on FRISCO

Students' Response	Score
Incorrectly or fails to identify as well as find important things and write them down.	0
Identifies and finds important things and writes them down.	1
Identifies and finds important things, writes them down, as well as provides reasons based on facts related to the problem-solving plan.	2
Identifies and finds important things, writes them down, provides reasons based on facts related to the problem-solving plan, as well as follows up on the reasons to reach a conclusion related to the problem-solving plan.	3
Identifies and finds important things, writes them down, provides reasons based on facts related to the problem-solving plan, follows up on the reasons to reach a conclusion related to the problem-solving plan, and compares with the real situation.	4

Students' Response	Score
Identifies and finds important things, writes them down, provides reasons based on facts related to the problem-solving plan, follows up on the reasons to reach a conclusion related to the problem-solving plan, compares with the real situation, and explains the terms used related to the problem-solving plan.	5
Identifies and finds important things, writes them down, provides reasons based on facts related to the problem-solving plan, follows up on the reasons to reach a conclusion related to the problem-solving plan, compares with the real situation, explains the terms used related to the problem-solving plan, determines the problem-solving as well as checks the whole problem-solving process.	6

The implementation steps for the lecturer's inquiry-based online learning approach, which incorporated a metacognitive strategy, are shown in Table 2.

Table 2. Steps of Implementing Inquiry-Based Online Learning with Metacognitive Strategy

Syntax of Inquiry-Based Online Learning with Metacognitive Strategy		
Inquiry-Based Online Learning		Metacognitive Strategy
Orientation	1. Introduction to the topic	1. Connecting initial knowledge with new knowledge
Conceptualization	2. Preparation of questions 3. Preparation of hypotheses	2. Ask questions
Investigation	4. Exploration 5. Experiment 6. Data interpretation	3. Generate ideas 4. Planning a strategy 5. Implement the solution
Conclusion	7. Conclusion	6. Evaluate
Discussion	8. Presentation 9. Reflection 10. Final evaluation	7. Evaluate

The online learning approach used by the lecturer for mathematics education students is inquiry-based and incorporates metacognitive strategy. In this approach, the lecturer assumes an active role as a motivator and facilitator while students actively participate in all stages of the learning process. The learning sessions take place online through Zoom meetings, with an e-module guiding the learning process, which is structured according to the stages of the model. E-module is designed to help students stay focused on learning and not lose direction, even when they experience issues such as signal loss. The learning process begins with the lecturer presenting a video on a topic that contains an open contextual problem statement. Students watch the video and connect their initial knowledge with the new one presented, thereby understanding the challenges they must solve.

The learning process in the inquiry-based online learning model with metacognitive strategy involves several stages. First, the lecturer stimulates students to generate initial questions based on the problem and acquire prior information by exploring online references. The students then revised their initial questions and determine more specific ones for hypothesis formulation. In the next stage, students investigate the things related to their ideas and explore through online searches with open-source materials. Furthermore, they collaborated with groupmates and shared previously prepared ideas. With the guidance of the lecturer, students interpreted the data on their problem-solving plans, solved mathematical issues, and organized presentations. This was followed by conclusion from the data with hypotheses and research questions. Finally, a presentation was made to criticize the discussion results, evaluate and revise students understanding of the problem. The students also shared their experiences during the various stages of learning in the inquiry-based online learning model with metacognitive strategy.

Quantitative data were generated from two tests, namely a pre-test of mathematics knowledge and a test of its critical thinking ability. The pre-test was administered before the mathematics on critical thinking ability and used to classify students into low, medium, and high ability levels, used to form groups for learning activities. The test was administered before and after the learning activities in the experimental and control groups. The test consisted of essay questions covering various aspects of critical thinking ability in mathematics. This study had independent and dependent variables. The independent variable entailed using either the inquiry-based online learning model with metacognitive strategy or the problem-based learning. Critical thinking ability in mathematics was the dependent variable. The data were analyzed using the Statistical Package for Social Science (SPSS) version 16.

