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Research Paper

Effectiveness of Smartphone-Based GeoGebra Integrated with Problem-Based Learning in Enhancing Students' Critical Thinking on Function Transformations

Farah Diba[1], **Irvan**[2]

[1,2]Postgraduate School of Mathematics Education, Universitas Muhammadiyah Sumatera Utara, Medan, Indonesia

Corresponding Author: Irvan

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ABSTRACT

Students' mathematical critical thinking skills, particularly regarding function transformations, are currently below expected standards, largely due to the abstract nature of the topic, which requires students to connect algebraic expressions with graphical representations. In order to improve these abilities, this study examines how effectively smartphone-based GeoGebra may be incorporated into a Problem-Based Learning (PBL) framework. A validated critical thinking test that aligned with Facione's paradigm was used to collect data using a quantitative one-group pretest–posttest design with 46 twelfth-grade students. The results showed an adequate reliability ($\alpha = 0.78$). Normalized gain (N-Gain), paired sample t-tests, and descriptive statistics were used in the analysis. The results showed that critical thinking abilities had significantly improved, with mean scores increasing from 49.46 in the pre-test to 79.37 in the post-test ($p < 0.001$). The N-Gain value of 0.59 indicates a moderate degree of progress. GeoGebra's dynamic visualization features, which let students view graphical changes in real time, and the PBL methodology, which promotes active inquiry and reflective thinking, are credited with this improvement. In conclusion, incorporating smartphone-based GeoGebra within a PBL environment effectively develops students' critical thinking skills in function transformation, underscoring the value of merging pedagogical strategies with interactive digital tools for deeper mathematical comprehension.

Keywords: GeoGebra; Mobile Learning; Function Transformation; Critical Thinking; Problem-Based Learning; Mathematical Visualization.

INTRODUCTION

The development of higher-order thinking, especially critical thinking, has gradually taken precedence over procedural fluency in mathematics education in recent years. This change is more than just rhetorical. It reflects a more general expectation that rather than only using formulas in normal ways, students should be able to interpret, analyze, and evaluate mathematical concepts (Facione, 2015). In many respects, mathematics is now seen as a tool for reasoning and making decisions, strongly related to the skills needed in the twenty-first century, such as digital literacy, problem solving, and self-directed learning. However, this is not often the case in classroom life. Many students still rely on methods they have committed to memory, frequently without fully comprehending the underlying ideas (Aizikovitsh-Udi & Cheng, 2015). This reliance becomes particularly problematic when students encounter unfamiliar problems, where procedural recall alone is insufficient. As a result, their ability to transfer knowledge across contexts remains limited, and their reasoning tends to stay at a superficial level.

This issue becomes even more evident in topics that require strong conceptual visualization, such as function transformations. Understanding how algebraic changes affect graphical representations is not always intuitive. A slight modification in an equation should correspond to a predictable shift, reflection, or dilation of a graph, yet many students struggle to make this connection. Traditional instructional approaches, which often rely on static representations, tend to reinforce procedural knowledge while leaving conceptual understanding underdeveloped (Daher & Anabousy, 2015). Without dynamic support, students are left to imagine transformations that are inherently visual and spatial in nature.

Dynamic visualization technologies are a viable option in this setting. In particular, GeoGebra is well known for its real-time linking of symbolic and graphical representations. Abstract concepts become more approachable and tangible when students can modify parameters and see the changes in graphs right away (Paraskevopoulos, 2022). Several empirical studies (Izdahara & Irvan, 2025; Arbain & Shukor, 2015) have demonstrated that GeoGebra enhances students' conceptual understanding, engagement, and overall learning outcomes. However, the way technology is incorporated into instruction directly affects how effective it is. It has been shown that problem-based learning (PBL) fosters critical thinking by engaging students in relevant problem-solving procedures. Students are encouraged to develop hypotheses, test their reasoning, and assess solutions through phases like problem orientation, investigation, and reflection (Subaini et al., 2022; Mushlihuddin et al., 2020). Through inquiry and discussion, students actively create their understanding rather than passively absorbing it.

