

Effectiveness of Problem-Based Learning with GeoGebra on Grade VII Students' Learning Outcomes in Polyhedra at SMP Negeri 1 Mangarabombang

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ABSTRACT

This study aims to assess the effectiveness of the Problem-Based Learning (PBL) model supported by GeoGebra on students' mathematics attainment in the topic of polyhedra (flat-sided solid figures) among seventh-grade students at SMPN 1 Mangarabombang. This study utilized quasi-experimental study used a nonequivalent control group design with a quantitative approach. The population consisted of all seventh-grade students from ten classes, and cluster random sampling was used to select the sample. As a result, the experimental group (PBL with GeoGebra) was VII Sultan Hasanuddin and class the control group (PBL without GeoGebra) was VII Andi Mappanyukki. Test and observation sheet are used to collect the data, and analyzed using descriptive and inferential statistical methods. The results revealed that the average post-test score in the experimental group reached 83.19, with 100% mastery (31 out of 31 students scoring ≥ 75), and a normalized gain score reached 0.77 (high category). In contrast, the average post-test score in the control group reached 78.29, with 93.55% mastery (29 out of 31 students scoring ≥ 75), and a gain score of 0.69 (moderate category). From the independent sample t-test revealed there is a statistically significant difference between the two groups. These findings suggest that incorporating GeoGebra into the PBL model leads to better mathematics learning outcomes compared to PBL without GeoGebra, as evidenced by higher post-test scores, greater mastery rates, and more substantial learning gains. This research contributes to mathematics education by highlighting the potential of technology-supported PBL to foster deeper conceptual understanding and problem-solving skills, and it may serve as a reference for developing more innovative and effective teaching strategies in the future.

KEYWORDS

Problem-Based Learning, Geogebra, Learning Outcomes, Three-Dimensional Shapes with Flat Surfaces

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A. Introduction

In Indonesia, mathematics is a core subject taught across all levels of education. Its primary objectives are to enable students to comprehend mathematical concepts, relate these concepts to real-world situations, and apply problem-solving algorithms efficiently in daily life (Taufik, 2024). However, achieving these objectives remains a serious challenge for the national education system. Data from the 2022 Programme for International Student Assessment (PISA) indicate that Indonesia came in 69th out of 81 participating countries, having an average mathematics score of 366, substantially lower than the OECD average of 475 (OECD, 2024). This represents a decline from the country's performance in the 2018 PISA cycle, indicating a worrying trend in students' mathematical proficiency. A similar result was found in the 2015 Trends in International Mathematics and Science Study TIMSS, which reported that Indonesian junior high school students ranked 45th out of 50 participating countries in mathematics achievement (Mullis et al., 2016). According to these findings,

the mathematics performance of Indonesian students remains considerably below international standards and point to an urgent need for improvements in instructional strategies and learning tools.

The weak performance of Indonesian students in mathematics is caused by several factors, one of which is the quality of mathematics education (Satria et al., 2025). In many classrooms, mathematics learning still feels less meaningful. Teaching often focuses only on students' ability to memorize information, where they are expected to recall and collect data without truly understanding the meaning or connecting it to real-life situations (Sagita, 2023). Additionally, mathematics is often perceived by students as a challenging subject due to its abstract nature, particularly in topics such as geometry and solid figures. Many elementary and junior high school students in Indonesia struggle to understand fundamental geometry topics, like shapes and planes (Naufal et al., 2025). Meanwhile, understanding geometric concepts is one of the important competencies that junior high school students are expected to master it, as outlined in the national curriculum. Geometry is not only foundational for more advanced mathematical topics, but also plays an important role in developing students' analytical, spatial and logical thinking skills (Hamda, 2024).

Mathematics learning issues like these are widespread across many regions in Indonesia, especially at the secondary school level (Putri et al., 2025). One example can be found at SMPN 1 Mangarabombang. Based on the researcher's observations, several challenges are still present in the mathematics classroom at this school. Many students talking during math lessons, some students finding the classroom atmosphere boring, and students often appear passive during math lessons, resulting in one-way communication between teacher and students. Besides that, classroom activities is limited to the use of textbooks and printed modules, which makes learning feel monotonous and causing students to feel bored and struggle to understand the concepts being taught, especially in geometry. Incorporating technology into the educational process is another crucial problem. Students are deprived of more dynamic, visual, and engaging mathematics education due to a technology gap caused by the lack of digital tools or interactive media. Furthermore, there are numerous other learning issues contributing to the low mathematics achievement of students at this school.

