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The effect of open-ended approach on enhancing mathematical understanding in vocational high school students

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ABSTRACT

This study aimed to evaluate the extent to which the open-ended approach affects students' mathematical understanding in vocational high schools (SMK). A quasi-experimental method with a pretest-posttest control group design was employed, comparing two groups of students (experimental and control) based on their test results before and after treatment. The research sample consisted of 72 students, selected using an intact-group sampling method (based on pre-existing classes) to minimize disruption to teaching and learning activities. This sampling approach considered real classroom conditions, ensuring that the study did not interfere with the established learning schedule and class structure. Data were collected using a descriptive test comprising three questions, each with a maximum score of 12. Data analysis was conducted in two stages: first, a normality test was performed to assess the data distribution; second, a mean difference test was conducted using the Mann-Whitney U Test due to the non-normal distribution of the data. The results showed that students taught using the open-ended approach achieved higher mathematical understanding than those who received direct instruction. This finding suggests that the open-ended approach is effective in fostering conceptual understanding through independent exploration. Therefore, this approach can be applied in mathematics instruction, particularly for topics such as sequences and series, which require conceptual comprehension and deep reasoning skills.

KEYWORDS

Open-ended approach; mathematical understanding; vocational high school; mathematics learning

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INTRODUCTION

Mathematics education in vocational high schools (SMK) often faces the challenge of low mathematical comprehension among students. For instance, in the topic of sequences and series, many students struggle to apply the arithmetic series formula to solve real-world problems, such as Students often fail to provide concrete examples or apply the arithmetic series formula to real-world problems, such as calculating gradual savings (Sukmayanti et al., 2025). PISA 2022 data indicate that Indonesian students' mathematical literacy ranks 72nd out of 81 countries, with an average score of 366, significantly below the OECD average of 472 (OECD, 2023). This issue is exacerbated in SMK, where the curriculum emphasizes vocational practice, leading students to perceive mathematics as abstract and less relevant (Kemdikbud, 2022). A report revealed that students had difficulty identifying geometric shapes based on formal definitions, were unable to visualize shapes, and failed to understand

geometric terms or symbols, which contributes to low national mathematics exam scores, averaging 48.5 in 2023 (BSNP, 2023).

Several factors contribute to the weak mathematical understanding of vocational students. First, the low relevance of the material, with only 30% of vocational mathematics content connected to vocational subjects. The revision of the mathematics curriculum has resulted in shorter teaching time, causing lecturers to place greater emphasis on theoretical (general) material and reduce applied content (Sevimli, 2022). Survey data shows that up to 75% of teaching activities still involve direct information delivery by teachers, while only about 22-26% are interactive or facilitative (Cox & Prestridge, 2020). More than 70% of students in one survey felt that math assignments were too difficult to complete on their own (Yang & Jamaludin, 2024), and about 66% felt stressed due to high expectations from teachers and parents (Mendoza et al., 2024).

Students with poor mathematics skills tend to fail at completing technical tasks that require numerical understanding, putting them at risk of failing or being unable to continue to the final level of vocational education (Oduro-Okyireh et al., 2024). Traditional teaching models are still widely used in vocational schools, especially for teaching theory (Wang, 2024). This model is considered incapable of meeting practical needs and developing 21st-century skills, thus encouraging the need for innovation (Hu & Gong, 2022). Only 30% of prospective mathematics teachers understand concepts, while 85% are proficient in procedures, meaning that the majority are not prepared to apply their knowledge to new situations (Arslan, 2010). Mathematics learning in vocational schools, which is still dominated by lecture and exercise methods, only trains students to memorize procedures, thus failing to build conceptual understanding, application skills, and higher order thinking skills (Ayuningsih, Dwijayani, & Ciptahadi, 2020).

Traditional lecture methods tend to create a passive learning environment, where students only receive information without active involvement (Lee & Paul, 2023; Dairo et al., 2024; Huang et al., 2020). A meta-analysis by Mediana et al. (2025) found that inquiry-based learning (IBL) has a very large effect size ($g = 0.913$ in general, and $g = 1.191$ specifically for mathematics), indicating a strong impact on mathematical concept understanding. Moreover, teacher-centered methods provide insufficient opportunities for students to develop problem-solving and reasoning skills, which are essential in the 21st-century curriculum (Graham, Burrill, & Curtis, 2018).

