
The Effectiveness of Digital Learning Media Based on Project Based Learning Assisted by Geogebra Classroom on Mathematics Learning Outcomes of Vocational High School Students

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Article Info

Article history:

Received: April 8th, 2026

Revised: April 30th, 2026

Accepted: April 30th, 2026

Available online: April 30th, 2026

<https://doi.org/10.33541/edumatsains.v10i4.8082>

Abstract

This research evaluates how Project-Based Learning (PjBL) integrated with GeoGebra Classroom influences the mathematical performance of vocational high school students specifically regarding trigonometry. The investigation employs a quantitative method characterized by a quasi-experimental design with a non-equivalent control group. The subjects of the study included two classes: one experimental class with 34 participants and one control class with 35 participants. The assessment tool utilized was a multiple-choice quiz consisting of 20 questions that underwent validation and reliability checks. Data analysis encompassed both descriptive and inferential statistics. The prerequisite tests conducted involved a normality assessment via the Kolmogorov-Smirnov test and a homogeneity test using the Levene test. The findings from the normality assessment indicated that not all data followed a normal distribution, prompting further analysis with nonparametric methods, specifically the Wilcoxon and Mann-Whitney tests. Additionally, the advancement in academic performance was evaluated through the N-Gain Score. The findings demonstrated a notable distinction between the pretest and posttest scores in both the experimental and control groups. The average N-Gain score for the experimental group was 0.66, categorized as moderate, whereas the control group recorded an average of 0.37, also within the moderate range. The Mann-Whitney test results indicated a significance level of 0.000.

Keywords: GeoGebra Classroom, Learning outcomes, N-Gain, PjBL, Quasi-experiment

1. Introduction

The rapid evolution of digital technology in the modern era has transformed educational requirements, making the integration of tech-based tools essential for boosting student performance. For mathematics specifically, interactive software facilitates the dynamic visualization of symbolic and abstract concepts, making them more accessible to learners. The integration of technology into the learning process is no longer complementary but a necessity to improve both the quality and effectiveness of students' academic performance. In the context

of mathematics learning, the use of interactive digital media allows for dynamic visualization of mathematical concepts, thus helping students understand abstract and symbolic material (Muchlis et al., 2021). Furthermore, the use of mathematical software such as GeoGebra is reported to be more effective in improving learning outcomes compared to conventional learning (Zuhra & Salehha, 2022).

Trigonometry remains a significant challenge for tenth-grade vocational students due to the complexity of ratios and functional representations. Traditional, teacher-led lectures often fail to engage students, leading to passive learning and diminished academic results. Research shows that students often have difficulty understanding the relationships between trigonometric concepts, including the relationship between angles, trigonometric ratios, and the graphical representation of complex functions, which has implications for low learning outcomes (Kasmawati, 2025). Mathematics learning, which is still dominated by one-way lecture methods, tends to make students passive, quickly become bored, and less motivated to actively participate in learning activities. This condition not only reduces student participation in class discussions but also negatively impacts student understanding of the material and academic achievement because their interaction and involvement are limited to one-sided information reception (Mutia et al., 2025).

Observations at SMKN 2 Rantau Utara confirmed that students struggled with connecting trigonometric concepts, exacerbated by a lack of digital media in the classroom. Students experience difficulties in connecting the concept of angles with trigonometric ratio values and in interpreting function graphs. In addition, the use of digital media in learning has not been maximized, so that learning is still teacher-centered. This condition shows a gap between the demands of 21st-century technology-based learning and classroom learning practices.

Consequently, this study explores using GeoGebra Classroom within a PjBL framework to bridge this gap. This platform enables interactive visualization of mathematical concepts and facilitates real-time monitoring of student activity. The use of GeoGebra has been proven effective in improving the understanding of mathematical concepts (Ghiffaari Mahardhika, 2024) and improving student learning outcomes in logarithmic functions (Ardiansyah, 2024). In addition, Budiarto, Sudirman, and Hidayanto found that GeoGebra- assisted learning on integral material at the high school level was able to increase the average value and learning completeness of students (Darum Budiarto, Sudirman, 2022).

