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Research Article

Improving Vocational School Students' Mathematical Communication Skills Through an Open-Ended Approach

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Abstract:

The rapid development of technology and industry across various sectors, such as digital technology, automation, and data analytics, requires a workforce with relevant technical skills. Although Vocational Schools (SMK) aim to produce ready-to-work labor in Indonesia, data shows that the unemployment rate among SMK graduates remains high. One of the causes is the lack of mastery in applied mathematics, which is essential in many industrial fields. This study aims to analyze the effectiveness of the open-ended approach in improving the mathematical communication skills of SMK students. The research method used is a quasi-experimental design with a pretest-posttest control group. The study involves two groups: an experimental group using the open-ended approach and a control group using a direct approach. The research population consists of eleventh-grade SMK students, with a purposive sampling method applied to two classes at SMK Dwi Putra Bangsa, namely classes XI Computer Network Engineering (TKJ 1 and TKJ 2), each of 36 students. The data analysis techniques used include normality, homogeneity, and Mann-Whitney U tests to compare differences between the experimental and control groups, as the data did not follow a normal distribution. The results show that using the open-ended approach, the experimental group experienced a more significant improvement in mathematical communication skills than the control group. This improvement is evident in the higher N-Gain results of the experimental group. In conclusion, the open-ended approach has proven to be more effective in improving the mathematical communication skills of SMK students. Therefore, it is recommended that this approach be implemented more widely in SMK to enhance students' readiness in facing the workforce's increasingly data-driven and technology-based challenges.

1. Introduction

The rapid development of technology and industry demands a skilled workforce, especially in areas that require specific technical skills such as digital technology, automation, and data analytics. A *World Economic Forum* (WEF) [1], report reveals that more than 50% of future jobs will require these skills. In Indonesia, although vocational high schools (SMK) are designed to produce ready-to-use workforce, data from the Central Statistics Agency (BPS) [2], shows that the open unemployment rate (TPT) of vocational school graduates reaches 9.42%, higher than high school graduates which is only 7.56%. This gap indicates a mismatch between the skills taught in vocational schools and the needs of the industry, which necessitates a review of the vocational education system to make it more relevant to the labour market.

To overcome this, the Ministry of Education, Culture, Research, and Technology [3], noted that

more than 3,500 vocational schools have implemented *a link and match* program with industry since 2021. This program aims to improve students' skills through industrial work experience (PKL) and company collaboration. However, even though this program has been implemented, data from *the Indonesian Institute for Development* (IID) [4], shows that only about 40% of vocational school graduates work in fields according to their skills, while the rest are forced to switch to the informal sector or continue their education to a higher level. This reflects a significant challenge in optimizing the role of vocational schools as a ready-to-use workforce printer.

Rapid changes in the industrial sector, especially with the Industrial Revolution 4.0, require vocational school curricula to adapt to the latest technological developments. For example, the manufacturing sector now requires skills in the areas of *Internet of Things* (IoT) and artificial intelligence (AI), while the financial services sector requires expertise in data *analytics and cybersecurity* (McKinsey Global Institute) [5]. However, a report by the Center for Education and Culture Policy Research [6], revealed that only 30% of vocational schools integrate the latest technology in their learning. This has led to many graduates having less relevant skills to the demands of modern industry. Some vocational schools that work with big tech companies such as the Apple Developer Academy and Samsung Innovation Campus have started teaching coding and design-based skills, but many schools still lack supporting infrastructure, such as digital labs and industry-based software.

Interest in vocational education in Indonesia continues to increase, with vocational school registrants increasing from 4.8 million in 2015 to more than 5.5 million in 2020 [7]. This increase is primarily fueled by the growing number of industry-based training programs that offer globally recognized skills certifications. For example, the tourism sector in Bali and Yogyakarta is collaborating with international certification bodies to train vocational school students with global service standards [8]. However, although job opportunities for vocational school graduates are becoming clearer, many face challenges in getting decent jobs, especially in areas with industry limitations.

Socioeconomic factors also play an important role in the readiness of vocational school students to enter the world of work. A report by the National Development Planning Agency [9]. shows that around 60% of vocational school students come from lower-middle-income families, which often experience limitations in accessing additional education or non-formal training. This causes students from low economic backgrounds to enter the world of work quickly, but with jobs with limited economic mobility. Meanwhile, students from higher-income families are more likely to continue their studies or work in companies with more stable salaries. For this reason, a more inclusive vocational education policy, such as providing skills scholarships and entrepreneurial support, is indispensable.

