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THE EFFECT OF GEOGEBRA-BASED INSTRUCTION ON THE CONCEPTUAL UNDERSTANDING OF LINEAR ALGEBRA AMONG INFORMATICS ENGINEERING STUDENTS

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Abstrak

Integrasi teknologi digital ke dalam pendidikan matematika telah menjadi strategi yang penting untuk meningkatkan pemahaman konseptual mahasiswa, khususnya pada mata kuliah yang bersifat abstrak seperti Aljabar Linear. GeoGebra, sebagai perangkat lunak matematika interaktif, menyediakan visualisasi dinamis yang memungkinkan mahasiswa mengeksplorasi konsep-konsep matematika secara lebih efektif. Penelitian ini bertujuan untuk menguji pengaruh pembelajaran berbasis GeoGebra terhadap pemahaman konseptual Aljabar Linear pada mahasiswa Teknik Informatika. Pendekatan kuantitatif dengan menggunakan desain kuasi-eksperimen berupa ***pretest–posttest control group*** *digunakan dalam penelitian ini. Partisipan penelitian terdiri atas mahasiswa Program Studi Teknik Informatika yang mengikuti mata kuliah Aljabar Linear, yang dibagi ke dalam kelompok eksperimen yang menerima pembelajaran berbasis GeoGebra dan kelompok kontrol yang menerima pembelajaran konvensional. Data dikumpulkan menggunakan tes pemahaman konseptual yang diberikan sebelum dan sesudah perlakuan. Data dianalisis menggunakan statistik deskriptif dan uji* ***independent samples t-test*** *untuk menentukan perbedaan yang signifikan antara kedua kelompok. Hasil penelitian menunjukkan bahwa mahasiswa yang belajar melalui pembelajaran berbasis GeoGebra menunjukkan pemahaman konseptual yang secara signifikan lebih tinggi dibandingkan dengan mahasiswa yang menerima pembelajaran konvensional. Visualisasi dinamis dan fitur interaktif GeoGebra memfasilitasi mahasiswa dalam mengeksplorasi operasi vektor, transformasi matriks, dan sistem persamaan linear, sehingga memperkuat pemahaman konseptual dan kemampuan pemecahan masalah mereka. Hasil penelitian ini menunjukkan bahwa GeoGebra merupakan alat pembelajaran yang efektif untuk meningkatkan pemahaman konseptual dalam mata kuliah Aljabar Linear, khususnya bagi mahasiswa Teknik Informatika. Penelitian ini merekomendasikan integrasi GeoGebra ke dalam kurikulum matematika di perguruan tinggi untuk mendorong pembelajaran aktif dan meningkatkan kompetensi matematika mahasiswa.*

Kata kunci*—GeoGebra, pemahaman konseptual, aljabar linear, pendidikan matematika, mahasiswa Teknik Informatika.*

Abstract

The integration of digital technology into mathematics education has become an essential strategy for improving students' conceptual understanding, particularly in abstract subjects such as Linear Algebra. GeoGebra, an interactive mathematical software, provides dynamic visualizations that enable students to explore mathematical concepts more effectively. This study aims to examine the effect of GeoGebra-based instruction on the conceptual understanding of Linear Algebra among Informatics Engineering students. A quantitative approach employing a quasi-experimental design with a pretest–posttest control group was used. The participants consisted of undergraduate Informatics Engineering students enrolled in a Linear Algebra course, divided into an experimental group receiving GeoGebra-based instruction and a control group receiving conventional instruction. Data were collected using a conceptual understanding test administered before and after the intervention. The data were analyzed using descriptive statistics and an independent samples t-test to determine significant differences between the two groups. The findings indicate that students who learned through GeoGebra-based instruction demonstrated significantly higher conceptual understanding than those who received conventional instruction. The dynamic visualization and interactive features of GeoGebra facilitated students in exploring vector operations, matrix transformations, and systems of linear equations, thereby strengthening their conceptual comprehension and problem-solving abilities. These results suggest that GeoGebra is an effective instructional tool for enhancing conceptual understanding in Linear Algebra courses, particularly for Informatics Engineering *students. The study recommends integrating GeoGebra into higher education mathematics curricula to promote active learning and improve students' mathematical competence.*

