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Students' Concept Understanding in Solving Mathematical Literacy Problems on The Material of Linear Equations of Two Variables

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ABSTRACT

This study aims to describe how well students understand concepts when working with linear equations with two variables in math literacy assignments. The study design uses descriptive qualitative approach. The study subjects were two eighth-grade students based on three categories of conceptual understanding determined during the data reduction procedure to become study participants taken at SMP Negeri 1 Lamongan. The data collection involves providing mathematical literacy exercises on linear equation of two variables (SPLDV) and conducting interviews. Students with medium understanding could grasp basic concepts but struggled with reasoning and complete representations, while those with low understanding relied on memorization and failed to translate real-world problems into mathematics, indicating a strong link between conceptual depth and mathematical literacy performance.

1. Introduction

Mathematics is a basic science that must be learnt by students and is always related to concepts. A concept in mathematics is an abstract idea that makes it possible to classify an object whether or not it belongs to that abstract idea (Hudojo, 2005). Concepts are (abstract) ideas that can be used or allow someone to classify or classify an object (Wardhani, 2008). If students grasp an idea, they can study mathematics with ease. Students must comprehend these ideas in order to learn mathematics more efficiently and use it in a variety of situations. Most of the students demonstrated significant difficulty in presenting contextual problems in mathematical form, particularly in formulating a mathematical model that aligned

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with the problem narrative. This finding aligns with the study results (Maria et al., 2022). Permendiknas No. 58 of 2014 explains that comprehending mathematical concepts is one of the teachings in mathematics.

Understanding concepts is the most crucial component of studying maths. Understanding a concept involves more than just mastering the subject. It also involves pupils being able to re-express ideas in a way that makes them easier to comprehend and implement (Fajar, 2018). Planting new mathematical concepts or ideas must be oriented to the previous concepts that students have learned, because students will understand better if the new concept they learn are related to the old concepts they already know (Hudojo, 1979).

The studyer draws the conclusion that grasping an idea is a process of mastering something that includes the capacity to explain, re-express, and relate concepts using their own phrases while maintaining the same meaning. This conclusion is based on the understanding of concepts by multiple specialists. A measurement device, or indicator, is required to ascertain the degree of comprehension of student concepts. This study uses indicators that refer to the opinion of Hudojo (1988), (Wardhani, 2008) and (Shadiq, 2009), namely (1) sorting objects based on their properties (according to the concept), (2) providing examples and non-examples of concepts, (3) transforming concepts into mathematical representations, (4) applying the relationship between concepts and procedures, and (5) applying concepts for problem solving.

When it comes to solving mathematical difficulties, conceptual understanding is a crucial starting point. "Students must learn mathematics with understanding, actively building new knowledge from experience and prior knowledge " is the National Council of Teachers of Mathematics' learning principle, which states that students must learn mathematics by comprehending and actively building new knowledge from experience and prior knowledge (NCTM, 2000). This is because many mathematics concepts have a strong relationship between one concept and another. The desired learning objectives are not met if pupils do not grasp the fundamentals of mathematics, and it is inevitable that they will struggle to solve mathematical problems.

Mathematical difficulties are not just routine problems; they can also be problems encountered in daily life. Mathematical literacy is a measure of the capacity to use mathematical concepts in everyday situations. The capacity to solve issues, particularly non-routine ones that call for novel applications of mathematical knowledge, is known as mathematical literacy (Schoenfeld, 1992). Therefore, mathematical literacy is important for students. According to Ojose (Ojose, 2011), "mathematics literacy is the knowledge to know and apply basic mathematics in our everyday living" it indicates Mathematics literacy is the capacity to comprehend and apply basic mathematics in day-to-day situations. According to Stacey (Stacey, 2011), The PISA 2006 evaluation defines mathematical literacy as the ability of people to conceive, apply, and evaluate mathematical concepts in a variety of contexts. Formulating entails identifying and characterizing mathematical concepts in practical contexts (OECD, 2018). It is about translating problems from real-world contexts into mathematical form. Applying mathematical ideas, methods, and logic to solve issues in a mathematical setting is known as "using". It involves selecting and using appropriate mathematical tools and techniques (Niss, 2003). It involves understanding the meaning and implications of the mathematical results. Mathematical literacy supports students to understand the function and use of mathematics in everyday

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applications (Yuliyani & Setyaningsih, 2022). According to Geraldine & Wijayanti (Yuliyani & Setyaningsih, 2022) The ability to understand, interpret, and apply mathematics to real-world issues is known as mathematical literacy.