Apart from learning media, selecting the right learning model is also important in improving student learning outcomes. PjBL is a student-centered learning model that involves completing real-world, contextual projects. This model focuses on students and provides opportunities to solve real-world problems through collaborative projects, encouraging active engagement, exploration, and a deeper understanding of concepts (Syarifah et al., 2021). Several studies have shown that the implementation of PjBL has a positive impact on improving learning outcomes. Marifah and Karimah reported that the implementation of PjBL in science learning in elementary schools was able to significantly increase the percentage of student learning completion after the model was implemented (Izzatul Ma'rifah, 2025). Another study by Rahmawati, Rosanawati, and Sadino also showed that the use of PjBL in mathematics learning increased student activity and the percentage of student learning completion (Annisya Nuraini Rahmawati, I Made Ratih Rosanawati, 2024). In addition, a study at SMK Negeri 2 Bojonegoro

showed that PjBL not only improved learning outcomes but also significantly increased student learning interest (Cahya et al., 2023) .

The integration of PjBL with digital technology further strengthens learning effectiveness because students not only receive information but also construct knowledge through technology-based project activities. Several studies have shown that the implementation of PjBL assisted with 3D GeoGebra significantly improves students' conceptual understanding and creativity (Wiana et al., 2024) . The GeoGebra -assisted PjBL model also has an impact on improving students' mathematical thinking skills (Wulandari et al., 2025) . Internationally, the integration of GeoGebra in PjBL has also been reported to significantly improve students' academic achievement (Kholid1 et al., 2022) .

Although various studies have proven the effectiveness of GeoGebra and PjBL separately, most studies still examine both in different contexts or place more emphasis on critical thinking skills and mathematical literacy (Kholid1 et al., 2022; Wiyanti & Hadi, 2023; Wulandari et al., 2025). However, research specifically integrating digital learning media on PjBL using GeoGebra Classroom and explicitly measuring cognitive learning outcomes in vocational high school students on trigonometry is still relatively limited. Furthermore, the context of vocational schools (SMK) has not been a focus of much research compared to general schools. In fact, the characteristics of learning in vocational schools, which emphasize applicative and contextual aspects are very relevant to the project-based approach.

Based on the context that has been explained, this research is focused on the application of digital learning media based on PjBL assisted by GeoGebra Classroom in trigonometry learning for grade X SMK to improve students' mathematics learning outcomes. This research is limited to measuring the cognitive aspects of students' learning outcomes, which include understanding the concept of angles, trigonometric ratios, and graphical representation of trigonometric functions, without specifically measuring collaboration skills or other affective aspects.

This study aims to advance technology-driven mathematics education, especially by merging the Project-Based Learning framework with the digital platform GeoGebra Classroom in math instruction within vocational institutions. Additionally, the findings in this study are anticipated to offer guidance to educators and upcoming researchers in crafting more engaging and interactive mathematics teaching innovations.

2. Methods

This research adopted a **quantitative quasi-experimental design**, specifically utilizing a non-equivalent control group framework. This research design was selected because the investigator was unable to oversee every factor impacting the educational experience, yet still administered an intervention to specific groups. The framework adopted was a non-equivalent control group setup, consisting of two categories: an experimental cohort and a control cohort.

The research design can be seen in Table 1 below:

Table 1.
Research Design

Group	Pre-test	Treatment	Post-test
Experiment	O1	X	O2
Control	O1	-	O2

Based on this design, both groups were given a pretest to determine the students' initial abilities. While the experimental group utilized PjBL digital resources via GeoGebra, the control group received standard conventional instruction. Subsequently, both cohorts were administered a post-assessment to evaluate educational results following the intervention.

The study focused on 69 tenth-grade students at SMKN 2 Rantau Utara, divided into an experimental group (34 students) and a control group (35 students). The entire population for this study consisted of all tenth-grade learners, divided into eight classes. The method of sampling utilized was purposive sampling, which involves choosing samples based on defined criteria.