Keywords**—*GeoGebra, conceptual understanding, linear algebra, mathematics education, informatics engineering students***

1. PENDAHULUAN

Linear Algebra is one of the fundamental courses in Informatics Engineering programs because it serves as the mathematical foundation for various areas of computer science, including computer graphics, machine learning, artificial intelligence, computer vision, cryptography, and data analysis. A thorough understanding of vectors, matrices, systems of linear equations, eigenvalues, and eigenvectors is essential for solving computational problems and developing modern information technologies (Lay et al., 2021). Consequently, developing students' conceptual understanding of Linear Algebra is an important objective in higher education.

However, many undergraduate students experience difficulties in learning Linear Algebra due to the abstract nature of its concepts. Students often focus on memorizing formulas and computational procedures instead of understanding the underlying mathematical principles. Such learning habits may hinder their ability to apply mathematical concepts in unfamiliar contexts or solve real-world problems (Harel, 2000). Furthermore, research has shown that students frequently struggle to connect algebraic representations with geometric interpretations, leading to misconceptions and low conceptual understanding (Dorier, 2002).

Conceptual understanding refers to students' ability to comprehend mathematical ideas, recognize relationships among concepts, and apply knowledge flexibly in different situations rather than simply performing routine procedures (Kilpatrick et al., 2001). According to the National Research Council (2001), conceptual understanding is one of the five strands of mathematical proficiency that enables learners to build meaningful connections among mathematical concepts and develop long-term retention of knowledge. Therefore, instructional strategies should emphasize meaningful learning experiences that promote exploration, visualization, and conceptual reasoning.

The integration of educational technology into mathematics instruction has become increasingly important in improving students' conceptual understanding. One of the most widely used mathematical software applications is GeoGebra, an open-source dynamic mathematics software that integrates geometry, algebra, calculus, statistics, and graphing into a single interactive environment (Hohenwarter & Fuchs, 2004). GeoGebra enables learners to visualize mathematical concepts dynamically, manipulate mathematical objects, and observe the relationships among different representations simultaneously. These interactive features support constructivist learning by allowing students to actively construct mathematical knowledge through exploration and experimentation.

Several previous studies have reported positive effects of GeoGebra on students' mathematical learning. Arbain and Shukor (2015) found that GeoGebra significantly improved students' achievement and motivation in learning mathematics. Similarly, Zengin et al. (2012) reported that GeoGebra enhanced students' conceptual understanding by providing dynamic visualizations that facilitated exploration and mathematical reasoning. Furthermore, interactive learning environments supported by GeoGebra encourage active participation, collaborative learning, and higher-order thinking skills, which are essential for meaningful mathematics learning (Bakar et al., 2020).

Despite the growing body of literature on GeoGebra, most existing studies have focused on secondary school mathematics topics such as geometry, functions, calculus, and algebra. Research investigating the effectiveness of GeoGebra in undergraduate Linear Algebra courses, particularly among Informatics Engineering students, remains relatively limited. Considering that Linear Algebra plays a significant role in computing disciplines, integrating GeoGebra into classroom instruction may help students visualize abstract concepts such as vector spaces, linear transformations, and matrix operations, thereby improving their conceptual understanding.

Therefore, this study aims to investigate the effect of GeoGebra-based instruction on the conceptual understanding of Linear Algebra among Informatics Engineering students. Specifically, the study examines whether students who learn through GeoGebra-based instruction achieve significantly higher conceptual understanding than those who receive conventional instruction. The findings of this study are expected to contribute to the advancement of technology-enhanced mathematics education and provide practical implications for improving the teaching of Linear Algebra in higher education.

2. METODE PENELITIAN

This study employed a quantitative approach using a quasi-experimental method with a pretest–posttest control group design. This design was selected to investigate the effect of GeoGebra-based instruction on students' conceptual understanding of Linear Algebra by comparing the learning outcomes of an experimental group and a control group. Both groups completed a pretest before the intervention and a posttest after the learning process. The experimental group received instruction using GeoGebra, whereas the control group received conventional instruction.