The low academic achievement of students is reflected in the learning outcomes at SMPN 1 Mangarabombang. Learning outcomes refer to the specific competencies or abilities that students acquire after going through the teaching and learning process, including cognitive, psychomotor, and affective skills (Nababan et al., 2024). Based on examination data from students in their first year of junior high school at SMPN 1 Mangarabombang in topic of polyhedra during the 2023/2024 academic year, it was found that in Class VII D, only 14 out of 31 students (45.16%) met the Minimum Competency Standard (KKM), with an average score of 79. Similarly, in Class VII G, only 13 out of 29 students (44.82%) achieved the KKM, despite the same average score of 79. Given that the school's KKM is set at 79, these results indicate that the majority of students have not yet met the expected minimum standard, suggesting persistent challenges in the learning mathematics process at the school.

To overcome these problems, it is important to use a learning model that helps students become more active during lessons. One student-centered model that can help increase student engagement and improve students learning outcomes is the Problem-Based Learning (PBL) model (Widyasari et al., 2023). PBL is an approach where learning begins with a problem, followed by asking questions, guiding students through investigation, and encouraging discussions among them (Sundayana & Maryati, 2024). The syntax of the PBL model includes the preliminary phase (initial observation), problem formulation phase, alternative strategy formulation phase, data collection phase (applying strategies), discussion phase, conclusion and evaluation phase (Syamsidah & Suryani, 2018). These phases can help students develop critical thinking skills, especially when solving geometry problems related to three-dimensional shapes. With this approach, students are anticipated to better understand the concepts and improve their learning outcomes (Usman et al., 2024).

In addition to using an effective learning model, choosing the right learning media is also important to help create an active classroom environment (Nurhayati et al., 2024). One of the learning tools commonly used in mathematics lessons is GeoGebra. GeoGebra is a modern, computer-based learning media designed for teaching mathematics, especially in topics like geometry and algebra (Syam et al., 2023). GeoGebra, with its dynamic and interactive interface, is well-suited for integration with various pedagogical approaches and educational theories, such as spatial learning, constructivism, cooperative learning, and collaborative learning. It enables students to actively explore and manipulate mathematical concepts, which fosters deeper understanding, increases engagement, and facilitates group activities through tools like GeoGebra Classroom and other collaborative features (Lotey et al., 2025). Studies on the use of instructional technology in mathematics education have shown that incorporating GeoGebra into classroom instruction enhances students' visualization skills and conceptual understanding, increases their interest in learning, and ultimately improves their academic performance (Owusu et al., 2023; Uwurukundo et al., 2024).

Several researchers have studied the effectiveness of PBL, the use of GeoGebra, and the combination of both, as seen in studies by Sagita (2023), Ribunu (2023), Purnama (2024), and Nirma Potabuga et al. (2021). These studies found that the PBL model has a significant effect on students' mathematics learning outcomes (Sagita, 2023). Meanwhile, students taught using GeoGebra showed better performance compared to those who learned through PowerPoint, particularly in topics like cubes and rectangular prisms (Ribunu et al., 2023). Similarly, students who used GeoGebra in class showed better learning results compared to those who did not (Purnama et al., 2024). Furthermore, the combination of PBL and GeoGebra has shown a positive impact on student achievement. Students who use the PBL model supported by GeoGebra had better results than those who were taught through conventional methods (Potabuga et al., 2022). These findings highlight the strong potential of the PBL model combined with GeoGebra in boosting students' learning outcomes.

Based on the aforementioned, it can be determined that the poor mathematics performance among students at SMPN 1 Mangarabombang stems primarily from the limited diversity in instructional approaches employed and the insufficient integration of interactive educational technologies. In particular, diagnostic data indicate that many students continue to struggle with the topic of polyhedra, as a considerable proportion have not yet achieved the Minimum Competency Standard (KKM). These observations provided the foundation for conducting research to address these pedagogical shortcomings. Therefore, this study aims to evaluate the effectiveness of implementing the Problem-Based Learning (PBL) model enhanced with GeoGebra software in improving mathematics learning outcomes for seventh-grade students studying polyhedra at SMP Negeri 1 Mangarabombang.

