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The Implications of Providing Ill-Structured Problems on Students' Learning Outcomes in the Topic of Polynomial

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Abstrak

Dalam matematika, masalah tidak terstruktur sering kali memberikan tantangan tersendiri bagi siswa karena keterbatasan informasi yang diberikan untuk menyelesaikan masalah tersebut. Tujuan penelitian ini adalah untuk mengetahui implikasi pemberian masalah tidak terstruktur terhadap hasil belajar siswa, khususnya pada materi suku banyak sesuai dengan silabus Kurikulum 2013. Penelitian ini merupakan penelitian eksperimen semu yang melibatkan subjek sebanyak 64 orang siswa kelas XI tahun ajaran 2022/2023 di SMA Santo Paulus Pontianak yang terbagi ke dalam dua kelompok, yaitu kelompok kontrol dan kelompok perlakuan, masing-masing sebanyak 32 orang siswa. Baik siswa di kelompok kontrol maupun kelompok perlakuan sama-sama menerima metode pembelajaran yang sama. Namun, siswa di kelompok perlakuan disodorkan sejumlah masalah tidak terstruktur secara berkelanjutan. Tes kemudian diberikan pada akhir pembelajaran. Nilai tes, baik siswa pada kelompok kontrol maupun kelompok perlakuan, dianalisis normalitasnya dengan menggunakan uji Kolmogorov-Smirnov, kemudian diuji signifikansinya dari segi rata-rata dengan menggunakan uji-t tidak berpasangan. Penelitian ini menghasilkan fakta bahwa pemberian masalah tidak terstruktur membuahkan dampak positif terhadap hasil belajar siswa. Dengan kata lain, penggunaan masalah tidak terstruktur pada materi suku banyak dapat menjadi alternatif untuk meningkatkan hasil belajar siswa, khususnya siswa SMA Santo Paulus Pontianak.
Kata Kunci: Hasil Belajar; Masalah Tidak Terstruktur; Suku Banyak.

Abstract

The aim of this study is to determine the implications of providing ill-structured problems on students' learning outcomes, specifically in the topic of polynomial according to the 2013 Curriculum syllabus. The subjects of this study were 65 students in grade XI of the 2022/2023 academic year at SMA Santo Paulus Pontianak, which was divided into two groups: the control group and the treatment group, with 32 students in each group. Both the control group and the treatment group received the same teaching method. However, the treatment group was consistently given a series of ill-structured problems. The implications of ill-structured problems on students' learning outcomes were assessed through the analysis of daily evaluation scores conducted during the final session. This study found that the provision of ill-structured problems had a positive impact on students' learning outcomes. This conclusion was drawn from statistical calculations using the independent t-test on the daily evaluation scores of the two groups, resulting in t-value of -2.2504 (equivalent to p-value of 0.01415) at a significance level of 5%. The study concludes that providing of ill-structured problems in the topic of polynomial can be an alternative to improve students' learning outcomes, particularly at SMA Santo Paulus Pontianak.
Keywords: Learning Outcome; Ill-Structured Problem; Polynomial.

I. INTRODUCTION

In today's context, the skill of reading situations to solve emerging problems has become incredibly important (Zhong & Xu, 2019). This skill is fundamental as humans have a need to understand every situation they encounter. Furthermore, it can be honed through mathematics education. Moreover, the mathematics curriculum at all levels of education is designed with the primary goal of problem-solving (Mairing, 2020). The essence of problem-solving is knowing what to do when facing unfamiliar problems (NCTM, 2000). However, the most limited information available makes problems difficult to solve using conventional methods. As a result, individuals must make an effort to seek as much experience as possible in facing similar problems. One such problem falls within the scope of mathematics education in schools.