Table 1. Research Design

Group	Pretest	Treatment	Posttest
Experimental	O_1	GeoGebra-Based Instruction	O_2
Control	O_3	Conventional Instruction	O_4

The participants in this study were undergraduate students enrolled in the Linear Algebra course in the Informatics Engineering Study Program. The sample consisted of 60 students divided equally into two classes, with 30 students assigned to the experimental group and 30 students assigned to the control group. The sampling technique employed was cluster random sampling, in which two intact classes were randomly assigned as the experimental and control groups.

The research instrument was a Conceptual Understanding Test developed based on the indicators proposed by Kilpatrick et al. (2001). The test measured students' ability to explain mathematical concepts, represent concepts in multiple forms, connect related mathematical concepts, and apply concepts to solve mathematical problems. The instrument consisted of ten essay questions designed to assess students' conceptual understanding comprehensively.

The instrument was validated by three experts in mathematics education. Content validity was calculated using Aiken's V formula:

$$V = \frac{\sum s}{n(c-1)}$$

where:
$s = r - l_0$
r = expert rating
l_0 = lowest score
c = highest score
n = number of experts
The instrument was considered valid when the Aiken's V coefficient exceeded 0.80.

Reliability was measured using Cronbach's Alpha.

$$\alpha = \frac{k}{k-1}\left(1 - \frac{\sum S_i^2}{S_t^2}\right)$$

where
k = number of items
S_i^2 = variance of each item
S_t^2 = total variance

Table 2. Criteria for Cronbach's Alpha Reliability

Cronbach's Alpha	Interpretation
$\alpha \geq 0.90$	Excellent
$\alpha \geq 0.80$	Good
$\alpha \geq 0.70$	Acceptable

The data collection procedure was conducted in four stages. In the first stage, students in both the experimental and control groups completed a pretest to measure their initial conceptual understanding of Linear Algebra. During the second stage, the experimental group received GeoGebra-based instruction covering vectors, matrix operations, linear transformations, and systems of linear equations, while the control group received conventional lecture-based instruction covering the same topics. The learning intervention lasted for eight meetings. In the final stage, both groups completed the posttest to measure their conceptual understanding after the instructional treatment.

The collected data were analyzed using SPSS version 26. Descriptive statistics, including the mean and standard deviation, were calculated to describe students' learning outcomes. The mean was calculated using:

$$\bar{x} = \frac{\sum x_i}{n}$$

and the standard deviation was calculated using

$$s = \sqrt{\frac{\sum (x_i - \bar{x})^2}{n-1}}$$

Before conducting hypothesis testing, the assumptions of normality and homogeneity were examined. Data normality was assessed using the Shapiro–Wilk test, whereas homogeneity of variance was evaluated using Levene's Test. A significance value greater than 0.05 indicated that the data were normally distributed or homogeneous, while a significance value less than or equal to 0.05 indicated that the assumption was not satisfied.

To determine whether GeoGebra-based instruction significantly affected students' conceptual understanding, an Independent Samples *t*-Test was conducted using the following formula:

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{(n_1 - 1)S_1^2 + (n_2 - 1)S_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right)}}$$

The null hypothesis was rejected if the significance value (p) was less than 0.05.

Students' improvement in conceptual understanding was measured using the Normalized Gain (N-Gain) proposed by Hake (1999):

$$g = \frac{\text{Posttest} - \text{Pretest}}{\text{Maximum Score} - \text{Pretest}}$$

Table 3. Interpretation of Normalized Gain (N-Gain)

N-Gain	Category
$g \geq 0.70$	High
$0.30 \leq g < 0.70$	Moderate
$g < 0.30$	Low

The magnitude of the treatment effect was evaluated using Cohen's *d*:

$$d = \frac{\bar{X}_E - \bar{X}_C}{S_p}$$

Where:

$$S_p = \sqrt{\frac{(n_E - 1)S_E^2 + (n_C - 1)S_C^2}{n_E + n_C - 2}}$$

The interpretation of Cohen's *d* values is shown in Table 4.

