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Procedural fluency of 10th-grade students on the spltv topic through discovery learning assisted by photomath

Ennja Carolin[1], Yusuf Hartono[2], Septy Sari Yukans[3]
[1,2,3]Mathematics Education Department, Sriwijaya University, South Sumatra, Indonesia
Correspondence: septysariyukans@fkip.unsri.ac.id

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Abstract

Procedural fluency is a crucial component of mathematical proficiency, enabling students to solve problems accurately and efficiently. This study aimed to describe the procedural fluency of tenth-grade students in solving Three-Variable Linear Equation Systems (SPLTV) through Discovery Learning assisted by Photomath. This study employed a descriptive qualitative approach, involving 39 tenth-grade students from a senior high school in Palembang. Three participants were selected as main participants based on their ability levels: high, moderate, and low. Data were collected through procedural fluency tests and interviews. The use of these two techniques provided a more comprehensive picture of students' procedural fluency. The results showed variation in students' procedural fluency levels. Students with high abilities were able to choose and utilise the appropriate solution procedures, apply the steps systematically, and modify or correct the procedures when they found inconsistencies in the results. Students in the moderate category can choose the correct method and attempt to recheck the solution results, but are not yet fully able to correct the errors found. Meanwhile, students with low abilities are not yet able to apply solution procedures, nor modify or correct procedures, even when errors occur in the solution.

Keywords: Procedural Fluency; SPLTV; Discovery Learning; Photomath; Learning Media

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INTRODUCTION

Mathematics is a crucial subject that plays a vital role in developing students' logical, systematic, and analytical thinking skills (Pratidiana & Muhayatun, 2021). According to Kilpatrick et al. (2001), there are five main skills must be developed in learning mathematics, namely: (1) conceptual understanding, (2) procedural fluency, (3) strategic competence, (4) adaptive reasoning, and (5) productive disposition. Procedural fluency encompasses three primary components: flexibility in employing various approaches to problem-solving, accuracy in the problem-solving process, and efficiency in resolving problems without becoming entangled in complex logic (Kilpatrick et al., 2001; Bahr & Garcia, 2008). Without adequate procedural fluency, students struggle to understand mathematical concepts and solve problems (Damayanti et al., 2018).

A study by Asmida et al. (2018) reported that students' procedural fluency fell into the moderate category, with a percentage of 68%, indicating that some students were not yet able to apply problem-solving steps regularly and systematically. In line with this, Rohyati et al. (2020) reported that approximately 70% of students remained in the low category in terms of procedural fluency. Many students struggle to choose the correct procedure, organize problem-solving steps in sequence, and provide reasons for the methods they use. This condition shows that procedural fluency remains a challenge in mathematics learning and requires further attention.

However, in educational practice, procedural fluency often receives inadequate emphasis (Safitri & Lestari, 2022). Several studies also show that students' abilities are still relatively low, as evidenced by their limited proficiency in applying procedures to solve algebraic problems and selecting appropriate solution steps or methods in linear programming tasks (Damayanti et al., 2018; Pratidiana & Muhayatun, 2021; Maksudi, 2025). These problems hinder students' ability to solve problems systematically and increase the prevalence of procedural errors. Such challenges are particularly evident in complex topics that demand strong procedural coordination, including SPLTV, where students frequently experience difficulties in translating contextual information into mathematical models, constructing accurate equations, performing elimination operations, determining subsequent solution steps, and conducting systematic verification (Thohari et al., 2024; Wahab & Sunarti, 2022; Nurhayati et al., 2022). Moreover, students' performance in SPLTV problem solving varies substantially across ability levels. Students with low abilities tend to fail to apply the steps sequentially, while students with high abilities still havehe potential to make mistakes at the checking stage (Hidayat et al., 2024).

Discovery Learning is one relevant approach to develop these skills, emphasizing the discovery of concepts or procedures through direct learning experiences (Indah, 2024). This model encourages students to think critically, try various methods, and find solutions independently (Alimuddin et al., 2021). However, in its application, students often experience difficulties due to the high cognitive load when they have to find solutions without adequate assistance. Therefore, supporting media is needed to help the discovery process run more smoothly.