The dominance of conventional methods also contributes to low cognitive engagement. Britwum et al. (2024) stated that students taught using a teacher-centered approach were more likely to exhibit a fixed mindset, while students taught using a student-centered approach tended to have a growth mindset and were more likely to believe that mathematical ability could be developed through effort. This is reinforced by PISA 2022 data showing that only 35% of vocational students in Indonesia are highly motivated to learn mathematics, far below the 52% average for high school students (OECD, 2023).

As a solution, the open-ended approach offers interactive and contextualized learning through problems with multiple solutions, stimulating critical and creative thinking. Open-ended problems allow students to explore various problem-solving strategies while building contextual understanding by linking problems to real-life situations. Desi et al. (2025) found that the open-ended approach was significantly more effective than traditional methods in improving middle school students' mathematical understanding, creative thinking skills, and self-confidence. An experimental study of vocational high school students conducted by Rifai et al. (2025) found that the group taught using the open-ended approach experienced a much higher increase in mathematical communication skills than the group taught using the direct method. This improvement was particularly evident in students' ability to present solutions diagrammatically, mathematically, and verbally, reflecting deeper conceptual understanding.

In the context of mathematical problem solving, students who learn using an open-ended approach are more active in trying, comparing, and evaluating various methods of solution, which is the essence of cognitive flexibility (Rahayuningsih et al., 2021; Hafidzah et al., 2021). According to Shimada and Becker (1997), open-ended problems trigger in-depth mathematical investigations, requiring students to consider alternative solutions rather than just a single correct answer. This process develops analysis, evaluation, and creation skills, key components of the HOTS taxonomy (Anderson & Krathwohl, 2001). Ibrahim and Widodo (2020) revealed that open-ended questions require students to think creatively and divergently, so that they become accustomed to seeking various alternative solutions and are more confident in dealing with non-routine problems.

Mathematical representation is a crucial indicator of conceptual understanding. Rolfes et al., (2021) found that learning mathematics with multiple representations (graphs, tables, verbal) resulted in a richer and more flexible understanding of concepts compared to using only one form of representation. Students were better able to transfer knowledge between forms of representation. Ruamba et al. (2025) emphasized that a multimodal approach

through visual, symbolic, verbal, and interactive means significantly improved understanding of abstract concepts, reduced cognitive load, and strengthened knowledge retention. Volkwyn et al. (2020) highlight the importance of open-ended representation-based tasks such as graphs for building representational competence, which is the ability to connect real-world phenomena with scientific concepts through various representations.

Despite its proven effectiveness at the junior and senior high school levels, the implementation of the open-ended approach in vocational schools remains limited. Several studies and literature reviews highlight that research with an open-ended approach on vocational students is still very limited or has not been a major focus (Solberg et al., 2023). In fact, the industrial and applied nature of vocational learning makes it well-suited for this approach. Komeini et al. (2022) stated that students who learned using the open-ended method achieved a 72% proficiency level in solving scenario-based problems, which was higher than those who learned using traditional methods.

Given this context, this study aims to implement the open-ended approach in vocational mathematics learning. This approach encourages open thinking and supports the achievement of learning objectives while preparing students for the dynamic demands of the workforce. The study develops a specialized open-ended approach for vocational high school mathematics, addressing gaps in prior research focused on general schools. The novelty of this study lies in: (1) developing mathematics problems based on vocational work contexts, (2) integrating 21st-century skills (deep understanding, collaboration) into assessment, and (3) providing ready-to-use instruments for vocational teachers. Unlike previous studies, this approach not only enhances conceptual understanding but also trains open-ended problem-solving skills relevant to workplace applications. The findings are expected to serve as a model for vocational mathematics education that aligns more closely with industry needs.

METHODS

This study employed a quasi-experimental design with a pretest-posttest control group because the sample selection was based on existing classes rather than random assignment (Ary, Jacobs, & Sorensen, 2010; Creswell, 2012). This method was chosen to maintain natural learning conditions without disrupting the existing class structure or schedule. Two instructional approaches were examined: the open-ended approach for the experimental group and direct instruction for the control group. The primary variable measured was the mathematical understanding of vocational high school students. This design allowed for a comparison of the effectiveness of the two approaches in real classroom settings.

To evaluate the effect of the intervention, both groups were administered a pretest before the learning process and a posttest afterward. The experimental group received open-ended instruction that promoted independent exploration, while the control group was taught using direct instruction. Quantitative data from these tests were analyzed to assess improvements in students' mathematical understanding. By carefully controlling the variables, this study aimed to investigate the effectiveness of the open-ended approach relative to direct instruction. The findings are expected to provide practical insights for improving mathematics teaching strategies.