Algebra is a fundamental branch of mathematics that plays a crucial role in solving real-world problems. Among its key topics, the system of linear equations of two variables (SPLDV) is particularly important for students to understand, as it provides a foundational tool for modeling and solving everyday contextual problems. The SPLDV material is one example of a mathematical environment that can be used in daily life. The importance of SPLDV in mathematical literacy is to develop contextual problem solving skills. The ability to translate real-world scenarios into mathematical representations and interpret solutions back in context is a core component of mathematical literacy (OECD, 2019). In addition, to deepen algebraic understanding, working with SPLDV contributes to a deeper understanding of fundamental algebraic concepts such as variables, equations, and systems of equations. Students learn how to meaningfully manipulate symbols to represent and solve problem. This strong conceptual understanding is important for the development of mathematical literacy (Kieran, 2007).

Mathematical literacy problems can be used to measure students' understanding in using mathematical symbols and numbers at the stage of solving problems related to everyday life. The strategy of developing mathematical literacy has its own role in the approach to learning mathematics, namely by using contexts that are closely related to students' daily experiences, always connecting them to various mathematical topics in the real world, then focusing on understanding concepts and reasoning in context, not just on skills in counting or computing (Susanto et al., 2021). Mathematical literacy is very important because it is not just about memorizing formulas, but includes critical thinking skills to interpret, analyze, and solve problems that involve numerical information (Salvia et al., 2022). The added value of mathematical literacy extends beyond understanding arithmetic, but more importantly, it develops problem-solving skills through logical reasoning and rational decision-making (Kusumah, 2011). One may argue that raising students' mathematical literacy can benefit in their development of the capacity to comprehend mathematical ideas when they are learning the subject.

In general, Indonesian students lack mathematical literacy. This can be seen from the PISA survey, which is an international level study in the context of assessing learning outcomes, one of which aims to test the mathematical literacy of 15-year-old students. Based on the results of the PISA survey obtained, the ranking of mathematical literacy obtained by students in Indonesia is ranked 69 out of 18 countries in 2022. Based on the PISA survey, we can know that the mathematical literacy skills of students in Indonesia are still below average. One of the reasons for the low literacy skills of students in Indonesia is the lack of introduction to numeracy problem-based exercises. The requirement for an assessment system in the execution of the learning process stems from the inadequate numeracy literacy of the pupils. Thus, to solve the existing problems, a solution is needed. One of the appropriate solutions to be implemented is to provide practice problems based on mathematical literacy. By providing practice problems based on mathematical literacy, it can indirectly train studentsconcept understanding, so that the more often students work on mathematical literacy problems, it will be able to improve students' concept understanding in solving mathematical literacy-based problems.

The ability to understand the right concepts will help students in linking the

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relationship between the concepts studied. But in reality, students still have low concept understanding skills. This is evidenced by the results of study conducted by Herawati & Kadarisma (Herawati & Kadarisma, 2021) which concluded that when students solve algebraic operation problems, students have difficulty because they do not understand the concept. The overall percentage of concept understanding ability indicators reached 54.40%. The study's findings show that pupils have a poor conceptual understanding when it comes to solving algebraic operation issues. Furthermore, the findings of a study by Mayasari and Habeahan (Mayasari & Habeahan, 2021) demonstrate that pupils in the low group have a 73% concept understanding ability when it comes to completing mathematical story problems. It is clear from the explanation of some concept understanding study findings that pupils' conceptual comprehension skills remain comparatively low. Students' inability to explain or recite the concepts they learn and to present them in mathematical representations is the factor that contributes to their inadequate concept understanding capacity.

Students' ability to understand mathematical concepts in solving problems involving systems of linear equations with two variables is still in the low category, as evidenced by students' inability to restate the solution to the given problem (Khairunnisa & Aini, 2019). Students' mathematical conceptual understanding ability in the linear programming material is low, with none of the conceptual understanding indicators being met, while students in the medium category only met one conceptual understanding indicator, namely the extrapolation indicator (Maure et al., 2020). The results of the analysis of students' mathematical concept understanding abilities are mostly in the low category (Fajar et al., 2019). Based on the problems that have been described, studyers want to describe students' concept understanding in solving mathematics literacy problems on the material of linear equations of two variables.

2. Method

This study employs a qualitative, descriptive study design. Thirty-one students participated in this March study at SMP Negeri 1 Lamongan. Data reduction, data presentation, and conclusion drawing are some of the data analysis approaches that are employed Miles & Huberman (Darmawan & Yusuf, 2022). The data collection procedure begins with giving mathematical literacy questions on the material of linear equations of two variables and the interview stage. In the data reduction stage, the studyer started by correcting the students' test results, then categorising students into 3 levels, namely students with a high level of concept understanding, students with a medium level of concept understanding, and students with a low level of concept understanding. These categories are based on grouping criteria using student scores (x), student average scores ($\bar{x}$), and standard deviation (s). The high level for $x > \bar{x} + s$, the medium level for $\bar{x} - s \leq x \leq \bar{x} + s$, and the low level for $x < \bar{x} + s$ (Arikunto, 2010).