Several studies have examined the use of Photomath as a technological tool to support students in mathematics learning. Rif'i & Yahfizham (2024) state that Photomath helps students follow problem-solving steps more clearly by presenting procedures in a structured and sequential manner. Hidayati & Yahfidzham (2024) show that Photomath supports students' understanding of mathematical procedures and enhances their computational thinking through coherent, step-by-step solutions. However, these studies primarily emphasize general procedural assistance and computational skills and have not specifically explored the role of Photomath in strengthening students' procedural fluency, particularly in solving SPLTV problems. This gap suggests a strong potential for integrating Photomath within Discovery Learning, as the application provides multiple solution methods, including elimination, substitution, Cramer's rule, and the Gauss–Jordan method in a clear and systematic format (Arief & Saputra, 2019; Karyadi, 2023). This feature can help students understand and refine the procedures they apply. Therefore, this study aims to describe the procedural fluency of tenth-grade students on SPLTV through Discovery Learning supported by Photomath.

METHODS

This study employed a qualitative descriptive method to describe students' procedural fluency on the topic of Three Variable Linear Equation Systems (SPLTV) through Discovery Learning, assisted by Photomath. The study was conducted with 39 students from the 10th grade of a senior high school in Palembang. Participants were selected using purposive sampling, a non-probability technique in which participants are deliberately selected based on specific criteria relevant to the research objectives. According to Tajik et al. (2024), purposive sampling allows researchers to choose individuals who are most suitable for answering research questions. In this study, three students were selected as main participants based on the results of procedural fluency tests and teacher recommendations, representing three ability levels: high, moderate, and low.

Data collection was conducted through procedural fluency tests and interviews. Procedural fluency tests were administered after learning to obtain an overview of students' procedural fluency in solving SPLTV problems, while interviews were used to gather in-depth information about students' thinking processes when solving the test questions.

The learning process used the Discovery Learning model combined with the use of the Photomath application. The student worksheets (LKPD) were designed following the Discovery Learning syntax, which consists of stimulation, problem identification, data collection, data processing, verification, and generalisation. At the verification stage, students were directed to use Photomath to compare their manual solutions with the solution steps displayed by the application. The use of Photomath at this stage helped students verify the accuracy of their procedures, identify mistakes, and confirm the correct solution steps.

The data obtained from tests and interviews were analysed descriptively. Qualitative data analysis followed the Miles and Huberman model (Sugiyono, 2020), which consists of three stages: (1) data reduction, where students' solutions to SPLTV problems and interview transcripts were organized, selected, and filtered based on indicators of procedural fluency; (2) data display, where the reduced data were presented in narrative form to describe differences in students' procedural fluency across the ability categories; and (3) drawing conclusions, where the findings were interpreted and rechecked by reviewing the data to ensure consistency between the steps of the SPLTV solutions, the interview statements, and the indicators analyzed. In addition, the analysis was conducted by grouping and interpreting student responses based on three indicators of procedural fluency: (1) selection and use of procedures, (2) appropriate application of procedures, and (3) modification or improvement of procedures.

RESULTS AND DISCUSSION

This section presents an analysis of students' procedural fluency in solving SPLTV problems, based on indicators of procedure selection and use, the appropriate application of procedures, and the modification or improvement of procedures. The analysis is based on students' answers and interviews, which are used to identify their thinking processes and the accuracy of the procedures applied.

Analysis of Student Answers to Problem Number 1

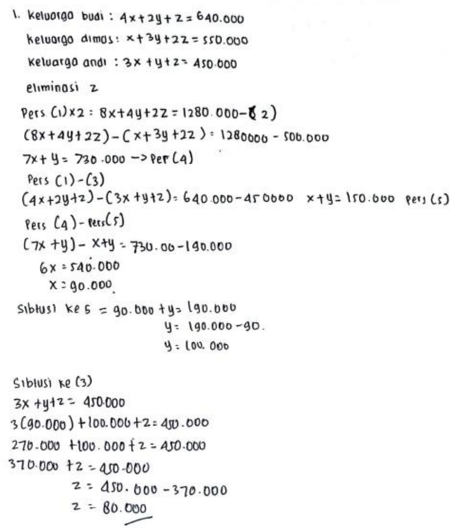
Problem number 1 is designed to measure two indicators of procedural fluency, namely (1) selecting and utilising procedures and (2) applying procedures appropriately. The problem number 1 for procedural fluency is depicted in Figure 1.