The primary assessment tool was a 20-item multiple-choice test, which underwent rigorous validation and reliability checks (Cronbach's Alpha of 0.91). Before implementation, the tool underwent validation and reliability testing. The validation process was executed using Product-Moment correlation facilitated by Microsoft Excel by comparing the score of each item with the aggregate score. Items were deemed valid if the calculated r_{hitung} exceeded the r_{tabel} at the 5% significance threshold, with outcomes revealing that all 20 items were valid with r_{hitung} values spanning from 0.50 to 0.68, surpassing r_{tabel} of 0.46. Additionally, the instrument's reliability was ascertained using Cronbach's Alpha coefficient, utilizing Microsoft Excel for analysis. The instrument demonstrated high reliability, as evidenced by a Cronbach's Alpha of 0.91., thereby confirming the instrument's appropriateness for research purposes. Data was gathered through a pretest to assess students' initial skill levels, followed by a posttest to evaluate learning outcomes subsequent to the instructional intervention.

Data analysis involved both descriptive and inferential statistics, including **N-Gain scores to measure academic growth** and nonparametric tests like the Wilcoxon and Mann-Whitney tests, as the data did not follow a normal distribution. Moreover, to assess the extent of enhancement in learning outcomes, an N-gain score assessment was conducted using the ensuing formula:

$$N-Gain = \frac{\text{post test score} - \text{pre test score}}{\text{maximum score} - \text{pre test score}}$$

The values of the N-gain are then categorized as follows:

Table 2.
N-Gain Score Category

N-Gain Value	Category
$g \geq 0.70$	Tall
$0.30 \leq g < 0.70$	Currently
$g < 0.30$	Low

The N-gain score category was used to determine the level of improvement of students' learning outcomes after implementing digital learning media based on PjBL with the assistance of GeoGebra Classroom. Thus, this series of analysis procedures aims to ensure that the research results obtained are valid and can be used as a basis for drawing conclusions regarding the effectiveness of the applied learning model.

Additionally, inferential statistical examination was employed to identify the variations in educational outcomes between the two groups. The analysis of data in this research aimed to assess the discrepancies in learning results between the experimental and control groups and the effectiveness of the instructional methods applied. Prior to hypothesis testing, necessary evaluations were conducted, which encompassed examinations for normality and homogeneity. The normality evaluation employed the Kolmogorov-Smirnov Test to determine if the data conformed to be a normal distribution. The results of the examination indicated that the pretest data for the control group conformed to a normal distribution (Sig. > 0.05), while the posttest data for the control group, along with the pretest and posttest data for the experimental group, did not conform to a normal distribution (Sig. < 0.05). Given that the data did not satisfy the normality assumption, the hypothesis testing was performed using a nonparametric test to compare the two independent groups.

The homogeneity assessment was performed using the Levene test to assess the consistency of variance among groups. This analysis was carried out on the pretest results within the Experimental and control class groups, which were established to verify that the initial variances were comparable in both collections before the treatment was applied. The homogeneity evaluation revealed that the data were coherent (Sig. > 0.05). Furthermore, the Wilcoxon test was utilized to examine the variations between pre-test and post-test scores within each class. To measure the degree of advancement in students' learning results, the N-Gain Score calculation was implemented. Finally, the Mann-Whitney test was conducted to assess the differences in the learning outcomes between the experimental and control groups.

The hypothesis in this study is a tentative assumption that must be proven through statistical testing to answer the research problem formulation. The proposed hypothesis is as follows:

Ho: There is no distinction in the enhancement of mathematics learning results between learners instructed with digital educational tools rooted in PjBL supported by GeoGebra Classroom and those receiving traditional instruction.

Ha: There is a discrepancy in the enhancement of mathematics learning results between learners instructed with digital educational tools rooted in PjBL supported by GeoGebra Classroom and those receiving traditional instruction.

The criteria for making decisions in this evaluation are as follows: If the significance level (Sig.) is less than 0.05, then H_0 is dismissed and H_a is acknowledged, indicating a noteworthy difference between the two groups. In contrast, if the significance level (Sig.) exceeds 0.05, then H_0 is accepted and H_a is dismissed, suggesting that there is no noteworthy difference between the two groups.

3. Result and Discussion

3.1. Results

Mathematics learning outcomes can be seen in Figure 1 and Table 3, indicating that students in the experimental group outperformed those in the control group.