In school mathematics education, there are instances where the problem-solving process involves non-routine problems that are subjectively rarely encountered by most students (Foster, 2023). One form of non-routine problem is presented as an ill-structured problem, contrasting with well-structured problems (Gradini, Yustinaningrum, & Safitri, 2022). Well-structured problems are defined as problems that are presented in a complete manner and have a specific answer obtained by applying appropriate procedures (Reed, 2016). In contrast, ill-structured problems yield non-unique answers due to the limited information provided (Yeong, 2021). Furthermore, ill-structured problems are characterized by their ambiguous nature, giving rise to multiple perspectives (Olewnik, Yerrick, Simmons, Lee, & Stuhlmiller, 2020), lacking clear solution steps, and involving multiple unknown elements (Miner-Romanoff, Rae, & Zakrzewski, 2019).

Ill-structured problems are generally challenging to solve due to the limited information provided, often resulting in multiple solutions or even the absence of a solution (Salam, 2022). However, ill-structured problems actually reflect the types of problems frequently encountered in the real world (Mahmud & Pratiwi, 2019). Furthermore, effective strategies for solving ill-structured problems generally differ from those used to solve well-structured problems (Norris, Grohs, & Knight, 2022). Important skills required to tackle ill-structured problems include problem-solving skills (Gupta, Giabbanelli, & Tawfik, 2018) and mastery of the subject matter (Milbourne & Wiebe, 2018). Specifically, ill-structured problems enhance students' strategic competence in the problem-solving process (Yeong, 2021) and imply the use of metacognitive strategies (Prayitno, Purwanto, Subanji, Susiswo, & Mutianingsih, 2022).

The use of ill-structured problems tends to provide students with the freedom to express their arguments without being limited to a single solution as is often the case (Huang & Ge, 2022). This freedom is expected to enhance students' agility in the problem-solving process, especially in improving critical thinking, creative thinking, and problem-solving skills (Miner-Romanoff, Rae, & Zakrzewski, 2019). Specifically, students' creativity in solving mathematical problems significantly increases when open-ended problems,

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which characterize ill-structured problems, are incorporated (Bahar, 2015; Pulgar, Candia, & Leonardi, 2020; Miner-Romanoff, Rae, & Zakrzewski, 2019; Febriani & Ratu, 2018). By using open-ended problems, students are given the opportunity to explore knowledge and experiences, and they are guided independently to solve problems using various techniques and diverse approaches (Lubis, Harahap, & Nasution, 2019).

Several studies have been conducted on the use of ill-structured problems in mathematics education. Santia et al. (2019) analyzed students' mathematical representation abilities in solving ill-structured problems, particularly in the topic of quadratic functions. Ghofiqi, Irawati, and Rahardi (2019) used ill-structured problems to assess the creative thinking abilities of low-achieving mathematics students. Nurjanah, Hidayanto, and Rahardjo (2019) described the thinking processes of students with logical-mathematical intelligence in solving math problems with limited information (characteristic of ill-structured problems). Furthermore, Mutianingsih et al. (2020) concluded that students who have incomplete mastery of the concept of rectangles are more likely to fail in providing solutions to ill-structured problems.

The providing of ill-structured problems related to specific mathematical skills or learning has been an area of research interest. For example, Muli, Kodirun, and Ruslan (2016) concluded that students' mathematical reasoning abilities were better when using structured problem-based learning models compared to ill-structured ones. The presence of ill-structured problems has the potential to enhance students' creative thinking skills because the solutions offered are divergent (Abdillah, Mastuti, & Rahman, 2018). Furthermore, using the cognitive load theory, Rodiawati (2018) concluded that worked examples using ill-structured problems can hone students' higher-order thinking skills. On the other hand, Rahmasari and Susanah (2022) found that students given ill-structured problems had lower self-efficacy compared to those given well-structured problems because they were not accustomed to such types of problems. Meanwhile, Hong and Kim (2016) affirmed that ill-structured problems combined with problem-based learning could enhance the level and forms of mathematical abstraction among elementary school students in South Korea, while Kim and Lim (2019) emphasized that a combination of specific scaffolding with strong metacognitive abilities would yield the best outcomes in online tasks representing ill-structured problems.