The study focused on 11th-grade students at vocational high schools (SMK) in Pandeglang Regency, Banten Province, across five skill programs to reflect the diversity of competencies. The Light Vehicle Engineering (TKR) and Motorcycle Engineering and Business (TBSM) programs emphasize automotive technical skills and business literacy, while Computer and Network Engineering (TKJ) (two study groups) focus on IT and network skills. The Office Automation and Management (OTKP) program develops administrative and data management competencies relevant to the modern business environment. Each program integrates theoretical and practical learning to equip students with both technical and soft skills required in industry.

Purposive sampling was employed to preserve the natural classroom environment. This non-probability technique allows researchers to select participants based on characteristics relevant to the study (Friday & Leah, 2024). Two TKJ classes were chosen as the sample: XI TKJ 1 (experimental group) and XI TKJ 2 (control group), each comprising 36 students, totaling 72 participants.

Data were collected using pretest and posttest essay questions that had been validated for accuracy. The aim was to comprehensively assess differences in student learning outcomes on the topic of sequences and series. The pretest measured students' initial abilities before instruction, while the posttest assessed learning achievement, evaluated the effectiveness of instructional methods, and analyzed the development of mathematical understanding. Essay questions were selected because they reveal detailed problem-solving steps, map logical reasoning, identify conceptual errors, and evaluate cognitive processes beyond the final answers.

Data analysis followed two statistical approaches. If data were normally distributed, a parametric test (independent samples *t*-test) was used to compare mean mathematical understanding between groups. If the data were not normally distributed, a nonparametric test

(Mann-Whitney U test) was applied (Field, 2018; Hair et al., 2019). Normality was assessed using the Shapiro-Wilk test, and homogeneity of variance was checked with Levene's test prior to conducting the t-test (Pallant, 2020).

RESULT AND DISCUSSION

Student mathematical understanding was assessed through the posttest following treatment with the open-ended approach. The data include sample size, value range (minimum–maximum), mean, and standard deviation to indicate variability. Pretest results confirmed that students in both groups had comparable initial mathematical understanding. This comprehensive analysis covers the entire research sample and enables an in-depth evaluation of learning outcomes by comparing experimental and control groups. The findings provide important insights into the impact of the open-ended approach on overall student learning.

Table 1 presents a detailed description of students' mathematical comprehension achievement based on the learning approach. This table highlights differences between the open-ended and direct instruction groups and serves as a foundation for conclusions regarding the effectiveness of the instructional methods implemented.

Table 1. Data Description

Approach	N	SMI	Min	Max	Mean	Std. Deviation
Open-Ended	36	12	6,00	12,00	9,2778	1,71733
Directly	36		5,00	12,00	8,4167	1,77884

Table 1 presents the mean mathematical comprehension achievement of students, showing that the group receiving the open-ended approach significantly outperformed the control group taught using the direct approach. This pattern of superiority was consistently observed across the entire sample. These empirical findings suggest that the open-ended approach has strong potential to enhance students' mathematical understanding. However, this conclusion requires further confirmation through statistical analysis to ensure its accuracy and validity. Statistical testing is necessary to evaluate whether the observed differences between the two learning approaches are significant. The following sections present the results of the mathematical understanding achievement tests based on the sampled students.

After providing a detailed description of the data, including initial summaries and statistical tests, the analysis proceeded to examine students' achievement in mathematical understanding. This presentation focuses on overall achievement results and is designed to comparatively investigate significant differences in competence between groups exposed to different instructional approaches. The data were obtained from a set of three validated essay

questions, each with a maximum score of 12. Once collected, the data underwent a series of prerequisite tests to verify compliance with statistical assumptions. Subsequently, a comparative analysis using the independent samples t-test was conducted to assess the significance of differences between the open-ended and direct instruction groups.

The statistical results were further analyzed to evaluate overall differences in achieving mathematical understanding between the two groups. A quantitative approach was employed to ensure objectivity and measurability. The results were presented systematically to illustrate the impact of the instructional treatment. The analysis began with a test for normality of the mathematical understanding data using the Shapiro-Wilk test, with scores from both groups included in the evaluation (see Table 1).

The normality test verified whether the data met the assumption of normality before proceeding with further analysis. The One-Sample Shapiro-Wilk (S-W) test, effective for small to medium sample sizes, was used. Calculations were performed using SPSS version 30 to ensure accuracy. The results of this normality test provide the basis for selecting the most appropriate statistical method to test the research hypothesis. Table 2 presents the results of the normality test for overall mathematical understanding achievement, offering a clear overview of the data distribution and supporting subsequent, structured analysis.