Figure 1

Average Students Learning Outcome

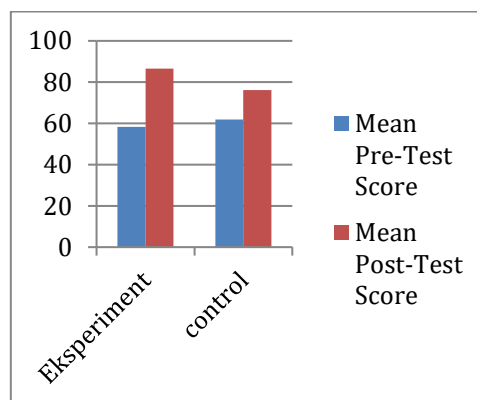


Table 3.

Statistical Analysis of Mathematics Learning Outcomes

	Min Value	Max Value	Average	Std. Deviation
Experiment Pre-Test	50	70	58.24	6,382
Post-Experiment Test	75	95	86.47	5,843
Pre-Test Control	50	75	61.86	7,080
Post-Test Control	65	85	76.14	5,435

According to Table 3 and the average graphical representation depicted in Figure 1 above, Statistical analysis revealed that both groups initially possessed similar baseline abilities, with the experimental group averaging 58.24 and the control group 61.86 on the pretest. However, post-intervention results showed a marked improvement in the experimental group, which reached an average score of 86.47, significantly higher than the control group's 76.14

Through the application of descriptive statistical analysis, it cannot be definitively stated that digital learning tools influenced student performance, specifically in PjBL supported by

GeoGebra Classroom, at SMKN 2 Rantau Utara. Therefore, a normality assessment was carried out to verify the accuracy of the obtained results. This assessment was conducted to ascertain whether the two classes originate from a population that follows a normal distribution.

The assessment of normality was conducted employing the Kolmogorov-Smirnov test utilizing IBM SPSS Statistics software. The criteria for testing, with a significance level of 5% ($\alpha = 0.05$), were established as follows:

- a. If the significance value (Sig.) is equal to or greater than 0.05, then H_a is accepted.
- b. If the significance value (Sig.) is less than 0.05, then H_0 is dismissed.

The findings of the normality test for pre-test and post-test data are presented in Table 4.

Table 4.
Normality Test

Group	Kolmogorov – Smirnov ^a		Information
	Data	Signification	
Experiment	Pretest	0.002	Not Normally Distributed
	Posttest	0.002	Not Normally Distributed
Control	Pretest	0.056	Normally Distributed
	Posttest	0,000	Not Normally Distributed

As indicated by Table 4, the results of the normality evaluation performed using the Kolmogorov-Smirnov test show that the pretest results for the experimental cohort have a significance value of $0.002 < 0.05$, implying it is not normally distributed. Similarly, the posttest results for the experimental cohort produced a significance value of $0.002 < 0.05$, reflecting that the data are not normally distributed. In contrast, the control group's pretest data reflected a significance value of $0.056 > 0.05$, confirming that it is normally distributed, whereas the posttest data displayed a significance value of $0.000 < 0.05$, signifying that the data is not normally distributed.

Thus, it can be concluded that most of the data in this study were not normally distributed, so further analysis used nonparametric tests.

Table 5.
Homogeneity Test

	Levene Statistics	Df1	Df2	Sig.
Experiment Control	0,233	1	67	0,631

According to Table 5, the findings from the homogeneity assessment via Levene's test yielded a significance value of 0.631, which is greater than 0.05. This suggests that the variance of the pretest data between the experimental and control classes is uniform. In the realm of a non-equivalent control group design, these findings imply that both groups possess similar baseline abilities, rendering them suitable for comparison when evaluating the effects of the administered treatment.

Table 6.
Wilcoxon test

Group	Z	Asymp.sig(2-tailed)	conclusion
Experiment	-5,109	0,000	Significant
Control	-5,441	0,000	Significant

According to the findings presented in Table 6, the Wilcoxon test reveals that the significance value for both the experimental and control classes, represented by a p-value of 0.000, is below the threshold of 0.05. This highlights a noteworthy improvement in scores from the pretest to the posttest in both groups, indicating a rise in student learning outcomes across the board.

Table 7.
N-Gain Test

Group	Average N-Gain	Average N-Gain Percent (%)	Category
Experiment	0.66	66%	Currently
Control	0.37	37%	Currently

As illustrated in table 7, The **N-Gain score for the experimental class was 0.66 (moderate)**, nearly doubling the control class's gain of 0.37. Even though both classes are deemed moderate, the experimental group's average N-Gain surpasses that of the control group. This signifies that the improvement among students in the experimental group resulted in more favorable learning outcomes compared to those in the control group.