B. Methodology

This research was designed to examine the effectiveness of the Problem-Based Learning (PBL) Model enhanced with GeoGebra software in improving mathematics achievement among seventh-grade students studying polyhedra at SMPN 1 Mangarabombang. The study was conducted in February 2025 at the aforementioned school.

The research employed a quantitative approach using an experimental design. Specifically, a quasi-experimental framework with a non-equivalent control group design was implemented. The study involved two distinct groups: an experimental group and a control group. To assess learning achievement, participants took pre-tests prior to instruction and post-tests following the intervention. The experimental group received instruction through the PBL model supplemented with GeoGebra technology, while the control group was taught using the same PBL approach but without the GeoGebra component.

The study population comprised 321 seventh-grade students across 10 different classes. Sample selection was carried out using cluster random sampling methodology. Class VII Sultan

Hasanuddin (31 students) was designated as the experimental group, and Class VII Andi Mappanyukki (31 students) served as the control group, resulting in a total sample size of 62 participants.

Research instruments included instructional materials (teaching modules and student activity sheets) and data collection instruments (observation forms for monitoring lesson implementation and achievement tests). Data gathering was accomplished through observational techniques and testing procedures. To ensure quality, the instruments were reviewed by two mathematics education experts who validated the relevance, clarity, and alignment of the items with the learning objectives. In addition, a pilot test was conducted on a small group of students outside the sample to confirm that the items were understandable, feasible, and consistent. Statistical analysis involved conducting an independent samples t-test, with prerequisite tests for normality and homogeneity performed beforehand. The effectiveness of the intervention was assessed using normalized gain (N-Gain) analysis with categories from "not effective" (<40%) to "effective" (>76%), following Hake's (1999) classification, which remains valid and is frequently used in recent studies (Nugroho et al., 2025)

Table 1. Interpretation Categories of N-Gain Effectiveness (Hake, 1999)

Percentage (%)	Category
< 40	Not effective
40–55	Less effective
56 – 75	Quite effective
> 76	Effective

C. Results and Discussion

This investigation sought to determine the effectiveness of the Problem-Based Learning model enhanced with GeoGebra compared to the standard PBL approach without technological support in enhancing students' mathematics performance. The research was implemented across six instructional sessions. The initial session involved administering pre-tests to evaluate students' baseline knowledge. Sessions two through five were dedicated to delivering the respective instructional treatments to each group. The final session concluded with post-test administration to measure learning achievements following the interventions. The instructional delivery proceeded according to the established protocols, with implementation analysis revealing an average score of 3.80 for both experimental and control groups, indicating that the learning process was executed at a "very well implemented" level.

Mathematics Achievement in the Experimental Group Using PBL with GeoGebra

The descriptive analysis of pre-test and post-test data from Class VII Sultan Hasanuddin revealed significant improvements in student performance on three-dimensional geometric concepts displayed in Table 2.

Table 2. Descriptive Statistics for Experimental Class Learning Outcomes

Statistic	Statistical Values of Learning Outcomes in the Experimental Class	
	Pretest	Posttest
Mean	28.06	83.19
Median	28.00	83.00
Std. Deviation	9.366	7.765
Minimum	9	70
Maximum	43	98
Range	34	28

Prior to the GeoGebra-enhanced PBL intervention, students achieved an average score of 28.06. Following the treatment implementation, this average increased substantially to 83.19, demonstrating considerable academic growth.

Table 3. Statistics on N-Gain Learning Outcomes of Students in the Experimental Class

Statistic	Value
Mean	0.7706
Median	0.7571
Std. Deviation	0.9669
Minimum	0.55
Maximum	0.97
Range	0.42

The learning improvement was further quantified through normalized gain analysis (see Tabel 3), which yielded an average N-Gain score of 0.77 for the experimental group. This score falls within the high effectiveness category according to established criteria. When examining individual student progress, 23 students demonstrated high-level improvement while 8 students showed moderate advancement. No students exhibited low-level improvement, indicating the intervention's consistent positive impact across all participants (see Table 4).

