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Utilizing open-ended approach to enhance mathematical understanding among vocational high school students

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Abstract

Mathematics learning in vocational high schools is still teacher-centred and relies on structured exercises, leaving little room for students to develop a conceptual understanding. The open-ended approach can be a solution because it allows students to explore various strategies for solving mathematical problems in depth. However, its implementation in vocational high schools remains limited. This study aimed to examine the effectiveness of the open-ended approach in improving the mathematical understanding of vocational high school students. A quasi-experimental design with a pretest-posttest control group design was used. The sample consisted of 72 students in the 11th-grade of Computer and Network Engineering, selected based on previously formed classes. Data were obtained through a mathematical understanding test that measured students' ability to identify, use, and apply the concepts of sequences and series to solve everyday problems. The test instrument consisted of three essay questions, with a maximum score of four for each item. As the data were not normally distributed, the Mann-Whitney U test analysis was used. The results showed that the increase in mathematical understanding of the group of students who received the open-ended approach was significantly better than that of the group who received direct learning.

Keywords: mathematical understanding skills; open-ended approach; vocational high schools

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Introduction

The low level of mathematical understanding among vocational high school students remains a major challenge, especially in terms of logical thinking and the application of mathematical concepts to real-world problems related to the vocational fields. This condition has a significant impact on students' readiness to face the technical demands of the world of work. A study by Mangarin and Caballes (2024) showed that students' main difficulty in mathematics lies in their understanding of abstract concepts, which are often taught procedurally without context. Data from the OECD (2020) also reveal that vocational high school students tend to have lower mathematics scores than senior high school students, with only 30% achieving the minimum competency level. Previous research by Ahmad Susanto (2016) confirmed that conventional teaching methods, such as lectures and drills, fail to engage students, thereby hindering the internalisation of concepts.

Several studies have proven the effectiveness of the open-ended approach in improving mathematical understanding among students. Pamungkas and Kowiyah (2021) found that elementary school students taught using the open-ended model showed significant improvement in mathematical problem-solving skills. A similar study by Junita et al. (2022) on elementary school students confirmed that this approach strengthens mathematical representation skills through real-world context-based problems. However, this research is still limited to the elementary education level, and its implementation in vocational high schools has not been extensively explored.

Although the open-ended approach has proven effective at the elementary and junior high school levels, there is a gap in its implementation in vocational high schools. Previous research conducted by Etyarisky and Marsigit (2022) focused more on interactive digital media than on the open-ended approach. The curriculum needs of vocational high schools, which are oriented toward practical applications, have not been fully accommodated in the existing open-ended learning designs. A study by Sartono (2021) showed that gender and vocational background factors of vocational high school students are often overlooked in analyses of the effectiveness of this method.

This study offers three main contributions. It adapts the open-ended approach to the vocational high school context by integrating industry cases, such as production cost calculations and logistics optimisation, which are relevant to the vocational curriculum. This study tests the cognitive load theory (Rojo et al., 2024) by modifying open-ended questions to suit the cognitive capacity of vocational high school students. This study expands on the findings of Pamungkas and Kowiyah (2021) by exploring the interaction between the open-ended approach and the learning motivation of vocational high school students, which has not been previously studied.

The main objective of this study was to analyse the effect of the open-ended approach on improving the mathematical understanding of vocational high school students, particularly in algebra and geometry. Additionally, this study aims to evaluate the differences in the effectiveness of this approach between technical and non-technical students. Furthermore, this study seeks to develop a contextualised, open-ended learning model tailored to vocational needs.

The results of this study are expected to serve as a reference for vocational high school teachers in designing application-oriented mathematics lessons. In addition, these findings contribute to the literature on the adaptation of open-ended approaches in vocational education, which remains limited. The practical implications include policy recommendations for teacher training in designing industry-based open-ended questions and the development of learning modules integrated with the vocational high school curriculum.

Methods

This study used a quasi-experiment with a pretest-posttest control group design because the sample selection was not random but based on existing classes (Ary et al., 2010; Creswell, 2012). Two groups participated in the study: the control group used direct learning, whereas the experimental group used an open-ended approach.