Even though GeoGebra and problem-based learning have been shown to be beneficial, most research to far has focused on these methods separately. Research that explicitly integrates GeoGebra into a framework for problem-based learning is currently lacking, particularly when the objective is to assist students in developing their critical thinking skills with regard to function transformation. This discrepancy is even more apparent in smartphone-based learning environments, where the adaptability and accessibility of mobile devices could further enhance student engagement and exploration. Furthermore, there is also a scarcity of empirical data from particular educational environments, such Indonesia's private Islamic secondary schools, where access to interactive learning resources may be uneven and teaching methods are still mostly traditional. Preliminary findings show that students at Khairul Imam Integrated Islamic High School in Medan struggle to connect algebraic manipulation with pictorial interpretation. The lack of dynamic and interactive learning resources is the main reason of this.

This study proposes an integrated approach that combines the Problem-Based Learning paradigm with smartphone-based GeoGebra to enhance students' function transformation critical thinking skills in order to bridge these gaps. This study shows GeoGebra as a crucial component of a problem-based learning environment that fosters inquiry, reasoning, and reflection, in contrast to previous research that tackles pedagogy and technology separately. Thus, the goal of this study is to determine how successfully integrating smartphone-based GeoGebra into a framework for problem-based learning might improve students' critical thinking skills. In particular, it looks into how dynamic visualization improves students' engagement and reasoning processes, measures the pace of change using pretest and posttest comparisons, and evaluates learning efficacy using N-Gain analysis.

The novelty of this study lies in three main aspects. First, it integrates GeoGebra and Problem-Based Learning within a single instructional framework specifically designed to target critical thinking in function transformation. Second, it utilizes smartphone-based mobile learning, allowing students to engage with mathematical exploration beyond the constraints of traditional classroom settings. Third, it provides empirical evidence from an underrepresented educational context, contributing to a more nuanced understanding of how technology-enhanced pedagogy operates in real classroom environments. Finally, this study anticipates both theoretical and practical contributions. Theoretically, it supports the claim that meaningful pedagogical and technological integration is necessary for the development of critical thinking. From a practical standpoint, it provides guidance for teachers who want to create more engaging and conceptually focused math lessons in the digital age.

RESEARCH METHODS

This study examined how students' critical thinking skills evolved following an instructional intervention using a one-group pretest–posttest design and a quantitative technique. The design was selected to provide preliminary empirical data regarding GeoGebra's potential integration into a Problem-Based Learning (PBL) framework in an actual classroom. Although the absence of a control group limits causal generalization, the methodology is nevertheless appropriate for exploratory research in technology-enhanced learning. Concurrent implementation of the intervention in two parallel classrooms strengthened the consistency of the outcomes and allowed for treatment replication. In the O_2–X–O_2 structure of the research design, O_2 represents the pre-test, X represents the GeoGebra-assisted PBL intervention given via cellphones, and O_2 represents the post-test.

The study was conducted at Khairul Imam Integrated Islamic High School in Medan, Indonesia, and 46 twelfth-grade students were selected using purposeful sampling. The participants, who were divided into two sessions of 23 students each, were between the ages of 17 and 18. Since all participants had access to personal smartphones that could run the GeoGebra application, mobile learning was introduced without the requirement for additional institutional facilities.

Data was gathered using a 15-item Critical Thinking Test on function transformations (7 multiple-choice and 8 essay questions) with a maximum score of 100. Facione's (2015) methodology was used in the creation of the tool, which includes interpretation, analysis, inference, and assessment. While multiple-choice questions focused on assessing interpretative understanding, essay questions were designed to capture more in-depth analytical and evaluative reasoning. After being examined by experts before being put into use, the instrument demonstrated sufficient reliability with a Cronbach's Alpha coefficient of 0.78.

GeoGebra was used as a dynamic visualization tool during the four sessions of the educational intervention, which followed the phases of the Problem-Based Learning model. Students were first presented with contextual challenges that required them to forecast changes in function graphical representations. After that, students collaborated in small groups to develop solutions. GeoGebra's dynamic features, including sliders, were used to alter function parameters during the study phase, enabling real-time transformation visualization. Following the presentation and group discussion of the exploration's findings, conceptual knowledge was strengthened through guided contemplation. Rotation and dilation, reflection across axes, and translation of linear and quadratic functions were all covered in the course material.

Students' personal smartphones were used as the main exploring tool in the implementation of mobile learning. This method gave students flexible access to GeoGebra outside of the classroom, enabling them to independently review and expand their knowledge. Additionally, the usage of personal devices promoted a more accessible learning environment and decreased reliance on computer lab facilities.