From the perspective of teachers, the creation of ill-structured problems is also an important part of their skill set in preparing assessment items. Moreover, ill-structured problems can be categorized as tasks that focus on higher-order thinking skills due to the limited information provided (Yeong, 2021). In fact, several studies indicate that teachers' ability to create such problems is still considered inadequate (Pratiwi, 2022; Sinta, Roebyanto, & Nuraini, 2022). Furthermore, the education system should provide

extensive opportunities for students to encounter ill-structured problems in various contexts, including curriculum-related aspects (Norris, Grohs, & Knight, 2022) and the role of teachers as implementers (Supeno, Prastowo, & Rahayu, 2020). Additionally, the concept of teacher scaffolding has emerged in determining the agenda for addressing ill-structured problems in order to achieve progress in mathematical proficiency (Cho & Kim, 2020). Therefore, ill-structured problems in the contemporary era, such as the present, have become a necessity to be incorporated into mathematics education.

In fact, as one of the branches of algebra, the topic of polynomial is considered difficult for students to understand (Ambarawati, 2015; Burhanzade & Aygör, 2015; Rahmawati, Sudirman, & Rahardi, 2021; Sangaji & Lukmana, 2023; Syahputra & Suhartini, 2014). Meanwhile, research on ill-structured mathematical problems is not widely conducted, despite the need to investigate the impact of involving ill-structured problems on students' summative learning outcomes, particularly in terms of assessment from the perspective of teachers.

Efforts in this regard are currently being undertaken by Mathematics teachers at SMA Santo Paulus Pontianak, a private school in Pontianak City. The learning outcomes of grade XI students majoring in MIPA (Mathematics and Natural Science) at SMA Santo Paulus Pontianak in the academic year 2021/2022 indicate that students' learning outcomes in the topic of polynomial have not reached their maximum potential. Out of 107 students, only 36 students have achieved the minimum passing grade criteria (≥75) in that topic. This fact strongly justifies the need for immediate efforts to evaluate the teaching and learning of polynomial, and one of the proposed approaches is to incorporate ill-structured problems. Therefore, this research will focus on the providing of ill-structured problems in teaching of polynomial to examine their impact on the students' learning outcomes of grade XI students majoring in MIPA at SMA Santo Paulus Pontianak in the academic year 2022/2023.

II. METHOD

This study is quasi-experimental research involving one control group and one treatment group. The research was conducted from April to June 2023, comprising 6 sessions (each session lasting for 90 minutes). The aim of this study is to determine the influence of learning that involves ill-structured problems on students' learning outcomes in the topic of polynomial. The research subjects are students of grade XI majoring in MIPA for the academic year 2022/2023 at SMA Santo Paulus Pontianak, which is a private school located in Pontianak, West Kalimantan. The class follows the curriculum outlined in 2013 Curriculum.

The research design used in this study is a non-equivalent posttest-only design. Specifically, the research was conducted by implementing the same teaching method in both the control group and the treatment group. However, the students in the control group were given tasks consisting entirely of well-structured problems, while the students in the

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treatment group were given tasks with well-structured problems and ill-structured problems. After completing learning sessions, each student in both the control and treatment groups will be given a daily evaluation test consisting entirely of well-structured problems.

The population of this study consists of the daily evaluation scores of 97 students in grade XI majoring in MIPA at SMA Santo Paulus Pontianak (academic year 2022/2023) in the topic of polynomial. It should be noted that two out of three grade XI were selected as the control group and the treatment group. In this study, the selection of the control and treatment groups took into consideration the collective mathematical abilities of the students in each group based on their Advanced Mathematics subject scores in the student report cards for the first semester of grade XI. The consideration was to choose the control and treatment groups with the smallest average score difference. This was done to reduce biases that could affect the findings of the research. Therefore, it can be said that purposive sampling technique was used in this study.