Table 4. Classification of Learning Gain Results of Students in the Experimental Class

Gain normality value	Frequency	Percentage	Criteria
$0.7 \leq n \leq 1$	23	74,19%	High
$0.3 \leq n < 0.7$	8	25,81%	Medium
$0 \leq n < 0.3$	0	0%	Low
Mean	31	100%	

Regarding mastery achievement based on the school's Minimum Competency Standard of 66 (see Tabel 5), the results showed dramatic improvement. Initially, no students met the minimum standard during pre-testing. However, following the PBL-GeoGebra intervention, all 31 students achieved the required competency level, resulting in 100% mastery. This outcome exceeded the classical mastery criterion requiring at least 75% of students to reach minimum standards.

Tabel 5. Mastery achievement in the experimental class.

Values	Criteria	Frequency		Percentage	
		Pretest	Posttest	Pretest	Posttest
86% – 100%	Completed, needs enrichment or more challenges	0	10	0%	32%
66% – 85%	Completed, no remedial work required	0	21	0%	68%
41% – 65%	Incomplete, remedial work required in necessary areas	0	0	0%	0%
0 – 40%	Incomplete, remedial throughout	31	0	100%	0%
Total		31	31	100%	100%

Mathematics Achievement in the Control Group Using PBL

The control group, taught through the Problem-Based Learning model without GeoGebra integration, also demonstrated notable improvement. Pre-test scores averaged 28.58, which increased to 78.29 following the PBL intervention. While this represents significant growth, the magnitude was less substantial than that observed in the experimental group as shown in Table 6.

Table 6. Descriptive Statistics for Control Class Learning Outcomes

Statistic	Statistical Values of Learning Outcomes in the Control Class	
	Pretest	Posttest
Mean	28.58	78.29
Median	28.00	78.00
Std. Deviation	8.413	6.934
Minimum	11	65
Maximum	46	91
Range	35	26

The normalized gain analysis for the control group yielded an average N-Gain score of 0.69, categorized as moderate effectiveness (see Table 7 and Table 8). Individual student performance analysis revealed that 16 students achieved moderate improvement while 15 students demonstrated high-level advancement. Similar to the experimental group, no students showed low-level improvement.

Table 7. Statistics on N-Gain Learning Outcomes of Students in the Experimental Class

Statistic	N-Gain Score
Mean	0.6993
Median	0.6944
Std. Deviation	0.8168
Minimum	0.54
Maximum	0.84
Range	0.30

Table 8. Classification of Learning Gain Results of Students in the Control Class

Gain normality value	Frequency	Percentage	Criteria
$0.7 \leq n \leq 1$	15	48.39%	High
$0.3 \leq n < 0.7$	16	51.61%	Medium
$0 \leq n < 0.3$	0	0%	Low
Mean	31	100%	

Concerning mastery achievement (see Table 9), the control group showed substantial progress from the baseline where no students initially met the minimum standard. Following the PBL intervention, 29 students achieved the competency threshold, resulting in 93.55% mastery. While this exceeded the required 75% classical mastery criterion, it remained below the experimental group's achievement level.

Tabel 9. Achievement of KKTP Learning Outcomes of Students in the Control Class

Values	Criteria	Frequency		Percentage	
		Pretest	Posttest	Pretest	Posttest
86% – 100%	Completed, needs enrichment or more challenges	0	4	0%	12.90%
66% – 85%	Completed, no remedial work required	0	25	0%	80.65%
41% – 65%	Incomplete, remedial work required in necessary areas	4	2	12.9%	6.45%
0 – 40%	Incomplete, remedial throughout	27	0	87.1%	0%
Total		31	31	100%	100%

Inferential Statistical Analysis Results

The research hypothesis was evaluated through an Independent Samples t-test analysis. Prior to conducting this statistical test, the necessary assumptions of normality and homogeneity were assessed using SPSS software. The analysis utilized normalized gain scores obtained from both the experimental and control groups.

Normality testing was conducted using the Shapiro-Wilk statistical method. The analysis revealed p-values of 0.852 for the experimental group and 0.511 for the control group. Given that both values exceeded the 0.05 significance threshold, the data from each group demonstrated normal distribution patterns, thereby satisfying the prerequisites for subsequent statistical analysis.