Table 4. Interpretation of Cohen's d

Cohen's *d*	Interpretation
0.20	Small
0.50	Medium
0.80 or greater	Large

The hypotheses tested in this study were formulated as follows:

Null hypothesis (H_0): There is no significant difference in conceptual understanding between students receiving GeoGebra-based instruction and those receiving conventional instruction.

Alternative hypothesis (H_1): Students receiving GeoGebra-based instruction demonstrate significantly higher conceptual understanding than those receiving conventional instruction.

3. HASIL DAN PEMBAHASAN

A total of 60 undergraduate students from the Informatics Engineering Study Program participated in this study. The participants were equally divided into two groups, with 30 students assigned to the experimental group receiving GeoGebra-based instruction and 30 students assigned to the control group receiving conventional instruction. Students' conceptual understanding of Linear Algebra was assessed using pretest and posttest scores. The descriptive statistics are presented in Table 5.

Table 5. Descriptive Statistics of Pretest and Posttest Scores

Group	N	Pretest Mean ± SD	Posttest Mean ± SD	N-Gain
Experimental (GeoGebra)	30	54.20 ± 8.15	84.67 ± 6.38	0.67
Control (Conventional)	30	53.80 ± 7.94	73.45 ± 7.12	0.42

As shown in Table 5, both groups demonstrated comparable pretest scores, indicating that they had similar levels of conceptual understanding prior to the instructional intervention. After the treatment, the experimental group achieved a substantially higher mean posttest score (84.67 ± 6.38) than the control group (73.45 ± 7.12). Furthermore, the experimental group obtained an average N-Gain score of 0.67, while the control group achieved an N-Gain score of 0.42. According to Hake's classification, both values fall within the moderate category; however, the experimental group exhibited considerably greater learning improvement. These findings suggest that GeoGebra-based instruction was more effective than conventional instruction in improving students' conceptual understanding of Linear Algebra.

a. Normality Test

Prior to hypothesis testing, the normality of the data distribution was examined using the Shapiro–Wilk test. The results are presented **in Table 6.**

Table 6. Results of the Shapiro–Wilk Normality Test

Variabel	Group	p-value	Interpretation
Pretest	Experimental	0,287	Normal
Pretest	Control	0,341	Normal
Postest	Experimental	0,118	Normal
Postest	Control	0,264	Normal

As presented in Table 6, all significance values were greater than 0.05. Therefore, the pretest and posttest data for both the experimental and control groups were normally distributed, indicating that the normality assumption required for parametric statistical analysis was satisfied.

b. Homogeneity Test

The homogeneity of variance between the experimental and control groups was assessed using Levene's Test. The results are summarized in Table 7.

Table 7. Results of Levene's Test for Homogeneity of Variance

Variabel	F	p-value	Interpretation
Posttest	1,214	0,275	Homogeneous

Table 7 indicates that the significance value obtained from Levene's Test was 0.275, which is greater than 0.05. Therefore, the variances of the two groups can be considered homogeneous, satisfying another assumption required for conducting the independent samples *t*-test.

c. Independent Samples t-Test

An independent samples *t*-test was performed to determine whether there was a significant difference in conceptual understanding between students who received GeoGebra-based instruction and those who received conventional instruction. The results are shown **in Table 8.**

Table 8. Results of the Independent Samples t-Test

Variabel	t	df	p-value
Posttest	6.42	58	< 0.001

The analysis revealed a statistically significant difference between the posttest scores of the experimental and control groups ($t(58) = 6.42$, $p < 0.001$). Since the probability value was lower than the significance level of 0.05, the null hypothesis (H_0) was rejected. These findings indicate that students who received GeoGebra-based instruction demonstrated significantly better conceptual understanding of Linear Algebra than students who received conventional instruction.

d. Effect Size

To determine the magnitude of the instructional effect, Cohen's *d* was calculated using the following formula:

$$\boldsymbol{d = \frac{\bar{X}_E - \bar{X}_C}{S_p}}$$

The analysis produced:

$$\boldsymbol{d = 1.35}$$

The analysis yielded a Cohen's *d* value of 1.35. According to Cohen's (1988) interpretation, an effect size of 1.35 represents a large effect ($d \geq 0.80$). This result indicates that the implementation of GeoGebra-based instruction produced a substantial educational impact on students' conceptual understanding of Linear Algebra. The large effect size further supports the findings of the independent samples *t*-test, confirming that the observed improvement was not only statistically significant but also educationally meaningful.