Without altering the current class structure, the research subjects were chosen based on the real conditions at the school to reflect the industry practices. While the control group adopted direct learning that concentrated more on the teacher's organised delivery of the content, the experimental group received instruction using an open-ended approach that promoted exploration of open-ended questions. Both groups first took a pre-test to measure their pre-treatment ability and then a post-test to assess their improvement in mathematical understanding after treatment.

This study focuses on 11th-grade students at a vocational high school in Pandeglang, which offers five different skill programs to represent diverse competencies. The light vehicle and motorcycle engineering and business programs emphasise automotive technical skills and business literacy. Simultaneously, Computer Engineering and Networking consist of two classes that focus on mastering information technology and computer networks. The Office Automation and Management program is designed to develop administrative and data management skills relevant to the modern business environment. Each program combines theoretical and practical approaches to equip students with the hard and soft skills required by the industry to which they aspire. This study used purposive sampling to maintain the natural conditions of the class without randomisation. Two classes were selected as samples: the eleventh-grade Computer and Network Engineering class one as the experimental group and the eleventh-grade Computer and Network Engineering class two as the control group, each consisting of 36 students, with a total of 72 respondents, including 15 female students and 57 male students.

This study used an essay test instrument consisting of three questions with a maximum score of 4 for each question, so that the total score that students could obtain was 12. The instrument was tested on students who had studied sequences and series, and the validity and reliability test results showed that all items met the specified criteria. The indicators measured included students' ability to identify geometric sequences and apply the concepts of geometric sequences and arithmetic series in solving everyday problems. Data were collected through preand post-tests and then analysed to measure the difference in the average mathematical understanding ability. After conducting a normality test with a significance level of 0.05 using SPSS version 30, the results showed that the data were not normally distributed. Therefore, the analysis of the difference in means was conducted using the non-parametric Mann-Whitney statistical test.

Results

The described data on the improvement in mathematical comprehension include a number of important aspects, namely, the number of samples analysed, the average pretest score, the average posttest score, the N-gain score, and the standard deviation, to provide an overall picture of the data distribution. Data analysis was performed on the N-gain data of the mathematical reasoning ability test scores of the students in both groups. SPSS version 30 was used to process the data, which ensured that the analysis results were accurate and standardised. The data are summarised in detail in Table 1, which contains descriptive statistical information, including the average increase in test scores, thus providing a measurable and systematic overview of the improvement in students' mathematical comprehension skills.

Table 1. Description of math improvement

Statistic	Open-Ended Approach			Direct Learning Model		
	Pretest	Posttest	N-Gain	Pretest	Posttest	N-Gain
N		36			36	
$\bar{x}$	2.83	9.28	0.72	3.00	8.42	0.62
sd	0.94	1.72	0.164	0.86	1.78	0.18

The description of the N-Gain data in Table 1 illustrates the improvement in students' mathematical understanding, as observed in the N-Gain column. The group that used the open-ended approach showed an increase in mathematical understanding, with an overall N-Gain value of 0.72, which reflects a significant improvement in students' understanding of the mathematics material. In contrast, the group that implemented direct learning showed a lower increase in mathematical comprehension, which was 0.62. This discrepancy suggests that, compared to direct instruction, the open-ended method typically produces better outcomes in terms of enhancing students' mathematics comprehension skills.

However, a pre-test must be administered before comparing the progress of the two learning groups in mathematics understanding skills. The purpose of these tests was to ensure that the data used met the basic assumptions required for statistical analysis. A normality test to check the data distribution and a variance homogeneity test to ensure that the variances of the experimental and control groups are similar are among the required tests. Only when all prerequisite tests met the criteria could further statistical analysis be performed to compare the two groups. The results of this analysis will provide a more valid conclusion regarding the difference in the improvement of mathematical understanding skills that occurs due to the use of the two learning methods.