Subsequently, a homogeneity test was conducted to evaluate whether the sample datasets exhibited equivalent variances. The homogeneity analysis of the normalized gain scores yielded a p-value of 0.305, which surpassed the established alpha level of 0.05. This result confirmed that the variances between the experimental and control groups were statistically equivalent, indicating homogeneous data characteristics.

With both fundamental assumptions successfully validated, the analysis proceeded to hypothesis testing through the Independent Samples t-test. This statistical procedure was employed to examine the mean differences in normalized gain scores between the two study groups, thereby determining whether significant differences existed in learning improvement outcomes. The statistical analysis was executed using SPSS software to ensure accuracy and reliability of results.

For hypothesis evaluation, the established decision criteria specify that when the p-value exceeds 0.05, the null hypothesis cannot be rejected and is therefore accepted. Conversely, when the p-value falls below 0.05, the null hypothesis is rejected in favor of the alternative hypothesis. Table 10 presents the comprehensive results of this hypothesis testing procedure, which examined the comparative learning outcome improvements between the experimental and control groups.

Tabel 10. Independent Sample t Test for Improvement in Students' Mathematics Learning Outcomes

		Outcomes						
<i>Levene's Test for Equality of Variances</i>				<i>t-test for Equality of Means</i>				
		F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference
Learning Outcomes	<i>Equal variances assumed</i>	1,071	0,305	3,160	60	0,002	7,13808	2,25900
	<i>Equal variances not assumed</i>			3,160	58,565	0,002	7,13808	2,25900

Referring to table 10, the results of the Independent Samples T-Test on the N-Gain scores of students' mathematics learning outcomes show a p-value of 0.002. Since the p-value < 0.05 , the null hypothesis is rejected, which means the alternative hypothesis is accepted. Therefore, it can be concluded that there is a significant difference in the improvement of mathematics learning outcomes between students who were taught using the PBL model with the help of GeoGebra and those who were taught using PBL without GeoGebra.

Discussion

In the control group, where students learned through the conventional Problem-Based Learning (PBL) model without the integration of digital tools, the post-test average reached 78.29. Out of 31 students, 29 successfully achieved mastery, producing a completion rate of 93.55%. Their normalized gain (N-Gain) stood at 0.69, which according to Hake's (1999) classification falls into the category of moderate effectiveness. These outcomes reaffirm the capacity of PBL to enhance

mathematics achievement as a standalone strategy. The findings resonate with Sagita (2023), who showed that the emphasis on student-centered inquiry and contextual problem solving in PBL fosters measurable progress in students' mathematical performance even in the absence of technological support.

A different picture emerged in the experimental group, which combined PBL with GeoGebra. Students in this group obtained a higher post-test mean of 83.19, with every participant (31 of 31) meeting the mastery benchmark. Their normalized gain was calculated at 0.77, indicating high effectiveness under Hake's (1999) criteria. Statistical testing using the Independent Samples t-test further confirmed the robustness of these results, yielding a p-value of 0.002, which demonstrates a significant difference in improvement compared to the control group. These findings strengthen earlier evidence from Hamda (2024), Ribunu et al. (2023), and Purnama et al. (2024), who documented that the use of GeoGebra promotes deeper conceptual understanding, stimulates student engagement, and enhances the visualization of abstract mathematical ideas, particularly in geometry.

The integration of GeoGebra within the Problem-Based Learning framework proved particularly effective, supporting previous research by Potabuga et al. (2022), who observed that students taught using the combined Problem-Based Learning and GeoGebra approach achieved superior learning outcomes compared to those receiving conventional instruction. The synergy between problem-based pedagogy and dynamic mathematical software appears to create an optimal learning environment that addresses both conceptual understanding and visual representation needs.

The enhanced effectiveness of the combined approach can be attributed to several factors. GeoGebra's interactive interface allows students to manipulate three-dimensional objects dynamically, providing immediate visual feedback that reinforces conceptual understanding. This capability is particularly valuable in geometry education, where spatial visualization skills are essential for comprehension. The software's capacity to present abstract mathematical concepts through concrete visual representations bridges the gap between theoretical knowledge and practical application, addressing one of the primary challenges in mathematics education identified by Lotey et al. (2025).