Table 8.
Mann-Whithney test

Information	Mark
Mann-Whitney U	77,500
Z	-6,236
Asymp.Sig.(2-tailed)	0,000

Furthermore, the Mann-Whitney test yielded a significance value of 0.000, confirming a statistically noteworthy difference in the enhancement of learning outcomes between the two cohorts

3.2. Discussion

Findings from the study utilizing a non-equivalent control group design indicated an increase in mathematics achievement among students in both the experimental and control groups. The Wilcoxon test results demonstrated a significance level of $0.000 < 0.05$ in each group, suggesting a substantial difference between the pretest and posttest scores. This implies that the teaching methods used in both classrooms were effective in improving student performance.

Nonetheless, the degree of enhancement in educational outcomes between the two groups revealed disparities. According to the findings from the N-Gain assessment, the mean rise in learning achievements in the experimental class was 0.66 (moderate category), whereas in the control class it stood at 0.37 (moderate category). While both fell within the same category, the

N-Gain figure in the experimental group surpassed that of the control group. This signifies that the use of digital learning tools grounded in PjBL with GeoGebra Classroom support yields superior educational outcomes compared to traditional teaching methods. These findings align with Pariaman (2025), which asserts that the implementation of the PjBL model, accompanied by GeoGebra Classroom, enhances students' grasp of mathematical concepts.

The distinction is corroborated by the outcomes of the Mann-Whitney test, revealing a significance value of $0.000 < 0.05$. This shows that a noteworthy difference exists in learning results between the experimental and control groups. Consequently, the alternative hypothesis (H_a) is affirmed, and the null hypothesis (H_0) is dismissed. This suggests that the implementation of digital learning resources grounded in PjBL, enhanced by GeoGebra Classroom, proves to be more effective in advancing students' performance in mathematics. This observation is further validated by research (Tilari et al., 2024), which illustrates that the GeoGebra-supported PjBL model significantly impacts students' mathematics achievement.

In the framework of the research methodology employed, the outcomes of the homogeneity assessment reveal that both groups exhibit uniform initial variance. This suggests that the preliminary abilities of students in the experimental group and the control group were quite similar prior to receiving treatment. Consequently, the disparity in the enhancement of learning achievements observed post-treatment can be more reliably attributed to the implementation of PjBL-based digital learning resources supported by GeoGebra Classroom.

Moreover, by utilizing this digital approach, students are encouraged to construct knowledge through hands-on projects while benefiting from interactive visualizations that clarify complex mathematical principles. This aligns with Wulandari et al. (2025), stating that employing PjBL supported by GeoGebra enhances students' mathematical literacy skills.

These findings are consistent with previous studies indicating that GeoGebra-supported learning can enhance students' conceptual understanding and mathematical reasoning. The implementation of PjBL assisted by GeoGebra has been reported to significantly improve students' mathematical reasoning abilities (Junita & Masrukan, 2025). However, although the experimental group achieved a higher N-gain score than the control group, both groups fall within the moderate category. This indicates that the difference in learning improvement between the two groups is not substantially significant in practical terms. In other words, both instructional approaches contributed to a comparable level of improvement in students' learning outcomes. Nevertheless, the relatively higher N-gain score in the experimental group suggests that the integration of GeoGebra within the PjBL framework provides a more effective contribution to enhancing students' learning outcomes.

4. Conclusion

From the findings of the conducted research and discussions, we can infer that there has been a rise in students' math achievement in both the experimental and control groups. This is supported by the Wilcoxon test, indicating a significant change in scores from pretest to posttest in each group. However, the improvement in the experimental group's average N-Gain value of 0.66 exceeds that of the control group, which stands at 0.37; both values are categorized within the medium range. Furthermore, results from the Mann-Whitney test reveal a notable difference

in the improvement of learning outcomes between the experimental and control cohorts. In conclusion, the **PjBL-GeoGebra model successfully elevates the mathematical achievement** of vocational students, providing a valuable framework for educators seeking to modernize classroom instruction

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