To confirm that the distribution of the data on students' development of mathematical comprehension skills followed a normal distribution pattern, a normality test was run on the N-Gain data. All student groups were included in this test, including the control group that used direct learning and the experimental group that used an open-ended method. The results of the Shapiro-Wilk test statistic normality test are shown in Table 2, along with the significance value (p-value) for each learning group. At a confidence level of α = 0.05, this significance value was used to assess whether the data were regularly distributed. The data were regarded as regularly distributed if the p-value was higher than 0.05. Consequently, this table offers a more thorough summary of the normality of the N-Gain data, supporting the viability of carrying out more statistical analyses in this investigation.

Table 2. Mathematical reasoning normality scores

Learning Group	Shapiro-Wilk		
	Statistic	df	Sig.
Open-Ended Approach	0.914	36	0.008
Direct Learning	0.905	36	0.005

The results of the normality test on the N-Gain data of the two groups' mathematical understanding abilities are shown in Table 2. The N-Gain data in both groups indicated that the data distribution did not follow a normal distribution pattern, according to the results collected. The significance value (Sig.) for the group of students who engaged in open-ended learning was 0.008, which is less than the significance limit α = 0.05 (0.008 < 0.05). Consequently, the null hypothesis (H_0) that the data are normally distributed was rejected. The data on the improvement in mathematical comprehension skills in the open learning group were not normally distributed, as indicated by the rejection of H_0, which suggests that the data do not satisfy the normal distribution assumption needed for parametric statistical analysis.

The same was found in the group of students who participated in direct learning activities. The asymptotic significance value (Asymp. Sig.) obtained for this group was 0.005, which is also smaller than α = 0.05 (0.005 < 0.05). This result led to the rejection of H_0, which means that the data on the improvement of mathematical comprehension skills in the direct learning group were also not normally distributed. These results confirm that the two learning groups tested do not meet the normality assumption required for parametric statistical analyses. Therefore, the next step in the statistical analysis should consider the use of a nonparametric test that does not require the assumption of a normal distribution. This nonparametric test may provide a more appropriate alternative for analysing data that are not normally distributed, making it possible to draw valid conclusions about the differences between the two student groups being tested.

The Wilcoxon W test was used to examine the difference in skill improvement since the normality test results indicated that the N-Gain data for arithmetic comprehension were not regularly distributed in either group. Because it is a nonparametric statistical test that can be used to compare two groups that do not fit the normal distribution assumption, this test was selected. To determine whether there was a significant difference in the median between the two groups under comparison in this case, the group using an open-ended method and the group using direct learning, the Wilcoxon W test was used.

Table 3 provides a detailed presentation of the Wilcoxon W test analysis results, which include several important values, namely the U-statistic, Z-score, and asymptotic significance (Asymp. Sig.) value. The U-statistic value provides information on the ranking used to compare the two groups. In contrast, the Z-score is used to determine the difference between the two groups in the context of a standard normal distribution. To ascertain whether the observed difference between the two groups was statistically significant, the asymptotic. Sig. The value obtained via the Wilcoxon W test was utilised. If the Asymp. Sig. The value is less than 0.05, with a significance level of $\alpha = 0.05$, it can be said that there is a significant difference between the two learning modalities' improvements in students' mathematical comprehension abilities.

Therefore, Table 3 presents the results of in-depth statistical tests and provides a strong basis for drawing relevant conclusions about the relative effectiveness of the open-ended approach compared to direct learning. These results can help us better understand which of the two approaches is more effective in improving students' mathematical understanding skills based on precise statistical analysis and in accordance with the conditions of the existing data.