Problem Number 1

Siska is a ticket taker at the circus. There are three types of tickets sold. The Budi family bought 4 children's tickets, 2 adult tickets, and 1 senior citizen ticket and paid IDR 640,000. The Dimas family bought 1 child ticket, 3 adult tickets, and 2 senior citizen tickets and paid IDR 550,000. The Andi family bought 3 child tickets, 1 adult ticket, and 1 senior citizen ticket and paid IDR 450,000. How much does each type of ticket sold by Siska cost?

Figure 1. Procedural fluency problem number 1

Additionally, the student's answer for problem number 1, as provided by ADP, is depicted in Figure 2.



Translate:

1. Budi's family: $4x + 2y + z = 640.000$
   Dimas'family: $x + 3y + 2z = 550.000$
   Andi's family: $3x + y + z = 450.000$

Eliminating z
Eq. (1) × 2:
$8x + 4y + 2z = 1.280.000$→ (Eq. 2)
$(8x + 4y + 2z) - (x + 3y + 2z) = 1.280.000 - 500.000$
$7x + y = 730.000$ → (Eq. 4)
Eq. (1) – Eq. (3):
$(4x + 2y + z) - (3x + y + z) = 640.000 - 450.000$
$x - y = 1,900,000$→ (Eq. 5)
Eq. (4) – Eq. (5):
$(7x + y) - x + y = 730.000 - 190.000$
$6x = 540.000$
$x = 90.000$
Substitute into Eq. (5): $90.000 + y = 190.000$
$y = 190.000 - 90.000$
$y = 100.000$
Substitute into Eq. (3):
$3x + y + z = 450.000$
$3(90.000) + 100.000 + z = 450.000$
$270.000 + 100.000 + z = 450.000$
$370.000 + z = 450.000$
$z = 450.000 - 370.000$
$z = 80.000$

Figure 2. The answer of student ADP for problem number 1

Based on ADP's answers to problem number 1, it can be seen that ADP can determine the method of solving SPLTV that is appropriate for the problem's form, namely, using the elimination–substitution method. The student correctly wrote down three equations based on the information in the problem, then systematically performed the elimination process to eliminate one of the variables. After that, ADP continued by substituting the results into other equations until obtaining the value of each variable with the correct final result.

According to ADP's explanation during the interview, ADP stated that he chose the elimination–substitution method because the steps were considered easier to follow. The results of the work and the interview explanation show that ADP was able to choose and utilise the solution procedure appropriately and efficiently, as well as apply the procedure accurately and logically in accordance with the principles of algebraic operations. Therefore, ADP is categorised as having high procedural fluency on problem number 1.

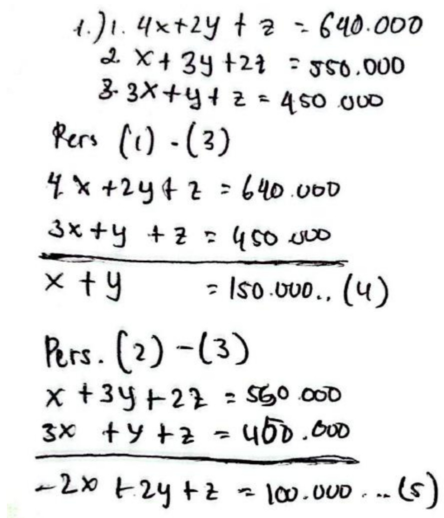
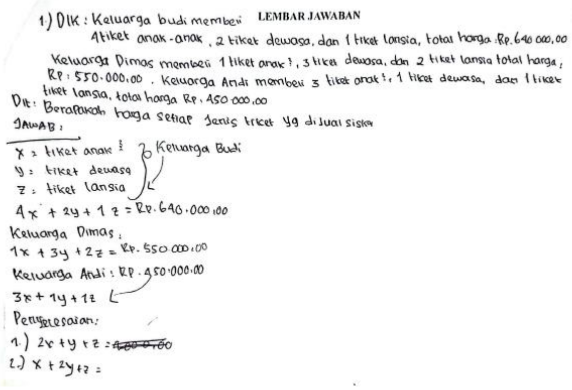