From the three classes, XI MIPA A, XI MIPA B, and XI MIPA C, the mean of report card grades for the Advanced Mathematics are 79.82, 76.22, and 74.34 respectively. This shows that XI MIPA B and XI MIPA C are the two classes with the smallest difference in average scores, which led the researcher to consider selecting them as the control and treatment groups. Specifically, class XI MIPA C was chosen as the treatment group, while class XI MIPA B was chosen as the control group. Thus, the sample taken in this study consisted of the daily evaluation scores of 64 students from these two classes.

The chosen topic for this research is polynomial. The students who are the subjects of this research receive learning based on the 2013 Curriculum. Therefore, any learning instructions will refer to the 2013 Curriculum syllabus. According to its syllabus, the topic of polynomial is covered in Basic Competence 3.4 as a knowledge aspect, which involves analyzing divisibility and polynomial factorization. Additionally, Basic Competence 4.4 as a skill aspect involves solving problems related to polynomial factorization.

Furthermore, the provision of ill-structured problems was carried out in the treatment group from the first to the fifth session. The sample questions representing ill-structured problems can be seen in Table 1.

Table 1.
Sample questions representing ill-structured problems

No.	Problem Statement
1.	If $f(x)$ and $g(x)$ are both quadratic polynomials such that $f(x)+g(x)=2x^2+5x-10$, determine $f(x)g(x)$.
2.	Let $g(x)$ be a monic cubic polynomial. If $h(x)$ is a quartic polynomial such that $g(x)+h(x)=x^4-x^3+7x^2-10$, determine $g(x)$ and $h(x)$.
3.	Let $f(x)$ and $g(x)$ be quartic polynomials. If $f(x)-g(x)$ is a quadratic polynomial, determine $f(x)$ and $g(x)$, and then evaluate $f(x)+g(x)$.
4.	Let $f(x)$ and $g(x)$ be a quadratic and linear polynomial, respectively. If the product of the two polynomials is a non-monic cubic polynomial that does not contain a constant term, determine $f(x)$ and $g(x)$.
5.	Given $f(x)=ax^2+bx+c$ is a quadratic polynomial that is divisible by $x-1$. If $a, b,$

	and c are integers and $0 < a + b + c < 10$, determine the values of a, b, and c.
6.	Let $f(x)$ and $g(x)$ be quadratic polynomials. The remainder when $f(x)$ and $g(x)$ are divided by $x + 1$ is 3. Determine $f(x)$ and $g(x)$.
7.	Let $f(x)$ be a cubic polynomial with three roots r_1, r_2, and r_3 where $r_1 + r_2 + r_3 = -\frac{3}{2}$ and $r_1 r_2 r_3 = \frac{9}{4}$. Evaluate $f(x)$.

The hypothesis proposed in this research is that the providing of ill-structured problems does not improve students' learning outcomes as the null hypothesis (H_0), while the alternative hypothesis (H_1) states otherwise. The improvement in students' learning outcomes can be determined by comparing the average daily evaluation scores of the treatment group to the control group. For that purpose, a statistical hypothesis test will be conducted. Furthermore, the testing will be performed as a one-tailed test. The null hypothesis will be rejected if the p-value obtained from the hypothesis test is greater than the chosen significance level, α = 5%.

Next, the collected samples will be tested using an independent sample t-test, assuming that the population variances are unknown and unequal. The use of the independent t-test assumes that the data is normally distributed. Therefore, the normality of the data needs to be tested first. In this study, the normality test will be conducted using the Kolmogorov-Smirnov test. The hypothesis is that the data follows a normal distribution as the null hypothesis (H_0), while the alternative hypothesis (H_1) suggests otherwise. If the obtained p-value from the Kolmogorov-Smirnov test is greater than the chosen significance level α = 5%, it is concluded that H_0 is not rejected, indicating that the tested data follows a normal distribution. The normality testing and calculation of the t-statistic involve the use of the RStudio application, specifically version 2022.12.0+353, which was performed on a Windows 11 operating system with a 64-bit processor, and Google Colab to generate Python outputs.