However, one of the main obstacles in the readiness of vocational school graduates to work in a growing industry is the lack of mastery of applied mathematics, which is essential in many industry areas. Most vocational school students, especially from low-income families, have difficulty accessing advanced mathematics training. This hinders their ability to face technical challenges in the world of work, given that applied mathematics is indispensable in various sectors such as manufacturing, information technology, and tourism. The report of the Center for Research and Culture (2023) shows that more than 60% of vocational school students have difficulties in analysis-based mathematics problems, which prevents them from understanding crucial technical concepts.

Mathematics learning in vocational schools is often focused on theory and lacks real-world applications. Results from the *Programme for International Student Assessment* (PISA) show that Indonesian students score low in applied mathematics comprehension, especially in problem-solving and data-driven decision-making (OECD), [10].The lack of integration between mathematics and vocational subjects makes it difficult for students to see the relevance between theory and practice, ultimately reducing their readiness to work in an increasingly data-driven industry.

With the rapid development of industries that utilize big data and artificial intelligence, vocational school students need strong math skills, especially in statistics, algebra, and basic calculus. A *McKinsey Global Institute* report [5], shows that only 30% of vocational school graduates have adequate numeracy skills to work in digital technology. This lack of skills limits their chances of landing high-paying jobs in the technology and manufacturing sectors.

In addition to technical skills, mathematical communication skills are also a crucial factor in the readiness of vocational school graduates. This ability includes not only an understanding of mathematical formulas and procedures, but also the ability to communicate ideas and solutions clearly and effectively. In the industrial world, vocational school graduates are often required to deliver data-

driven analysis to colleagues who do not share the same technical background. However, according to Sheila and Adirakasiwi [11], most vocational school students have low mathematical communication skills, with an average score of only 39.31 out of 100. In addition, Sistyawati [12], reported that students' mathematical communication skills are still low, because only 34.4% of students can answer questions correctly related to row and series material. Therefore, it is important to improve this mathematical communication ability so that vocational school graduates can interact more effectively in the increasingly data-driven world of work.

An open-ended *approach* to learning mathematics can be the solution to overcome these challenges. In many contexts, *open-ended* leads more to the liberation of individuals to develop ideas and thoughts without being bound by rigid rules or formats. *Open-ended questions* are one example of the application of this approach, which allows individuals or respondents to provide answers beyond pre-prepared choices. *An open-ended* approach refers to techniques that allow individuals to think and express their views more broadly and creatively, without the influence of strict structures or boundaries in a particular situation [13],

The *open-ended* approach is based on constructivist learning theory that emphasizes the importance of the learning process rather than just the achievement of the result. In this approach, students are not only directed to find the correct answer but must also be able to explain and elaborate the steps of their completion systematically. Becker and Shimada [14], suggest four stages in *open-ended learning*: providing open-ended problems, building understanding through experience, exploring various strategies, and presenting problem-solving results.

In mathematics learning, *an open-ended* approach is used to encourage students to think of correct answers and explore various possible answers, ideas, or solutions. This is very important in the development of critical thinking and creativity. Paul and Elder [15] emphasize that *open-ended* questions can guide students to think more deeply, hone their analytical skills, and develop solutions based on their understanding, rather than relying solely on previously learned knowledge. In addition, Dewey [16], highlighted the importance of experience in learning. He believed that a good education allows students to actively engage in the learning process and develop their thinking abilities through real experience and free exploration, which can be achieved using *an open-ended* approach.

The *open-ended* approach to mathematics learning has advantages, especially in increasing creativity, developing critical thinking skills, and flexibility in decision-making. Simon [17] explains that effective decision-making must involve a variety of alternatives that can be analyzed and considered in depth. The *open-ended* approach allows decision-makers to see the various sides and potential in complex situations. This approach allows individuals to think outside existing boundaries, leading to more innovative and creative problem-solving. Students or individuals involved in *open-ended* processes can develop the ability to analyze information and make more informed decisions. This approach allows the exploration of various solutions or alternatives in complex situations.