The studyer selected two students from each level of understanding of student concepts to be used as study subjects because this selection will be used as a separate unit of analysis for in-depth interviews on how they build and develop an understanding of mathematical concepts when facing and solving problems on the material of two-variable linear equation systems. At the data presentation stage, the data obtained were focused and classified according to the indicators of concept understanding from Hudojo (1988), (Wardhani, 2008), and (Shadiq, 2009). Presentation in narrative form with the aim of combining information so that it can

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describe the situation that occurs. The interview method in this study is semi-structured interview. Drawing conclusions aims to achieve the study objectives

The studyer is the primary tool used in this study. In addition to planning, studyers also gather, analyze, and report on data. Studyers also have supporting instruments, namely mathematical literacy questions and interview guidelines. The interview guidelines in this study were adjusted to the indicators of concept understanding previously described. Processing of test results obtained by students is statistical in the form of scores according to indicators of understanding of mathematical concepts and percentage qualifications based on (Arikunto, 2013).

3. Results and Discussion

The purpose of this study is to characterize how well students comprehend concepts when tackling mathematical literacy tasks using linear equations of two variables. Each student is given four description questions, each of which contains several indicators that measure understanding of a mathematical concept. The data generated from this study is in the form of scores obtained by students in testing the ability to understand concepts when answering questions related to SPLDV material. Student test results were analysed using rubric scoring guidelines for understanding mathematical concepts. The scores of each test item were summed up for each student. Based on the scores obtained, students were grouped according to high, medium and low groups.

Table 1. Test Results of Concept Understanding of Class VIII Students

Number of Students	Maximum Value	Minumum Value	Average
31	100	20	78.61

From the data listed in the Table 1, the measurement test of students' concept understanding ability shows that they have not succeeded in achieving the Minimum Completion Criteria (KKM) value determined by the school for class VIII, which is 82. The range of values recorded recorded the maximum value of students reached 100, while the minimum value was recorded as 20, with an average value of 78.61. This assessment is calculated from the scores that have been converted to a scale of 1-100 by comparing the individual student's score to the total maximum score that can be obtained, then multiplying it by 100. Information related to the percentage of students who reached the KKM score can be seen in Table 2.

Table 2. Results of Analysis of Student Concept Understanding Indicators

KKM Category	Value	Number of Students	Percentage
Achieved	> 82	9	29%
Not Achieved	< 82	22	71%

It can be seen in Table 2 that student assessments have been classified according to the achievement of the KKM. The results show that about 29% of the total number of students, or equivalent to 9 students, have reached or exceeded the KKM value set by the school. Meanwhile, about 71% of the students, or 22 other students, have not achieved the specified KKM score. Furthermore, to determine the high and low percentage of understanding of concepts in solving problems in students according to Arikunto (Arikunto, 2012) by means of standard deviation.

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Table 3. Level of Concept Understanding of Class VIII Students

Category	Value Interval	Number of Students	Percentage
High	$Value \geq 89.61$	8	26%
Medium	$67.3 < Value < 89.61$	20	64%
Low	$Value \leq 67.3$	3	10%

Table 3 shows the level of understanding of grade VIII students of SPLDV material through solving related problems. In the high category, 8 students or 26% of all students scored more than 89.61. In contrast, the low category consisted of 3 students (10%) with a score of less than 67.3. The majority of students, around 64%, fell into the medium category with 20 students scoring between 67.3 and 89.61. These results indicate that students in class VIII who fall into the high category have been able to understand the SPLDV material well, as reflected in the highest score of 100. However, the results of this category only apply in the context of class VIII and are specific study subjects in this study. Based on the explanation of the study results from the value of each indicator, there were 3 students who got the maximum score when solving questions about SPLDV material.

Eight students demonstrated a high degree of concept understanding, twenty shown a medium level, and three demonstrated a poor level, according to the findings of the exam questions completed by thirty-one students. Additionally, two pupils were chosen as study subjects from each conceptual understanding level. S1 and S2 represent study subjects with a high level of concept comprehension, S3 and S4 represent study subjects with a medium level of concept understanding, and S5 and S6 represent study subjects with a low level of concept understanding.

Studyers analysed students' answers according to the indicators of concept understanding. Based on the data obtained after analysing the data on students' answers, students' abilities on each indicator of concept understanding can be observed in Table 4.