III. RESULT AND DISCUSSION

The daily evaluation score data obtained from the sixth session were then processed using a valid statistical procedure. The results of the Kolmogorov-Smirnov normality test for the control group and treatment group involving the use of RStudio can be seen in Table 2.

Table 2.
Results of the Kolmogorov-Smirnov Normality Test

Group	p-value	Conclusion
Control group	0.2562	Normally distributed
Treatment group	0.8360	Normally distributed

Table 2 shows that the obtained p-values from the Kolmogorov-Smirnov normality test for the control group and treatment group are 0.2562 and 0.8360, respectively. Since the p-values for both groups are larger than the significance level α = 5%, it is concluded that H_0 is not rejected, indicating that the data follows a normal distribution.

Specifically, Figure 1 displays the box plot and scatter plot of the daily evaluation score data for the control group and treatment group.

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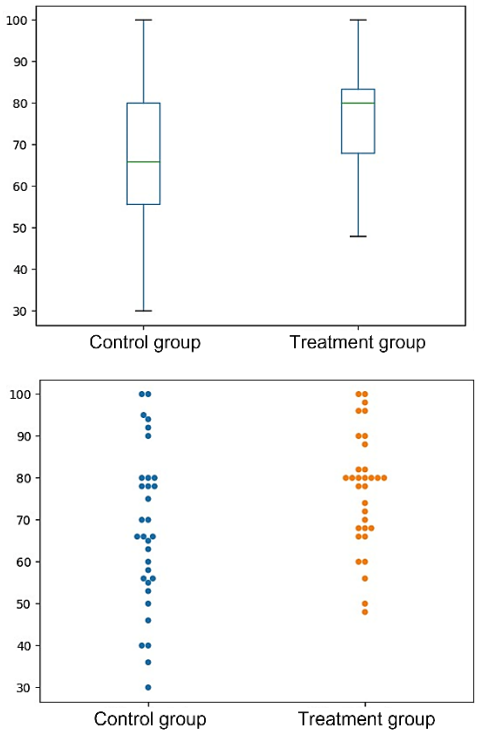

Figure 1. Box Plot and Scatter Plot of the Data

Furthermore, to enrich the descriptive statistical analysis, Table 3 presents the summary statistics obtained from the control group and the treatment group data.

Table 3.
Summary Statistics of the Control Group and Treatment Group Data.

Statistic	Control Group	Treatment Group
Sample size	32	32
Minimum score	30	48
Maximum score	100	100
Range	70	52
Mean	67.69	77.00
Median	66.00	80.00
Mode	66.00, 78.00, 80.00	80.00

From Table 3, statistical information regarding the treatment group and control group data is obtained. Specifically, Table 3 also provides the mean values of the treatment group and control group data, which are 77.00 and 67.69, respectively. The hypothesis that the mean daily evaluation scores obtained from the treatment group are higher than the control group will be statistically tested using an independent t-test.

The independent t-test conducted on the treatment group and control group data using the RStudio provides information as shown in Figure 2.

```
data:  x3 and x4
t = -2.2504, df = 56.905, p-value = 0.01415
alternative hypothesis: true difference in means is less than 0
95 percent confidence interval:
      -Inf -2.393288
sample estimates:
mean of x mean of y
  67.6875   77.0000
```

Figure 2. Output of the Independent t-test using the Rstudio

From Figure 2, the obtained t-statistic is -2.2504, degrees of freedom (df) is 56.905, and the p-value is 0.01415. Since the p-value is smaller than α = 5%, it is concluded that H_0 is rejected, indicating that the use of ill-structured problems improves students' learning outcomes. Furthermore, by considering the statistic of means, it can be said that the average daily evaluation scores of students who received learning involving ill-structured problems are relatively higher than those of students who received learning without ill-structured problems.

The following are samples of student responses of ill-structured problems given by the teacher in the treatment class.