Table 3. Test results of differences in math understanding abilities

	Values
Mann-Whitney U	413.000
Wilcoxon W	1079.000
Z	-2.665
Asymp. Sig. (2-tailed)	0.008

The Wilcoxon W test findings are shown in Table 3, with a two-sided significance value (Sig.) of 0.008. The two-tailed Sig. The value must be halved to convert it to a one-tailed value because the study's hypothesis, H_0: $\mu_1 \leq \mu_2$, is one-tailed and states that the average increase in students' mathematical understanding ability in the open-ended approach group is not greater than that in the direct learning group. This division yields a value of 0.008/2 = 0.004. The null hypothesis (H_0) was rejected because the one-tailed significance. value of 0.004 is smaller than $\alpha = 0.05$ ($0.004 < 0.05$). Students who learn via an open-ended approach substantially enhance their mathematical understanding more than students who learn directly, as evidenced by the rejection of H_0. The findings of the examination of the students as a whole thus support the conclusion that the open-ended approach is more successful than direct learning in enhancing students' mathematics comprehension abilities.

For a deeper understanding and analysis, the improvement in students' mathematical understanding in this study was classified into three categories based on the level of improvement: high, medium, and low. This classification refers to the criteria adopted by Ali et al. (2021), which allows for a more detailed analysis of the distribution of levels of improvement in each group. Table 4 presents a systematic overview of the analysis's findings, including the average N-gain, the number of students in each category, and the percentage of students who improved at each level. In addition to providing specific information about the distribution and trend of learning skill improvement among students in both groups, this table offers a thorough picture of how well open-ended and direct learning approaches enhance students' mathematical comprehension abilities.

Table 4. Summary of average math improvement

Learning Group	(N-Gain)	Category
Open-Ended Approach	0.72	High
Direct Learning	0.62	Medium

The data presented in Table 4 demonstrate that students' mathematics comprehension improved considerably more in the open-method learning group than in the direct-learning group. This finding is supported by the Wilcoxon W test results, which showed a significance value (Sig. = 0.004) below the significance level of α = 0.05. The difference in the two groups' improvements in mathematical understanding was statistically significant, providing strong evidence that the open-ended method is more successful in enhancing students' mathematical understanding.

Discussion

Through a comprehensive statistical data analysis process, this study successfully revealed significant findings related to the influence of two learning approaches, open-ended and direct, on students' learning. These findings demonstrate that the improvements in mathematical comprehension of the two groups varied significantly. Specifically, students in the open-ended learning group improved their arithmetic understanding skills more than those in the direct learning group. This discrepancy demonstrates a wider trend in which the open-ended approach is more successful in fostering students' overall learning capacities, in addition to the element of individual progress. These results offer a profound understanding of the advantages of the open-ended method in producing a more significant and successful educational process for teachers. This supports Talafian et al. 's(2024) assertion that pupils are reminded of questions with related concepts that they have already learned.

This conclusion is corroborated by the N-Gain data analysis results, which demonstrate that students who received instruction via an open-ended approach improved their mathematics comprehension abilities more than those who received direct instruction. This difference is very clear at the overall level, where the group of students who used the open-ended approach showed a higher average N-gain. This suggests that the open-ended approach is more effective in helping students improve their mathematical understanding than the direct learning applied to the control group does. Daas et al. (2023) state that this approach is an innovation that is effective as a practical implementation in mathematics learning due to the study design that uses open resources and readily available tools, making it very suitable for regular use in the classroom, especially when time and resources are limited.

Data analysis of students' attainment of mathematical comprehension skills, which demonstrated a notable change following the application of learning, supports this assertion. Prior to the start of instruction, the pre-test results indicated that there was no discernible difference between the groups that used direct learning and the open approach. However, the two groups' improvements in mathematical comprehension differed significantly after the treatment was implemented, according to the post-test data. This discrepancy demonstrates that the open-ended approach is more successful than direct learning in enhancing students' comprehension of mathematical topics and has a noteworthy beneficial impact on their ability to develop their mathematical understanding.

These findings suggest that the open-ended approach significantly enhances students' capacity for mathematical understanding. The overall results of the data analysis provide empirical evidence that the open-ended approach is more effective than direct learning in promoting improved mathematical understanding among primary school teachers. This was particularly evident in the post-test results, where the open-ended learning group showed a significant improvement over the direct learning group. This discrepancy demonstrates how well the open-ended approach works to enhance students' learning results, particularly in the area of mathematical comprehension, which can help students become more adept at solving problems. According to Heliawati et al. (2021), students who receive an open-ended approach outperform those who receive regular instruction in terms of their mathematics understanding and success in mathematics.