Data analysis employed both descriptive and inferential statistics. Descriptive statistics like mean and standard deviation were used to summarize the students' performance. To ascertain whether the data distribution was normal, the Shapiro-Wilk test was employed. Because the data were normally distributed ($p > 0.05$), a paired sample t-test was employed to assess the significance of changes between pre-test and post-test scores at a significance level of 0.05. To determine the degree of improvement, normalized gain (N-Gain) was calculated in compliance with Hake (1998), and the results were categorized into high, medium, and low levels. In order to provide a broader overview of the intervention's practical impact, Cohen's d was also employed to compute effect size. A number of steps were implemented to reduce possible risks to internal validity. To lessen the impacts of maturation, the intervention was carried out within a set period of time, and both classes used the same teaching strategies. To reduce testing bias, the pre-test and post-test were conducted using the same instrument under close supervision.

Additionally, ethical issues were discussed. The management of the school approved the study, and participation was entirely voluntary. After being informed of the goals and methods of the study, all students gave their informed consent, and their data was kept private at all times.

RESULT AND DISCUSSION

The findings of the investigation are based on the students' pre-test and post-test scores, which were used to assess their critical thinking skills in function transformation. Using GeoGebra-assisted problem-based learning, a descriptive study reveals a notable improvement.

Table 1. Descriptive Statistics of Critical Thinking Scores

Statistics	Pre-Test	Post-Test
Maximum	60	95
Minimum	40	70
Mean	49.46	79.37
Standard Deviation	6.07	7.16

The primary average score of 49.46 indicates that students' ability to think critically about function transformation was still somewhat low. They frequently appeared to rely more on formal procedures than on more in-depth analysis. The average increased by 29.91 points to 79.37 following the intervention. That is a significant leap. The fact that the minimum post-test score was higher than the maximum pre-test score is even more noteworthy. This suggests, at least in theory, that the group as a whole improved rather than that gains were concentrated in a small number of students.

A Shapiro-Wilk normality test was performed to see whether the data satisfied the presumptions needed for parametric testing before proceeding with the investigation. Although it is occasionally disregarded, this stage is crucial because it ensures that the statistical findings that follow are well-founded. Table 2 displays the test's results.

Tabel 2. Shapiro–Wilk Normality Test Results

Data	Statistik W	Sig. (p)	Decision
Pre-Test	0.972	0.118	Normal
Post-Test	0.978	0.214	Normal

When the significance value was higher than 0.05, the parametric testing assumptions were met and the data were normally distributed. A paired sample t-test was then run. With a p-value of less than 0.001, the results showed a statistically significant difference between the pre-test and post-test scores. In other words, the shift is unlikely to be the product of chance. This suggests that the GeoGebra-assisted Problem-Based Learning approach improved students' critical thinking skills. However, even while the rise in mean scores is straightforward, it does not adequately convey the significance of the change. When starting abilities differ or the greatest attainable score is not taken into account, raw discrepancies can occasionally be deceptive. Normalized Gain (N-Gain), which provides a fairer way to analyze improvement by comparing actual gains to the maximum feasible gains, was therefore used to broaden the research. Table 3 displays the findings of this investigation.

Tabel 3. N-Gain Calculation Results

Component	Value
Mean pre-test	49.46
Post-Test Mean	79.37
Maximum Score	100
N-Gain	0.59
Category	Medium

As seen in Table 3, the N-Gain value of 0.59 falls within the moderate range. This implies that the intervention enhanced students' critical thinking skills, even though the degree of change was not high enough. This outcome is noteworthy, but it also raises the important question of why the improvement was only moderate.

The intervention's comparatively brief length is one reasonable explanation. Critical thinking takes time to develop and necessitates consistent exposure to mentally taxing activities. Students might not have had enough time to completely absorb higher-order thinking processes with just four educational sessions. Additionally, how quickly students adjusted to a more inquiry-oriented approach may have been influenced by their earlier learning experiences, which frequently place an emphasis on procedural practice.

This improvement indicates to be made possible in large part by GeoGebra's dynamic visualization. GeoGebra lessens the abstraction usually involved with function transformations by letting students work with function parameters and see changes in graphical representations in real time. According to cognitive load theory, students can concentrate more on reasoning and interpretation when symbolic and pictorial representations are integrated to lessen needless cognitive stress.

By building instruction around inquiry and problem-solving, the Problem-Based Learning paradigm also fosters the growth of critical thinking. Students are urged to develop theories, test them, and assess the viability of their answers. Constructivist learning, in which information is actively created through interaction and reflection, is reflected in this process. Observations in the classroom show that students grew more sensitive to conceptual understanding rather than just procedural accuracy, more open to share their ideas, and more involved in debates.