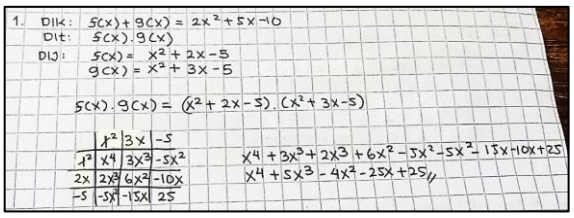

Figure 3. Student response for Problem 1

Figure 3 shows one of student responses for Problem 1 based on Table 1. The problem requires students to determine two polynomials with certain conditions involving polynomial addition. After that, students are expected to perform polynomial multiplication based on the knowledge they have acquired. This is one of ill-structured problems due to the limited information provided, namely the simultaneous unknowns of the polynomials $f(x)$ and $g(x)$. Conversely, if $f(x)$ is known, $g(x)$ can be determined uniquely, and the same applies when $g(x)$ is known.

Based on Figure 3, the student chose $f(x) = x^2 + 2x - 5$ and $g(x) = x^2 + 3x - 5$. These two quadratic polynomials satisfy the condition, and their sum is $f(x) + g(x) = 2x^2 + 5x - 10$. After obtaining the two suitable polynomials, the student multiplied them, resulting in a quartic polynomial $f(x)g(x) = (x^2 + 2x - 5)(x^2 + 3x - 5) = x^4 + 5x^3 - 4x^2 - 25x + 25$.

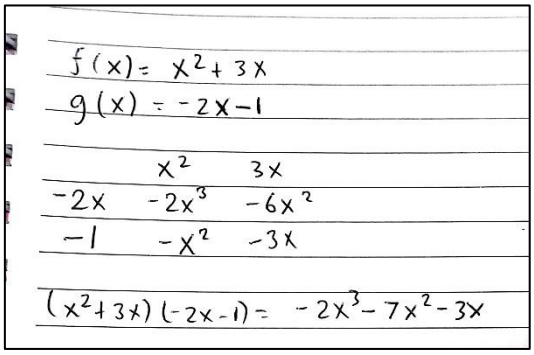

Figure 4. Student response for Problem 4

Figure 4 shows one of student responses for Problem 4 based on Table 1. The problem requires students to determine two polynomials with specific conditions involving the remainder. In this case, students need to find two quadratic polynomials that have a remainder of 3 when divided by $x + 1$. With the knowledge they have acquired, students are expected to solve Problem 2. Furthermore, Problem 2 falls into the category of ill-structured problems due to the lack of specific instructions regarding the polynomials $f(x)$ and $g(x)$. In this case, $f(x)$ and $g(x)$ are not unique. Specifically, students need to choose a linear polynomial $h(x)$ such that $h(x)(x + 1) + 3$ results in a quadratic polynomial. The limited information available requires students to engage in deeper analysis, leading to higher-order thinking skills. Additionally, Rodiawati (2018) states that ill-structured problems can be used to develop students' higher-order thinking skills.

Based on Figure 4, the student chose $f(x) = x^2 + 3x$ and $g(x) = -2x - 1$, which are respectively a quadratic and a linear polynomial, satisfying the given conditions. The student then provided evidence that the product of $f(x)$ and $g(x)$ is a cubic polynomial that does not contain a constant term: $f(x)g(x) = -2x^3 - 7x^2 - 3x$. This study also found that students with a good mastery of the subject are more responsive in solving ill-structured problems, aligning with the findings (Mutianingsih, Prayitno, Sugandi, Fitriatien, & Kurniawan, 2020) that state mastery of the subject is crucial in problem-solving processes.