The results showed that the students made the most mistakes when applying arithmetic sequences to solve everyday problems. Although students understood the concept, 58.33% still made mistakes in the steps to solve the problem, indicating that conceptual understanding had not been fully integrated with procedural skills. Question 3 proved to be the most difficult, with 66.67% of students making mistakes, particularly those in the intermediate ability group, followed by question 2 with an error rate of 52.38%. A more in-depth analysis found that the main errors were procedural, such as carelessness in calculations, particularly when performing multiplication or exponentiation.

In terms of learning outcomes, the group that used the open-ended approach achieved an average post-test score of 9.28 (77.33% of the ideal score) with a standard deviation of 1.72, which is classified as "good." Meanwhile, the control group with the direct approach obtained an average score of 8.42 (70.17%) with a standard deviation of 1.78, which is also classified as "good." The difference in the average scores between the two groups shows that the open-ended approach is more effective in improving students' understanding of mathematics, even though both approaches are in the same category. This finding also emphasises the importance of training procedural skills integrated with conceptual understanding through an open-ended approach to minimise students' errors in solving mathematical problems.

Mathematical understanding is an important foundation in mathematics learning, which includes students' ability to understand concepts, principles, and relationships between ideas in mathematics (Anderson et al., 2023). Mathematical understanding is not limited to memorising procedures but also involves the ability to apply concepts in various contexts (Daas et al., 2025). One approach that is considered effective in developing this ability is the open-ended approach, which provides opportunities for students to explore various solutions to a problem (Pott et al., 2021). This approach encourages students to think creatively and deeply, thereby strengthening their conceptual understanding (Rowlett et al., 2025). Thus, there is a close relationship between the open-ended approach and improved mathematical understanding of the problem.

The open-ended approach focuses on presenting problems that have multiple solutions or ways of solving them, thereby stimulating students to think divergently (Micheal et al., 2024). Open-ended problems allow students to develop problem-solving strategies according to their level of understanding (Citci et al., 2024). This is in line with constructivist theory, which emphasises that students actively construct knowledge through learning experiences (Jacobson et al., 2018). When students are given the freedom to explore solutions, they tend to understand mathematical concepts more deeply (Yao et al., 2020). Therefore, the open-ended approach can be an effective means of improving students' mathematical understanding.

The open-ended approach positively contributes to students' mathematical understanding. Several studies, such as those conducted by Husband et al. (2023), show that this approach triggers discussion and collaboration, thereby enriching students' perspectives (Khatin et al., 2022). In addition, the open-ended approach helps identify students' conceptual errors, enabling teachers to provide appropriate feedback (Devlin et al., 2023). Coetzer (2023) also found that students who learn with open-ended problems have a better understanding than those who learn through conventional methods. Thus, this approach not only improves mathematical understanding but also encourages critical reflections.

The impact of the open-ended approach is evident at various educational levels. At the elementary school level, this approach influences learning outcomes and mathematical reasoning (Triet et al., 2024). Meanwhile, at the junior high school level, there is an increase in creative thinking skills and conceptual understanding (Hornburg et al. (2022). These findings are in line with the research by Rotem et al. (2024), who showed an increase in the mathematical understanding of MT students. Furthermore, the open-ended approach also influences the creative thinking abilities of high school students (Tambunan, Fauzi, & Sitompul, 2025). Thus, the open-ended approach can be an effective learning strategy at various educational levels and contexts.

In addition, the open-ended approach encourages student engagement in the learning process (Enzinger, 2024). When students feel that their opinions are valued, their intrinsic motivation to understand mathematics increases (Artzt, 2024). High motivation correlates with a deeper understanding, as students are more willing to explore concepts independently (Huang et al., 2024). The open-ended approach also reduces math anxiety, which often hinders understanding (Triet, 2024). Thus, this approach not only improves understanding but also creates a positive learning environment for students.