The areas of interpretation and analysis appear to have seen the most gains, according to a deeper look at the students' answers. Students were more confident in their abilities to explain the relationships between changes in function parameters and graphical transformations. Improvements in inference and evaluation were also observed, although to a lesser extent. This pattern aligns with previous studies suggesting that visualization tools are particularly effective in supporting foundational aspects of critical thinking before more advanced evaluative skills fully develop.

These results are in line with past studies. While Paraskevopoulos (2022) emphasizes GeoGebra's significance in bridging symbolic and graphical representations, Dahal et al. (2023) stress the program's efficiency in depicting geometric transformations. According to Zulnaidi and Zakaria (2012) and Ridha et al. (2020), GeoGebra improves conceptual and procedural knowledge. From a pedagogical standpoint, the results of Subaini et al. (2022) and Irvan and Muslihuddin (2020), which show how problem-based learning enhances mathematical critical thinking, are supported by the observed efficacy of the approach.

The integration of mobile learning further strengthens these outcomes. By utilizing personal smartphones, students gain flexible access to learning tools, allowing them to explore concepts beyond classroom constraints. This flexibility appears to enhance engagement and promote independent learning, consistent with findings by Crompton and Burke (2018). An important aspect of the learning process emerges when students' predictions do not align with the graphical output displayed in GeoGebra. These moments create cognitive conflict, prompting students to reconsider their assumptions and refine their understanding. Such experiences are widely recognized as critical for meaningful learning, as they encourage deeper reflection and conceptual restructuring.

There are a few things to be considerate of in spite of these positive outcomes. The absence of a control group limits the ability to attribute improvements only to the intervention, and the moderate N-Gain value indicates that more optimization is needed. Future research should extend the intervention, employ more precise experimental designs, and look at different mathematical topics in order to evaluate the consistency of these findings. Overall, the results suggest that integrating GeoGebra, problem-based learning, and mobile learning can provide a learning environment that improves students' performance and encourages the development of critical thinking abilities. In this case, GeoGebra provides both a visual aid and a cognitive tool that fosters inquiry, reasoning, and conceptual understanding.

CONCLUSION

This study indicates that students' critical thinking skills regarding function transformation are greatly improved when smartphone-based GeoGebra is integrated into a framework for problem-based learning. The significant change in pre-test to post-test scores and the moderate N-Gain highlight how interactive technology and inquiry-based education can enhance learning outcomes and the quality of students' reasoning processes.

A key finding lies in the role of dynamic visualization. By enabling students to observe real-time changes in graphical representations, GeoGebra helps bridge the gap between symbolic manipulation and geometric understanding. This process appears to reduce the abstractness of function transformations and supports students in constructing more coherent conceptual frameworks. When embedded within a Problem-Based Learning environment, this technological support becomes more than a visual aid. It functions as a cognitive tool that encourages exploration, hypothesis testing, and reflective thinking.

From a theoretical standpoint, the results support the idea that pedagogical design and technological affordances must be meaningfully aligned for the development of critical thinking in mathematics. The findings are consistent with cognitive load theory, which holds that well-designed representations might enable more effective processing of complicated information, and constructivist viewpoints, which hold that learning arises through active involvement. The study emphasizes the potential of using students' personal smartphones as easily available educational resources. These technologies can be repositioned as platforms for meaningful mathematical research instead of being viewed as diversions, which would lessen reliance on specialist infrastructure like computer labs. This is especially important for schools who don't have much access to technology.

However, several limitations present in the study must be acknowledged. Firstly, the moderate N-Gain result indicates that the short duration of the intervention may have restricted the enhancement of higher-level critical thinking skills. Additionally, the absence of a control group constrains the ability to make definitive causal claims regarding the outcomes. Hence, it is recommended that future research employs more rigorous experimental designs, extends the duration of the implementation, and explores the applicability of this strategy across diverse mathematical subjects and educational contexts. Overall, the study provides clear evidence that integrating GeoGebra-based mobile learning with problem-based learning constitutes a viable and pedagogically relevant method to address the requirements of 21st-century mathematics education. Importantly, it suggests that technology, when thoughtfully incorporated into educational design, can significantly foster deeper and more reflective mathematical thinking.

Declaration by Authors

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