3. RESULT AND DISCUSSION

a. Improvement of Mathematics Critical Thinking Based on Learning Models)

The N-gain data classifies the increase in mathematics critical thinking ability. The average N-gain of the experimental and control classes is shown in Table 3.

Table 3. Average Score of N-gain Mathematics Critical Thinking

Class	Average N-Gain Score	Category
Experiment	0,82	High
Control	0,31	Medium

The average improvement of the experimental class, comprising mathematical students as prospective teachers who received inquiry-based online learning with metacognitive strategy, is in the high category, while the control class is in the medium. This indicates that the improvement of critical thinking ability in the experimental class is higher than in the control. It also shows that the inquiry-based online learning model with metacognitive strategy has a more positive impact on improving critical thinking ability in mathematics than the problem-based online learning model.

Table 4 shows a correlation between improvement in critical thinking ability and an increase in the average N-gain for all critical thinking indicators. In other words, the data suggests that as critical thinking ability improves, the N-gain values for all critical thinking indicators tend to increase.

Table 4. Average N-gain Score Based on Mathematics Critical Thinking Ability Indicators

Class	Average N-gain Mathematics Critical Thinking Ability			
	Proof	Generalization	Alternative Answers	Problem Solution
Experiment	0.75	0.82	0,74	0.89
Control	0.21	0.36	0.22	0.27

The results in Table 4 suggested that the average N-gain of critical thinking ability for the experimental group was higher than the control. This indicated that mathematics students who received inquiry-based online learning exhibited more significant improvement in critical thinking ability than those who received problem-based online learning. Overall, these findings suggested that the inquiry-based online learning model might be more effective in enhancing critical thinking ability in mathematics students.

Inferential testing was conducted to determine the significance of the differences in N-gain scores for critical thinking ability between the experimental and control groups. An independent samples t-test was performed to compare the means of the two independent samples. Prior to conducting the t-test, normality and homogeneity tests were conducted. The normality test results for both groups showed a significance value > .05, indicating that the N-gain scores for both groups were normally distributed. The homogeneity test also showed a significance value > .05, implying that the N-gain scores for both groups were homogenous. The t-test aimed to test the null hypothesis (H0) and its alternative hypothesis (H1). H0 stated that there was no significant difference in improving critical thinking ability between students who received inquiry-based online learning with metacognitive strategy and those who received problem-based online learning. On the other hand, H1 stated that there was a significant difference in the improvement of critical thinking ability between the two groups. H0 is accepted or rejected assuming the significance level is > or ⩽ .05, respectively. The results of the independent samples t-test at a significance level of 0.05 are shown in Table 5.

Table 5. Results of the Independent Samples Test N-gain on Mathematics Critical Thinking

	t-value	Sig. (2-tailed)	Conclusion
t-test for Equality of Means	16.607	0.000	H_0 Rejected

The independent sample t-test on the N-gain scores for critical thinking ability showed a Sig. (2-tailed) value of .000 < .05, indicating a significant difference between the experimental and control groups. The null hypothesis (Ho) was rejected, meaning that the increase in mathematics critical thinking ability in the experimental group differed from the control. Additionally, the Sig. (1-tailed) value was < .05, suggesting that the improvement in mathematics critical thinking ability in the experimental class was better than control. These findings demonstrated that students who received inquiry-based online learning with metacognitive strategy exhibited a more significant improvement in their critical thinking ability compared receiving problem-based online learning.

b. Improved Mathematics Critical Thinking through the Application of Students' Initial Knowledge and Learning Models

The differences in the improvement of mathematics critical thinking ability were analyzed based on the initial knowledge of the participants, which were categorized into high, medium, and low groups. The average increase in critical thinking ability for each initial knowledge group is presented in Table 6.