Some challenges in implementing the open-ended approach include the need for teacher readiness and longer learning time (Uegatani, 2024). Teachers must be trained to design open-ended problems that are appropriate for students' ability levels Abdissa et al., (2024). In addition, evaluating learning outcomes using this approach requires a comprehensive rubric to assess various possible solutions Spitzer et al., (2025). Nevertheless, the benefits of the open-ended approach in improving mathematical understanding far outweigh the challenges (Borji et al., 2025). Therefore, teacher training and the development of supporting teaching materials should be prioritised.

The open-ended approach has great potential to improve the mathematical understanding of vocational school students, especially because of its ability to relate mathematical concepts to vocational contexts. Through open-ended problems relevant to students' fields of study, this approach encourages discussion and collaboration, allowing students to exchange ideas to solve real-world problems. For example, in learning linear functions, teachers can provide cases of production cost optimization or break-even point analysis so that students not only understand the formula but also its application in the world of work. This approach also helps teachers identify students' conceptual errors more effectively, such as when analysing their understanding of geometry for graphic or engineering design, so that the feedback provided is more accurate and reinforces students' understanding.

In addition, the open-ended approach trains vocational school students to think creatively and find various solutions to a single problem, such as analysing sales data using different methods or calculating machine efficiency using various variables. This is in line with the needs of the world of work, which demands problem-solving and innovation skills. By designing contextual open-ended problems according to the major, mathematics learning becomes more meaningful and interesting for vocational school students. This approach not only improves conceptual understanding but also develops critical thinking skills, creativity, and collaboration, which are key competencies required of vocational school graduates. For implementation, teachers can use case studies from the industry, integrate collaborative projects between majors, and give students the freedom to explore various solutions.

Based on this description, the open-ended approach has a significant relationship with improving the mathematical understanding of students in vocational high schools. This approach not only encourages divergent thinking and strengthens conceptual-procedural understanding but also increases learning motivation through contextual applications. Although there are challenges in its implementation, such as the need for more thorough material preparation, various studies have proven the effectiveness of this method. Therefore, integrating the open-ended approach into mathematics learning can be an effective strategy for developing a deep understanding while preparing students to face the challenges of the working world.

Conclusion

Students who use open-ended learning strategies demonstrate greater gains in mathematics comprehension than those who use direct learning strategies. Students can actively participate in the learning process with the open-ended method, which fosters critical thinking, autonomous problem-solving, and exploration of various approaches to mathematical challenges. This enhances their capacity to comprehend mathematical ideas more thoroughly. However, because direct learning typically offers pre-made answers, pupils are less accustomed to a more adaptable and imaginative approach to problem-solving. Therefore, it can be concluded that the open-ended approach has a significant influence on improving students' mathematical understanding skills, especially at the vocational high school level, by giving students more opportunities to develop their critical and analytical thinking skills in a mathematical context.

Several issues require attention. First, as the open-ended approach to mathematics instruction is more successful in enhancing students' mathematical comprehension abilities, it should be promoted in vocational high schools. This approach allows students to think creatively and analytically and to be more active in finding different solutions to mathematical problems. Therefore, the mathematics curriculum needs to be structured to support the implementation of this approach by presenting materials and questions that allow students to explore different solutions. Additionally, math teachers must receive training on how to effectively manage open-ended learning, which includes creating questions that push students to think more deeply. Assessment of learning also needs to be adapted, with more emphasis on students' thinking processes and understanding of concepts rather than just the correct answer. Therefore, mathematics teaching needs to adopt an open and flexible approach to improve students' mathematical understanding, especially in relating abstract concepts to real contexts.

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Conflicts of Interest

The authors state that they have no conflicts of interest. Furthermore, the writers have addressed the ethical concerns of plagiarism, misconduct, data fabrication and/or falsification, duplicate publishing and/or submission, and redundancy.

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Author Contributions

Rusdian Rifai: Conceptualization, original draft writing, editing, and graphics; **Turmudi**: Methodology, formal analysis, and writing, including review and editing; **Jarnawi Afgani Dahlan** and **Suhendra**: oversight and validation.

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