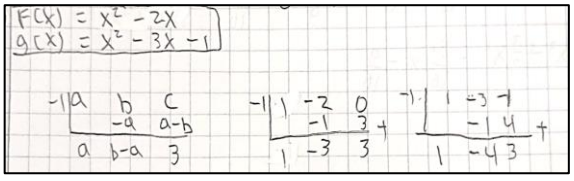

Figure 5. Problem 6 of Ill-Structured Problem

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Figure 5 shows one of student responses for Problem 6 based on Table 1. The problem requires students to determine two polynomials with stricter conditions. Firstly, students need to have adequate knowledge of polynomial degrees. Secondly, they should understand the definitions of constant polynomials and nonmonic polynomials in order to proceed. Students are also expected to use reasoning to understand how the multiplication of two polynomials results in another polynomial that does not contain constant terms. Afterward, students can determine two polynomials, $f(x)$ and $g(x)$, based on their own creativity. This situation reflects the fact that ill-structured problems can progressively enhance students' creativity (Ghofiqi, Irawati, & Rahardi, 2019). When facing ill-structured problems, students need to develop creative thinking skills to identify patterns or relationships that may not be apparent at first glance (Firdausi, Sujadi, & Nurhasanah, 2021). Based on Figure 5, the student chose $f(x) = x^2 - 2x$ and $g(x) = x^2 - 3x - 1$. The claim is then proven using the Horner's method that both polynomials have a remainder of 3 when divided by $x + 1$.

The incorporation of ill-structured problems in mathematics education can significantly enhance students' learning outcomes by fostering critical thinking, creativity, and problem-solving skills. Unlike well-structured problems, which have a single correct solution and a clear pathway to the answer, ill-structured problems present ambiguous, incomplete information that requires students to engage deeply with the content and develop multiple strategies for finding solutions (Yeong, 2021). This approach mirrors real-world scenarios, encouraging students to apply their knowledge flexibly and think divergently (Miner-Romanoff, Rae, & Zakrzewski, 2019). Furthermore, the open-ended nature of ill-structured problems promotes metacognitive strategies, allowing students to monitor and regulate their thought processes during problem-solving (Prayitno, Purwanto, Subanji, Susiswo, & Mutianingsih, 2022). Studies have shown that when students are regularly exposed to such problems, they develop greater adaptability and strategic competence, which are crucial for tackling complex mathematical challenges (Gupta, Giabbanelli, & Tawfik, 2018). Therefore, embedding ill-structured problems within the curriculum can provide a robust framework for improving students' overall mathematical proficiency and learning outcomes.

The skill of teachers in formulating ill-structured problems is also equivalent to their ability to formulate higher order thinking skills (HOTS) problems, as it is a competence that every teacher should ideally possess as part of assessment development (Pratiwi, 2022). In practice, it is not recommended for teachers to directly introduce ill-structured problems in the classroom without first providing well-structured problems. Regardless, well-structured problems will still serve as an introduction for students to deepen their understanding of the taught material. Furthermore, the provision of ill-structured

problems should be accompanied by continuous guidance and support so that students can better comprehend the patterns and appropriate strategies to solve them (Rahmasari & Susanah, 2022). The providing of ill-structured problems can open the door to creativity for students as the answers are open-ended. However, teachers need to allocate more time to assess the diverse range of answers as a consequence of providing open-ended questions.

IV. CONCLUSION

The providing of ill-structured problems in the topic of polynomial can be an alternative to improve students' learning outcomes, especially for students at SMA Santo Paulus Pontianak. It is statistically evident that the average daily evaluation scores of students who received learning that involved ill-structured problems in the topic of polynomial, with a mean score of 77.00, were higher compared to the average daily evaluation scores of students who received learning without the involvement of ill-structured problems, with a mean score of 67.69. Moreover, the presence of ill-structured problems also provides students with the opportunity to enhance their creativity in solving given problems. As a result, students' creative thinking abilities will improve as they become accustomed to assignments that involve ill-structured problems.

This study only focused on the use of ill-structured problems in the topic of polynomial. Therefore, similar research on other mathematical topics can be an open opportunity for other researchers to explore. Additionally, the implications of using ill-structured problems can also be investigated in variables other than learning outcomes, such as creative thinking abilities, critical thinking abilities, and so on.

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