This approach is expected to help vocational school students develop mathematical skills that are more relevant to the needs of the industry. Thus, students will have more applicative abilities in facing challenges in the world of work. In addition, this approach also aims to improve students' mathematical communication skills, so they are better prepared to contribute in various professional fields.

2. Research Methods

This study aims to analyze the effectiveness of learning with *an open-ended* approach in improving mathematical communication skills. The method used was a quantitative experiment with *a pretest-posttest control group* design, which involved two groups: the experimental group using *an open-ended* approach and the control group using a direct approach. This study is a *quasi-experimental* because the selection of subjects for each group is not done randomly, but based on the existing class [18,19],

The selection of research subjects considers the real conditions in the school without changing the existing class structure, to reflect field practice. The experimental group was given learning with *an open-ended* approach that emphasized open-ended problem exploration, while the control group used a hands-on approach that focused on the teacher's structured delivery of the material. Both groups were given a *pretest* to measure initial ability, and a posttest after treatment to measure improved mathematical communication skills.

The research sample consisted of 72 SMK Dwi Putra Bangsa grade XI students, who were selected using *purposive sampling* techniques. Class XI Network Computer Engineering (TKJ 1) became an experimental group and (XI TKJ 2) became a control group, each amounting to 36 students. The instrument used is a description test to measure students' mathematical communication skills on

row and series material, which has been tried first to ensure its validity and reliability.

Data were analyzed by statistical tests, including normality tests, variance homogeneity tests, and differences between experimental and control groups using SPSS version 30 at a significance level of 5% (0.05). The data analyzed is N-gain, which measures the improvement of students' abilities. This analysis aims to determine the significant differences between the two groups in improving students' mathematical communication.

3. Results and Discussion

The description of improving mathematical communication skills was carried out by assessment using three description questions. Each question has a maximum score of 12, which is applied to the initial test (*pretest*) and final test (*posttest*). In order to make the analysis more detailed and easier to understand, the data on *the pretest and posttest results* have been summarized in Table 1. The table presents the average scores and standard deviations for both tests. The presentation of this data aims to make it easier for readers to identify patterns of improvement in students' mathematical communication skills.

Table 1. *Description of Mathematical Communication Skills Improvement*

Statistics	Open-Ended Approach			Direct Approach		
	Pretes	Postes	N-Gain	Pretes	Postes	N-Gain
N	36			36		
x̄	3,2222	9,9444	,7800	3,0556	9,1944	,7028
sd	1,53271	1,01262	,08626	1,41309	1,41056	,12409

Based on the N-Gain data in Table 1, the improvement of mathematical communication ability can be analyzed through the N-Gain column. The students who participated in learning with *an open-ended* approach obtained an N-Gain score of 0.7800. The students who participated in learning with a direct approach received an N-Gain score of 0.7028. In comparison, the N-Gain values of both groups showed a relatively similar improvement, but with a slight advantage in the group that followed the *open-ended* approach. Although both groups showed improvements, the group with *an open-ended* approach experienced a more significant increase. This indicates that learning using *an open-ended* approach improves students' mathematical communication skills more effectively than a direct approach.

Before conducting a difference test on the improvement of mathematical communication skills between the two groups, it is necessary to conduct a prerequisite test to ensure the feasibility of the data. The first prerequisite test performed is the normality test, which aims to determine whether the distribution of N-Gain data follows a typical distribution pattern. If the data met the normality assumption, the analysis was followed by a homogeneity test, which was used to check for variance similarity between groups.

The homogeneity test calculation was performed using *the Levene test*, which specifically tests the uniformity of variance between groups at a particular significance level, such as $\alpha = 0.05$. If the test results show homogeneous variance, then the difference in the improvement of mathematical communication skills can be analyzed by parametric test methods, such as t-tests. Conversely, if the data is not homogeneous or not normally distributed, then the analysis is continued with a non-parametric test, such as *the Mann-Whitney U*.

The normality test of the data to improve students' mathematical communication skills was carried out using *the One-Sample Shapiro-Wilk* (*S-W*) method. This method was chosen because it has good accuracy to test the normal distribution of data with small to medium sizes. The results of the normality test calculation can be seen in Table 2, which presents detailed information about the statistical test value, significance, and interpretation of the distribution of N-Gain data. The table helps determine whether or not the data being tested follows a normal distribution, which is an important step in determining the appropriate advanced statistical analysis.