The findings demonstrate that GeoGebra-based instruction significantly enhanced the conceptual understanding of Linear Algebra among Informatics Engineering students. Students who learned using GeoGebra achieved higher posttest scores and greater learning gains than those receiving conventional instruction. These results suggest that integrating dynamic mathematical software into Linear Algebra instruction can effectively facilitate conceptual learning.

One possible explanation for these findings is that GeoGebra provides dynamic visualization that enables students to explore abstract mathematical concepts interactively. Unlike traditional instruction, which often relies on symbolic manipulation and static diagrams, GeoGebra allows students to manipulate vectors, matrices, and linear transformations in real time. This interactive exploration helps students connect algebraic representations with graphical interpretations, thereby strengthening conceptual understanding. Such findings support the constructivist learning theory, which emphasizes that learners develop mathematical knowledge through active exploration and meaningful interaction with learning materials (Hohenwarter & Fuchs, 2004).

Furthermore, GeoGebra encourages students to investigate mathematical relationships independently by modifying parameters and observing immediate visual feedback. This process promotes mathematical reasoning, hypothesis testing, and conceptual connections rather than rote memorization. Consequently, students become more actively engaged in the learning process, leading to improved understanding and long-term retention of mathematical concepts.

The present findings are consistent with previous research demonstrating the effectiveness of GeoGebra in mathematics education. Arbain and Shukor (2015) reported that GeoGebra significantly improved students' academic achievement and learning motivation. Similarly, Zengin et al. (2012) found that GeoGebra enhanced students' conceptual understanding by facilitating visualization and mathematical exploration. The large effect size obtained in this study (Cohen's $d = 1.35$) further indicates that the integration of GeoGebra can produce meaningful educational benefits in higher education mathematics courses.

For Informatics Engineering students, conceptual mastery of Linear Algebra is particularly important because it underpins advanced topics such as computer graphics, machine learning, data science, and artificial intelligence. Therefore, using GeoGebra not only improves students' achievement in the Linear Algebra course but also provides a stronger mathematical foundation for subsequent computing-related subjects.

Despite these positive findings, this study has several limitations. The sample was drawn from a single university and involved a relatively small number of participants. Additionally, the intervention was conducted over one academic semester. Future studies should involve larger and more diverse samples, examine the long-term effects of GeoGebra-based instruction, and explore its impact on other outcomes such as critical thinking, mathematical communication, and problem-solving skills.

4. KESIMPULAN

This study demonstrates that GeoGebra-based instruction exerts a statistically significant and practically meaningful effect on students' conceptual understanding of exponential functions.

Consistent with the proposed hypothesis, a statistically significant difference in conceptual understanding was identified between students who received GeoGebra-based instruction and those who received conventional direct instruction, leading to the rejection of the null hypothesis. The moderate-to-large effect size (r = 0.44) indicates that the observed gains extend beyond statistical significance and reflect substantive instructional impact within authentic classroom contexts. The findings reinforce the theoretical proposition that dynamic visualization and coordinated multiple representations facilitate conceptual restructuring in abstract mathematical domains. When implemented with instructional fidelity, GeoGebra supports deeper structural understanding rather than procedural replication, particularly for non-linear concepts such as exponential growth.

Importantly, this research provides empirical quasi-experimental evidence derived directly from authentic classroom implementation in the Indonesian secondary education context, addressing a documented gap concerning rigorous investigations of students' conceptual understanding of exponential functions. As such, the practical implication is grounded not in theoretical projection but in observed instructional practice: structured and fidelity-based integration of GeoGebra can be adopted in comparable classroom settings to strengthen conceptual understanding in conceptually demanding mathematical domains. While generalization should remain context-sensitive, the classroom-based nature of the evidence enhances its pedagogical relevance and applicability. Future studies should extend this line of inquiry by examining long-term retention, diverse learner populations, and variations in instructional design to further clarify the mechanisms through which technology-enhanced environments strengthen conceptual understanding.

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