Figure 3. The answer of student PS for problem number 1

Based on the answer provided by PS, the student has written down the three SPLTV equations correctly, according to the information in the problem. PS then performed subtraction operations between the equations, for example, subtracting equation (1) from (3) and equation (2) from (3). These steps demonstrate that PS began to employ the concept of elimination, which involves simplifying the system of equations by removing variables through algebraic operations. However, the PS solution process stopped halfway. PS produced several new equations but did not continue to find the complete values of the variables. Thus, the solution was incomplete and did not reach the final values of each variable.

According to the PS explanation, he planned to eliminate between equations (4) and (5), but in equation (5), there was still the variable z, so PS felt confused and hesitant to continue the solution. This condition indicates that PS actually understood the procedure that should be carried out, but was unable to apply it correctly when encountering an equation that did not match. This reinforces that PS was able to choose the correct procedure, but did not fully apply it systematically and correctly. Thus, PS is categorised as having moderate procedural fluency in problem number 1. Furthermore, the student's answer for problem number 1, as given by HSK, is depicted in Figure 4.



Translate:

1) Given: Budi's family bought 4 child tickets, 2 adult tickets, and 1 senior ticket, with a total price of IDR 640.000.
   Dimas's family bought 1 child ticket, 3 adult tickets, and 2 senior tickets, with a total price of IDR 550.000.
   Andi's family bought 3 child tickets, 1 adult ticket, and 1 senior ticket, with a total price of IDR 450.000.
   Asked: What is the price of each type of ticket sold?
   Answer:
   x =child ticket
   y =adult ticket
   z =senior ticket
   Budi's family
   $4x + 2y + z = 640.000,00$
   Dimas's family:
   $1x + 3y + 2z = 550.000,00$
   Andi's family:
   $3x + 1y + z = 450.000,00$
   Solution:
   1.) $2x + y + z =$
   2.) $x + 2y + z =$

Figure 4. The answer of student HSK for problem number 1

Based on the answers provided by HSK, it is evident that HSK only wrote down the information from the problem in the form of three equations without continuing the process of elimination or substitution. According to the HSK explanation during the interview, he was confused about which equation to eliminate first and forgot the next steps to take. This indicates that HSK is not yet able to select and apply the appropriate procedures, and is unable to follow the steps to solve the problem correctly and logically. Therefore, HSK is categorised as having low procedural fluency on problem number 1.

Overall, the analysis of problem number 1 reveals that students' procedural fluency abilities vary by subject. Subject ADP has met both indicators well, PS has met some of the indicators, and HSK has not met either.

Analysis of Student Answers to Problem Number 2

Problem number 2 aims to measure the indicator of procedural fluency, namely, (3) modifying or improving procedures. In this problem, students are expected to review the steps taken and correct procedural errors if any discrepancies are found in the results. The following image shows problem number 2 for procedural fluency. Additionally, procedural fluency problem number 2 is illustrated in Figure 5.

Problem Number 2

Raka solved the following system of equations using the combined method.

$$2x + y + z = 30..... (1)$$
$$x + 2y + z = 32..... (2)$$
$$x + y + 2z = 28..... (3)$$

Raka's steps:

1. Eliminate variable z from equations (1) and (2)
2. Eliminate variable z from equations (1) and (3)
3. Solve the resulting SPLDV
4. Substitute the result into one of the equations to obtain the third variable

After calculating, the final result obtained by Raka is:

$$x = 10, y = 5, z = 5$$

Do you agree with the result obtained by Raka? Show your reasoning. If you find an error, correct the solution until the correct solution is found.

Figure 5. Procedural fluency problem number 2

Based on these problems, students were asked to solve a system of three linear equations and then check the steps they had taken to solve them. The following image shows the results of ADP's solution to problem number 2, which formed the basis for analysing procedural fluency in the indicator of modifying or improving procedures.