Table 6. Average N-gain Score Based on Initial Mathematics Knowledge

Competencies Being Assessed		N-gain of Mathematics Critical Thinking		
Learning Model		Experimental Group	Control Group	Difference
Initial Mathematics Knowledge Category	High	0.93	0.32	0.61
	Middle	0.82	0.31	0.50
	Low	0.69	0.29	0.40

Table 6 provides evidence that critical thinking ability of the experimental class improved more than the control across all three initial knowledge categories, namely high, medium, and low. Specifically, the differences in improvement were 0.61, 0.50, and 0.40, respectively. Consequently, students who received inquiry-based online learning with metacognitive strategy showed more significant improvement compared to those who received problem-based online learning, regardless of all initial knowledge categories.

This study also examined the difference in the average improvement of mathematics critical thinking ability within the inquiry-based online learning class that used metacognitive strategy based on initial knowledge categories. The results showed that the high group had a greater average N-gain value than the medium and low groups, with a difference of 0.11. Meanwhile, the high group had a greater average N-gain than the low group, with a difference of 0.24. The medium group had a greater average N-gain compared to the low group, with a difference of 0.13. This suggested that the improvement in mathematics critical thinking ability of the high group was higher than the medium and low groups, while the medium one showed a more significant improvement than the low group.

The improvement in mathematics critical thinking ability in the class using problem-based online learning was also found to differ based on initial knowledge categories. The average N-gain of the high group differed by 0.01 from the medium group and 0.03 from the low one. Meanwhile, the medium and low groups differed by 0.02. These results suggested a relationship between initial knowledge and improving mathematics critical thinking ability.

An independent sample t-test was conducted to determine the significance of the difference in improving mathematics critical thinking ability based on initial knowledge, with normality and homogeneity prerequisite tests performed before the independent sample t-test. The N-gain scores for all initial knowledge groups were found to be normally distributed and homogenous, satisfying the criteria for the t-test. The hypothesis tested was H_o, to ascertain whether there is a difference in the improvement of critical thinking ability between students receiving inquiry-based online learning with metacognitive strategy and those acquiring problem-based online learning based on initial knowledge, while H_1 is the opposite. The results of the independent sample t-test are shown in Table 7.

Table 7. Results of Independent Sample t-test N-Gain Based on Initial Mathematics Knowledge

Learning Model	Initial Math Knowledge	t-value	Sig.	Conclusion
Experimental Group >< Control Group	High >< High	10.143	.000	H_0 Rejected
	High >< Middle	16.739	.000	H_0 Rejected
	High >< Low	18.300	.000	H_0 Rejected
	Middle >< High	9.850	.000	H_0 Rejected
	Middle >< Middle	13.110	.000	H_0 Rejected
	Middle >< Low	14.745	.000	H_0 Rejected
	Low >< High	5.043	.000	H_0 Rejected
	Low >< Medium	6.843	.000	H_0 Rejected
	Low >< Low	8.033	.000	H_0 Rejected

The results from all three initial knowledge categories in both the experimental and control groups exhibited a significant value of .000 < .05. This suggested that there was a difference in the enhancement of critical thinking ability among students receiving the inquiry-based online learning model with metacognitive strategy and those acquiring the problem-based online learning model in respect to their initial knowledge.

Furthermore, the interaction of learning and initial knowledge in enhancing mathematics critical thinking ability was also tested inferentially using a two-way ANOVA test. Prior to this test, normality and homogeneity tests were performed, and the N-gain scores were found to be normally and homogeneously distributed in each category. The hypothesis tested was H_0, depicting no interaction between learning and initial mathematics ability in improving mathematics critical thinking ability. H_1 shows an interaction between learning and initial mathematics ability in improving mathematics critical thinking ability. The results of the two-way ANOVA test are shown in Table 8.

Table 8. Results of the Two-Way Anova Test N-Gain Score

Learning Model	Mean Square	R squared	Sig.	Conclusion
Experimental Group >< Control Group	.042	.629	.030	H_0 Rejected

The results of the two-way ANOVA test indicated that the Sig. value (2-tailed) is .030 < .05, indicating the presence of an interaction. As a result, the null hypothesis H0 was rejected, signifying an interaction between learning and initial mathematics ability in enhancing critical thinking. Therefore, it could be concluded that both learning and initial mathematics ability had an impact on mathematics critical thinking. The R-squared value of .629 or 62.9% denoted the degree of influence conferred by the learning model and initial knowledge.