Furthermore, the integration of technology within the Problem-Based Learning framework supports constructivist learning principles by enabling students to actively explore mathematical relationships and test hypotheses through direct manipulation of geometric objects. This approach aligns with contemporary educational theories that emphasize active learning and student engagement as critical components of effective instruction. Research by Owusu et al. (2023) and Uwurukundo et al. (2024) has consistently demonstrated that incorporating GeoGebra into mathematics instruction enhances students' visualization skills, increases learning engagement, and ultimately improves academic performance.

The study's findings also address broader concerns about mathematics education quality in Indonesia, as highlighted by recent international assessments. The significant improvements observed in both groups suggest that implementing student-centered pedagogical approaches, particularly when enhanced with appropriate technological tools, can contribute to addressing the educational challenges identified in PISA and TIMSS evaluations. The complete mastery achievement in the experimental group and the substantial improvement in the control group indicate that both approaches represent viable strategies for improving mathematics education outcomes.

While the current study demonstrates promising results, several limitations must be acknowledged. The research was conducted within a single educational institution using a relatively small sample size, which may limit the generalizability of findings to broader educational contexts. Additionally, not all students possessed prior familiarity with GeoGebra software, which may have influenced initial learning experiences. The study's focus on cognitive outcomes, while important, did not examine other relevant factors such as student engagement levels, attitudes toward mathematics, or long-term retention of learned concepts.

Despite these limitations, the research provides compelling evidence that integrating GeoGebra within Problem-Based Learning frameworks represents an effective instructional strategy for geometry education at the junior secondary level. The statistically significant differences in learning outcomes, combined with the practical significance demonstrated through effect sizes and mastery rates, suggest that this approach merits consideration for broader implementation in mathematics education programs. Future research should explore the long-term effects of such interventions and examine their effectiveness across diverse educational settings and student populations.

D. Conclusion

This investigation provides substantial evidence that Problem-Based Learning enhanced with GeoGebra technology significantly improves mathematics learning outcomes among seventh-grade students studying polyhedra at SMP Negeri 1 Mangarabombang. Students who received instruction through the GeoGebra-enhanced Problem-Based Learning model achieved exceptional academic performance with an average post-test score of 83.19, complete mastery attainment of 100%, and a normalized gain score of 0.77 classified within the high effectiveness category, significantly exceeding the performance of students taught through standard Problem-Based Learning who achieved an average post-test score of 78.29, mastery rate of 93.55%, and a normalized gain score of 0.69 categorized as moderate effectiveness. The Independent Samples t-test confirmed statistical significance with a p-value of 0.002, establishing that GeoGebra integration within the Problem-Based Learning framework produces measurably enhanced educational outcomes through dynamic visualization capabilities that facilitate deeper conceptual understanding of three-dimensional geometric concepts.

These findings carry significant implications for mathematics education practice, particularly in addressing documented challenges facing Indonesian students in international assessments, as the complete mastery achievement demonstrated by the experimental group suggests that appropriately designed technological interventions can substantially improve learning outcomes when integrated within effective pedagogical frameworks. The research contributes to the growing body of evidence supporting educational technology integration within student-centered pedagogical approaches, indicating that the combination of Problem-Based Learning and GeoGebra represents a practical and effective instructional strategy that addresses both conceptual understanding and visual representation needs while aligning with contemporary educational theories emphasizing active learning and student engagement. For educational practitioners, these findings suggest that investing in both pedagogical training and technological resources yields substantial returns in student achievement, with the effectiveness of Problem-Based Learning as a standalone approach combined with enhanced benefits through GeoGebra integration providing educators flexible implementation options based on available resources and institutional capabilities. The evidence strongly supports the conclusion that Problem-Based Learning enhanced with GeoGebra technology represents an effective and practical approach for improving mathematics education outcomes, particularly in geometry instruction at the junior secondary level, offering a promising pathway for addressing existing challenges in mathematics education while preparing students for increasingly technology-integrated learning environments.

Nevertheless, this study has limitations. It was conducted in a single institution with a relatively small sample size, which restricts the generalizability of findings. Future research should therefore involve larger and more diverse populations, investigate long-term retention of learning, and examine additional factors such as student motivation, engagement, and attitudes toward mathematics. Addressing these areas will provide a more comprehensive understanding of the impact of GeoGebra-enhanced PBL and its potential to strengthen mathematics education in broader contexts.

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