Table 2*. Results of the Normality Test of Both Groups*

Class	Shapiro-Wilk		
	Statistic	Df	Sig.
POE	,898	36	,003
PL	,903	36	,004

Table 2 shows the results of the normality test on the data on the improvement of mathematical communication skills of students in both groups, namely the group of students treated with an open-ended approach and students treated with a direct approach. The students who used *the open-ended* approach obtained a significance value (Sig.) of 0.003, which is smaller than the significance level (α) of 0.05. Meanwhile, the group of students who used the direct approach got a significance value

(Sig.) of 0.004, which is also smaller than α = 0.05. This shows that the data on improving students' mathematical communication skills in both learning groups is not normally distributed. These findings indicate that further statistical analysis needs to use nonparametric methods that do not assume the normality of the data.

Because the normality test results showed that both classes, both those using *the open-ended* approach and the direct approach, were not normally distributed, a difference analysis was carried out using a non-parametric test, namely *the Mann-Whitney U test*. This test was chosen because it could compare two independent groups without requiring standard distribution assumptions in the data. The results *of the Mann-Whitney U* test are presented in detail in Table 3, including statistical test scores, significance levels, and interpretation of the differences between the two groups in improving students' mathematical communication skills. This analysis provides a deeper insight into the effectiveness of each learning approach.

Table 3. *Average Difference Test Results*

	Nilai
Mann-Whitney U	424,500
Wilcoxon W	1090,500
Z	-2,560
Asymp. Sig. (2-tailed)	,010

Table 3 shows the results of the *Mann-Whitney U* test which shows that the significance value (Sig.) for the two-sided (*2-tailed*) test is 0.010. Given that the hypothesis being tested is one-sided, namely, the significance value (H_0: $\mu_1 \leq \mu_2$*Sig. 2-tailed*) must be divided in two to obtain the significance value of one party. The calculation yields a value of Sig. (*1-tailed*). Since the value of Sig. ($\frac{0,010}{2} =$ 0,005*1-tailed*) = 0.005 is smaller than the predetermined level of significance (α = 0.05), the null hypothesis () is rejected. Thus, it can be concluded that an alternative hypothesis is accepted, stating that "The improvement of mathematical communication skills of students who acquire learning with H_0: $\mu_1 \leq \mu_2$*an open-ended* approach is better than students who acquire learning with a hands-on approach is reviewed from the overall student." These results support the claim that *the open-ended* approach significantly improves students' mathematical communication skills.

This presentation provides a detailed explanation of improving students' mathematical communication skills based on the N-Gain data analyzed for the group using *an open-ended* approach and the group with a direct approach. The analysis showed that students who received learning with *an open-ended* approach experienced a more significant increase in mathematical communication skills than students with a direct approach. This shows that *the open-ended* approach has a more effective impact on improving overall mathematical communication skills.

In order to provide a more structured understanding, improving students' mathematical communication skills is summarized in the categories adopted from Meltzer (2002). This category includes high, medium, and low improvement levels, which allows for a more in-depth analysis of learning outcomes. The recapitulation of this data is presented in Table 4. It includes information such as the average N-Gain, the distribution of students in each category, and the comparison of improvements between groups, making it easier for readers to understand the pattern of learning outcomes based on the approach used.

Table 4. *Average Recap of Mathematical Communication Ability Improvement*

Learning	Increased (N-Gain)	Category
POE	0,7800	High
PL	0,7028	High

Table 4 explains in detail that the improvement of mathematical communication skills of students who receive learning with *an open-ended* approach is higher than that of students who use a direct approach. Data analysis showed significant differences between these two groups, as shown by the results of *the Mann-Whitney U* test with the one-party hypothesis. The test results showed a significance value (Sig. = 0.005), smaller than the set significance level (α = 0.05), so the difference was statistically acceptable.

When reviewing the mathematical communication skills pretest data, no significant differences were found between the students who used the *open-ended* approach and the group with the direct approach. This showed that both groups of students had comparable initial mathematical communication skills before treatment was given. After being given treatment, it was found that there was a significant difference in the improvement of mathematical communication skills between the two groups. Students who followed learning with an *open-ended* approach showed greater improvement than students with a hands-on approach. These findings indicate that learning with *an open-ended* approach has a significant positive influence on improving students' overall mathematical communication skills.