This study found that incorporating metacognitive strategy into inquiry-based online learning could improve mathematics critical thinking ability more than problem-based online learning. This was demonstrated by the experimental class's high improvement category, while the control tended to be moderate to low. The hypothesis test results also supported the idea that students receiving inquiry-based online learning with metacognitive strategy had better critical thinking ability than acquiring problem-based online learning. These results were consistent with Fuad (2017) and Prayogi et al. (2018) that inquiry could improve critical thinking, logical reasoning, and problem-solving ability. Metacognitive strategy was also inseparable from the inquiry process because it could monitor and regulate one's thinking based on the difference between knowledge and cognitive regulation (Schraw et al., 2012).

Inquiry-based online learning with metacognitive strategy started by introducing the topic through activities such as watching videos, connecting prior knowledge with new concepts, identifying challenges to be tackled, and taking notes on observations and comprehension. The exploration phase, the core of this approach for developing critical thinking in mathematics, involved students generating multiple ideas, conducting investigations, exploring online resources, verifying information accuracy, as well as generating and recording new ideas and findings. Furthermore, in the online experiment section, students learnt in groups, tried to share, considered and selected ideas, generated alternative problem-solving strategy, made plans including problem-solving strategy, tested hypotheses, and took notes. In the online data interpretation phase, they analyzed data, solved problems, created presentation materials, and drew generalizations. Finally, students drew conclusions, compared results, and took notes on their findings. This method fostered students' engagement, enhanced critical thinking ability, and promoted active learning.

Inquiry-based online learning with a metacognitive strategy entails a sequence of activities that require students to investigate and search for information related to the material being studied (Seranica et al., 2018). This approach emphasizes the discovery process, which can promote students' engagement and develop critical thinking ability (Pedaste et al., 2015; Seranica et al., 2018). Students are expected to actively search, investigate, construct, discover, and collaborate on the concepts learned, stimulating their critical thinking ability in mathematics to achieve these goals (Nurhayati et al., 2019). Additionally, this approach fosters enthusiasm and motivation among students to recall, recognize, and connect prior and new knowledge (Sundari & Indrayani, 2020).

This study utilizes flexible online learning and e-module technology to implement inquiry-based online learning with metacognitive strategy. E-module technology enables the integration of various media types, making the learning experience more dynamic, effective, and enjoyable. According to Irwansyah et al. (2017), Istuningsih et al. (2018), and Seruni et al. (2020), this approach stimulates learning interest, motivation, and activity. Furthermore, cyber technology enables broader investigation, providing greater opportunities for building and discovering knowledge independently. This approach promotes activity in learning and enhances critical thinking ability (Seranica et al., 2018).

4. CONCLUSION

The process of improving the mathematics critical thinking ability in students receiving inquiry-based online learning with metacognitive strategy differs from those participating in the problem-based process. Students receiving inquiry-based online learning with metacognitive strategy experience greater improvement in their mathematics critical thinking ability than those obtaining online learning. Differences also occur in the improvement of their mathematics critical thinking ability based on initial mathematics knowledge. Additionally, there is an interaction between the learning model used and initial knowledge. The improvement of critical thinking ability increases with initial knowledge in both models, but students receiving inquiry-based online learning with metacognitive strategy exhibit greater improvement.

The findings of this study have significant implications for enhancing students' mathematics critical thinking ability through an innovative learning approach known as inquiry-based online learning with metacognitive strategy. This model fosters a supportive pedagogical environment with careful planning and promotes motivation, interaction, and understanding in learning. Additionally, the model exemplifies the synergy between learning and technological development, providing a tangible illustration of how education can adapt to the changing times and fluctuations in learning conditions.

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