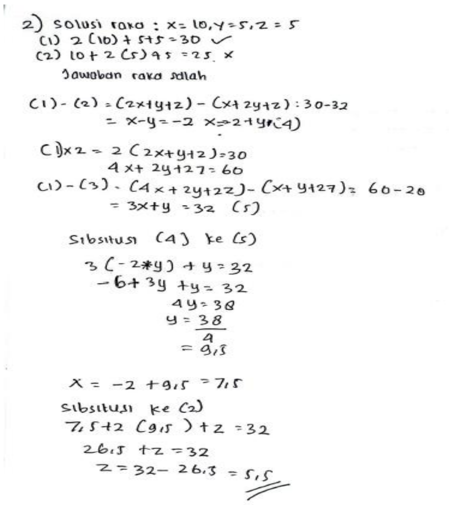
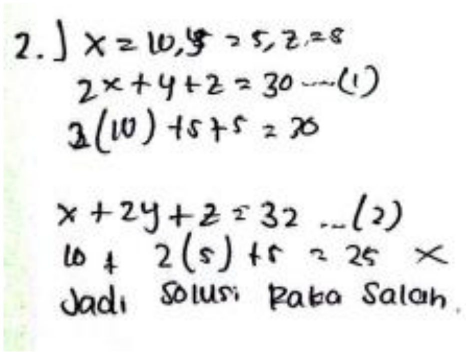


Figure 6. The answer of student ADP for problem number 2

Based on the ADP answers to problem number 2, it can be seen that ADP rechecked the solution by substituting the variable values into the original equation. This step shows an effort to ensure the accuracy of the procedure used.

According to the ADP explanation, the steps taken to solve the problem were correct, but the final result was not accurate. This shows that ADP can understand and apply the solution procedure correctly and can reassess the results of their work. Thus, ADP is categorised as having high procedural fluency, especially in terms of checking and reassessing the accuracy of the results against the procedures that have been applied.



So, Raka solution is wrong.

Figure 7. The answer of student PS for problem number 2

Based on PS's answer to problem number 2, it appears that PS tried to recheck his solution. PS substituted the variable values into the equation and wrote that the calculation in the problem was incorrect, then stated that "Raka's solution is wrong."

According to the PS explanation, he realised that there was an error in the calculation results in the question, but did not continue to write down the correct solution because he did not have enough time. This indicates that PS could recheck the results of his solution, but did not have time to correct the procedural error he identified. Thus, PS was categorised as having moderate procedural fluency on problem number 2. In addition, the answer of student HSK for problem number 2 is illustrated in Figure 8.

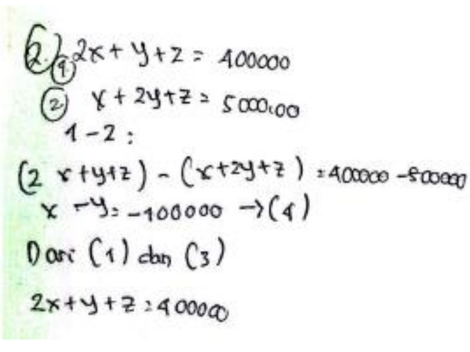


Figure 8. The answer of student HSK for problem number 2

Based on HSK's answer to problem number 2, it is clear that HSK did not attempt to recheck their work. HSK only wrote down the equation without verifying or checking the results. The equation written down also contained errors because it did not match the problem.

According to the HSK explanation, he realised that there was an error in writing the equation and did not continue with the solution because he was confused about the next step to take. This indicates that HSK lacks the ability to recheck and correct the procedures used, nor is he able to assess the suitability of the results obtained from the solution steps taken. Thus, HSK is categorised as having low procedural fluency on problem number 2.

Based on the analysis of the answers from the three participants to problem number 2, it is evident that the students' ability to modify or correct procedures exhibits clear variations. Subject ADP was able to recheck the results of the solution and realised that the results were inconsistent with the problem. Subject PS also demonstrated the ability to recheck the results of their solutions by substituting values into the equation, but did not continue with the corrections due to time constraints during the test. Meanwhile, subject HSK was unable to check or correct the procedures used and even made mistakes in writing the equation, which indicated a lack of understanding of the solution steps.