Table 2. Results of the Normality Test of the Data

Approach	Shapiro-Wilk		
	Statistic	Df	Sig.
Open-Ended	,938	36	,044
Directly	,927	36	,021

Table 2 presents the results of the normality test for the distribution of mathematical understanding scores based on the learning approach. The Shapiro-Wilk test yielded $p = 0.044$ for the open-ended group and $p = 0.021$ for the direct learning group. At a significance level of $\alpha = 0.05$, both p-values are less than α, indicating rejection of the normality hypothesis (H_0). Therefore, the data distribution of mathematical understanding scores in both groups is non-normal.

Since the data for both groups are not normally distributed, the analysis proceeded using nonparametric methods that do not assume normality. To examine differences in the central tendency of mathematical understanding between the groups, the Mann-Whitney U test was employed as a nonparametric alternative to the independent samples *t*-test. The statistical output of the Mann-Whitney U test, which measures the differences between groups, is presented in Table 3.

Table 3. Result if the Mean Difference Test

Mann-Whitney U	467,500
Wilcoxon W	1133,500
Z	-2,065
Asymp. Sig. (2-tailed)	0,039

Table 3 presents the results of the comparative analysis of students' mathematical understanding. The Asymp. Sig. (2-tailed) value was 0.039. Using a one-tailed test, this value is divided by two, resulting in Sig. (1-tailed) = 0.0195. Comparing this value with the significance level ($\alpha = 0.05$), we find that $0.0195 < 0.05$. Therefore, it can be concluded that students who received the open-ended approach demonstrated superior achievement in comprehensive mathematical understanding compared to those who received direct instruction.

An in-depth statistical analysis was conducted to examine the impact of the open-ended approach versus direct learning on students' mathematical understanding. The results revealed significant differences in learning outcomes between the two groups, with the open-ended group showing greater progress. This finding supports the research hypothesis and indicates that the open-ended approach provides a more meaningful and effective learning experience.

The consistency of these results is reinforced by achievement data showing significant development of mathematical understanding in the open-ended group. These findings align with Rohmah & Ulya (2021), concludes that the CORE learning model through an open-ended approach provides opportunities for students to develop and analyze ideas, thereby improving mathematical critical thinking skills. Empirical evidence is further reflected in consistently higher average scores in the open-ended group, indicating a more optimal impact on students' overall mathematical understanding.

A comparison of pretest and post-test scores revealed no significant differences between groups before the intervention, confirming that both groups started at a similar level. However, post-test results indicated a clear achievement gap in favor of the open-ended group, confirming the effectiveness of this approach in improving learning outcomes, particularly in mathematical understanding.

Analysis of student errors revealed that the most frequent mistakes occurred in applying arithmetic sequence rules to real-world contexts (58.33%), highlighting gaps in integrating conceptual understanding with procedural skills. Problem 3 posed the greatest challenge (66.67% errors), followed by Problem 2 (52.38% errors). Most errors were

procedural, such as miscalculations, indicating the need for more integrated exercises in the open-ended approach.

Quantitatively, the open-ended group achieved a mean score of 9.28 (77.33% of the ideal score) with a standard deviation of 1.72, classified as "good." In comparison, the direct learning group scored a mean of 8.42 (70.17%) with a standard deviation of 1.78. Although both groups fall within the "good" category, the higher mean of the open-ended group demonstrates the approach's superiority in optimizing students' mathematical understanding.

This study focused on measuring the mathematical understanding of 72 XI-grade Computer and Network Engineering students on sequences and series. Methodological limitations include the quasi-experimental design, which could not fully control for confounding variables, the essay test instrument, which may not capture the full complexity of the open-ended approach, and the short duration of the study, which only allows assessment of short-term effects. Additionally, the approach may need further adaptation for vocational students, who are practically oriented, and external factors such as student motivation and environmental support were difficult to control.

Future research could expand the sample to include more vocational schools across different fields and adapt the open-ended approach by integrating mathematically relevant problems in vocational contexts. These enhancements could provide a stronger foundation for developing more effective mathematics learning strategies in vocational education

CONCLUSION

The study found that students who received the open-ended approach achieved better mathematical understanding than those who followed direct instruction. The positive impact of this approach stems from its emphasis on exploration and independent construction of knowledge. Unlike procedural direct instruction, the open-ended approach encourages students to discuss, experiment, and develop their understanding actively. Consequently, it not only improves learning outcomes but also strengthens the foundation for long-term conceptual understanding. Therefore, the open-ended approach is recommended as an alternative in vocational mathematics education, particularly for preparing students to meet the challenges of their future careers.

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