The analysis showed a significant difference in the improvement of mathematical communication

skills between the group of students who received learning with an open-ended approach and those who used a direct approach. This difference suggests that *the open-ended* approach improves students' mathematical communication skills more effectively than the direct approach. This can be due to the characteristics of *the open-ended* approach that allows students to more actively communicate and discuss in understanding mathematical concepts.

Improving mathematical communication skills in the group with this *open-ended* approach also provides tangible evidence that the approach has a significant positive impact on students' mathematical communication development. This approach can encourage students to be more confident in conveying their mathematical ideas. Thus, *an open-ended* approach not only aids mathematical comprehension but also enhances students' ability to communicate effectively in a mathematical context.

This significant difference suggests that learning with *an open-ended approach* has varying influences depending on the student's initial mathematical ability. This approach tends to be more effective because it encourages students' active involvement in the learning process, improving their mathematical communication skills. On the other hand, students who already have strong basic skills, so the resulting improvement tends to be more stable even though it remains significant in a specific context.

These results indicate that the *open-ended* approach has an overall positive influence on the mathematical communication ability between groups. However, this approach's effectiveness varies according to each group's needs and characteristics. Thus, *open-ended* learning can be considered an adaptive and flexible method in improving students' mathematical communication skills.

Students who receive learning with *an open-ended* approach still make mistakes when working on mathematical communication skills postes, especially in procedural errors. The most frequent error occurs in determining ratios in problems related to the concept of infinite geometric series in the context of everyday problems. This fallacy suggests that even if students understand the basic concepts, they still have difficulty applying them accurately in more complex situations.

The postes question considered the most difficult by students is question number 3, where 44.44% of students make mistakes in solving the problem. This question requires students to determine the ratio of infinite geometric series in the form of story questions that require careful procedural steps. In addition, question number 1 is also a challenge for students, with 38% of students experiencing errors caused mainly by inaccuracies in understanding the context of the question or doing the correct calculations. This error indicates the need for more emphasis on learning that integrates conceptual understanding and procedural skills.

Overall, the average post-post score of mathematical communication skills in the group of students who received learning with *an open-ended* approach was 9.94 or 82.83%, with a standard deviation of 1.01. When converted into learning outcome criteria, this score is in the "excellent" category, demonstrating the effectiveness of *the open-ended* approach in improving students' mathematical communication skills. In comparison, the average score in the control group using the direct approach was 9.19 or 76.58%, with a standard deviation of 1.41, which was in the "good" category. This difference in score confirms that the *open-ended* approach has a more significant impact on improving students' mathematical communication skills than the direct approach.

4. Conclusions and Suggestions

The improvement of mathematical communication skills of students who obtained learning with *an open-ended* approach showed better results than those who obtained learning with a direct approach, based on an analysis of the entire group of students. These findings confirm that the application of *an open-ended* approach has a significant influence on improving students' ability to communicate their mathematical ideas, especially among Vocational High School (SMK) students. This approach allows students to be more active in developing solutions, arguing, and communicating their mathematical thinking in a more structured and in-depth manner. In particular, students who get an *open-ended* approach consistently improve in conveying ideas and mathematical solutions more effectively, especially in more structured procedural explanations and arguments. This suggests that *an open-ended* approach has a greater positive impact on developing students' mathematical communication skills, which is important to support their academic and professional skills in the future.

Based on findings that show that *the open-ended* approach is more effective in improving students' mathematical communication skills, it is recommended that educators in Vocational High Schools (SMK) gradually begin to implement this approach in mathematics learning. To start, teachers can design multiple learning sessions using

an open-ended approach that engages students in group discussions, case studies, or presenting open-ended problems that require them to come up with various solutions. Educators can also train students to be more active in arguing and explaining their thoughts, by providing constructive feedback. In addition, short training or workshops for teachers to understand the basic techniques of *the open-ended* approach can help them implement this method more confidently and effectively. With these realistic and planned steps, it is hoped that students' mathematical communication skills can develop significantly, without requiring drastic changes in the existing curriculum.

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- **Ethical approval:** The conducted research is not related to either human or animal use.
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