Based on the results of test data analysis and interviews, it was found that students' procedural fluency in solving SPLTV problems through Discovery Learning assisted by Photomath showed variations in each category of ability. These differences can be seen in how students fulfil the three indicators of procedural fluency, namely (1) selecting and utilising procedures, (2) applying procedures appropriately, and (3) modifying or correcting procedures when encountering inconsistent results.

In the high-ability category, students were able to meet the three indicators of procedural fluency effectively. In the first indicator, students were able to choose the appropriate solution procedure, such as the elimination–substitution method, based on the given equation form. In the second indicator, the steps applied were systematic and accurate, and students did not experience any obstacles in performing algebraic manipulations to form new equations or eliminate variables. In the third indicator, students are able to recheck the substitution results and correct the steps if discrepancies are found.

These findings align with the research by Handayani & Aisyah (2024), which reported that the most common mistake made by students on the SPLTV topic occurred at the recheck stage, with a percentage of 42%. However, in this study, this type of error did not appear in students in the high ability category. This indicates that students in this category can carry out the three indicators of procedural fluency in an integrated manner, including checking and correcting the steps of the solution as necessary. These findings confirm that the ability to review and correct the steps of the solution is an essential component of procedural accuracy.

Students in the moderate ability category have met the first indicator quite well, namely, being able to understand information and choose the appropriate initial procedure. However, in the second indicator, students still encounter obstacles in algebraic manipulation, especially when they need to adjust the form of the equation or create a new equation for the elimination process. Difficulties such as computational errors, stopping in the middle of a step, or not knowing the following procedure are forms of process skill weaknesses that have also been identified in previous studies, particularly in the context of SPLTV (Anggraeni & Arif, 2023; Dewi & Kartini, 2021). On the third indicator, students in the moderate category were able to detect inaccuracies in the results through simple checks, but were not yet able to systematically correct the steps. This condition shows that their evaluative abilities are still developing.

Meanwhile, students in the low ability category were not yet able to meet the three indicators of procedural fluency. On the first indicator, they were only able to write down the basic equation from the information in the question without being able to determine the appropriate solution procedure. In the second indicator, students are unable to continue the solution process due to difficulties in performing algebraic manipulations, such as forming new equations or eliminating variables. Computational errors, carelessness, and inability to continue the steps are common characteristics of process errors in SPLTV, as shown in previous studies (Anggraeni & Arif, 2023; Dewi & Kartini, 2021). In the third indicator, students did not make any effort to correct their steps, indicating that their reflection and self-control abilities were still very limited in the SPLTV solving process.

Overall, the results of this study suggest that Discovery Learning, assisted by Photomath, has the potential to support students' procedural fluency by presenting structured solution steps during learning activities. This is in line with the findings of

Nurlaelah et al. (2024), which state that Photomath can help minimise procedural errors by presenting explicit and sequential representations of solution steps.

In this study, students with high abilities were able to utilise the verification experience using Photomath during learning to recheck and correct the procedures they applied independently during the test. Students with moderate skills were able to recognise inconsistencies in the results, but were not consistent in correcting the steps or completing the procedures to the end. Meanwhile, students with low abilities were unable to continue solving problems from the initial stage. They did not demonstrate the application of appropriate methods, so the experience of seeing the sequence of solution steps through Photomath did not have a significant impact on them. These findings suggest that although Photomath can support the development of students' procedural fluency, its effectiveness remains significantly influenced by each student's initial conceptual understanding and cognitive readiness.

CONCLUSION

Based on the results of research on the procedural fluency of 10th-grade students on the topic of Three-Variable Linear Equation Systems through Discovery Learning assisted by Photomath, it was found that student abilities varied in each category. Students with high skills were able to select and utilise appropriate solution procedures, apply the steps systematically, and modify or correct the procedures when they found inconsistencies in the results. Students in the moderate category were able to choose the right method and attempted to recheck the results of the solution, but were not yet fully able to correct the errors found. Meanwhile, students with low abilities were unable to apply the solution procedure, nor modify or correct it, even though mistakes were present in the solution results.

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