Table 4. Results of Analysis of Student Concept Understanding Indicators

No.	Concept Understanding Indicator	Percentage
1.	Sorting objects based on their properties	28%
2.	Providing examples and non-examples of the concept	23%
3.	Transforming concepts into mathematical representations	21%
4.	Applying the relationship between concepts and procedures	16%
5.	Applying concepts for problem solving	12%

Based on the data recorded in Table 4, it can be seen that the percentage of students' mastery of each indicator of students' concept understanding ability has a relatively small variation. The indicator that measures students' ability to sort objects based on their properties shows the highest percentage of mastery with a score of 28%. Meanwhile, the indicator that measures students' ability to apply concepts for problem solving has the lowest percentage of mastery, only reaching 12%. From the analysis of the percentage of score achievement on each indicator, it was found that the majority of mathematical concept understanding ability of grade VIII students was still at a moderate level. This is due to the number of students who have not reached the maximum score on each indicator of understanding mathematical concepts. The results of the analysis of indicators of concept understanding in students are as follows:

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1. Sorting Objects Based on Their Properties
   In the first indicator, students must be able to classify objects based on certain properties according to the concept. Students are asked to explain the meaning of SPLDV and state which are coefficients, variables, and constants in an equation.

The examination of the test question responses on this indicator reveals that subjects S1, S2, S3, and S4 are able to accurately and precisely classify things based on certain features in accordance with their conceptions and describe the meaning of linear equations of two variables (SPLDV). Because they can comprehend the fundamental ideas of SPLDV and practice enough conceptual issues, study participants can readily identify characteristics with the concept of SPLDV and define it, according to the findings of their interviews.

Subject S5 provided a partial explanation of the meaning of linear equations involving two variables, however S5 mistakenly classified items based on specific features in accordance with the concept. This is evident in subject S5's work, which is supported by the findings of the subsequent interview. Excerpts of the interview results of subject S5

P : "*OK, now let me ask you, what is SPLDV?*"
S5 : "*an equation that has two variables*"
P : "*Can you tell which are the variables, constants and coefficients of the equation y=12000+3000(x-2)?*"
S5 : "*the variables are x and y, the coefficient is 3000, and the constant is 12000*"

In the meantime, subject S6 provided a less accurate explanation of the meaning of linear equations involving two variables, and S6 erroneously classified items based on specific attributes in accordance with the concept. This is evident in subject S6's work, which is supported by the findings of the subsequent interview. Excerpts of the interview results of subject S6

P : "*OK, now let me ask you, what is SPLDV?*"
S6 : "*SPLDV has two variables*"
P : "*Can you tell which are the variables, constants and coefficients of the equation y=12000+3000(x-2)?*"
S6 : "*the variables are x and y, the coefficient is 12000, and the constant is 3000.*"

Based on the results of interviews with S5 and S6, it is known that the reason the subject does not understand the definition and properties of SPLDV is that the subject does not understand the definition of SPLDV and only memorises the concept of SPLDV. In addition, the subject is also difficult to identify or distinguish properties that are relevant to the concept of SPLDV. According to Astuti et al. (Astuti et al., 2018) explains that the ability of students to locate, convey, comprehend, parse in many ways, and draw inferences about a concept based on their knowledge is a component of concept understanding.

2. Provide Examples and Non-Examples of The Concept
   Students must be able to give both instances and non-examples of a topic in

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order to pass the second indicator. Based on their work on test questions, students are requested to provide instances and non-examples of the idea of linear equations of two variables, along with the justifications for their answers.

The results of the analysis on this indicator show that subjects S1, S2, S4, and S6 can provide examples and non-examples as well as the reasons for the concept of linear equations of two variables correctly. Based on the interview results, it is known that the reason they can fulfil this indicator is that they are used to thinking critically if given non-routine problems and understand how the concept is applied in a real context.

Subjects S3 and S5 are able to correctly give instances and justifications for the idea of linear equations of two variables, but they make mistakes when defending non-examples of the concept. This can be seen in the work of subjects S3 and S5 which is reinforced by the following interview results. Excerpts of the interview results of subject S3

P : "*Can you name any non-examples of SPLDV?*"
S3 : "*You can, for example* $3y = 12 - y$"
P : "*why isn't it a SPLDV?*"
S3 : "*because it has 2 variables, namely 3y and -y*"

Excerpts of the interview results of subject S5

P : "*Can you name any non-Examples of SPLDV?*"
S5 : "$2x + 3y = 5$ "
P : "*why isn't it part of PLSV?*"
S5 : "*because there are 3 variables*"

According to the results of the interviews, subject S3's inability to provide examples and non-examples of the concept of linear equations of two variables and their causes is known to be caused by a lack of practice problems, which prevents him from developing critical thinking skills and makes it difficult for him to create examples based on concepts. Meanwhile, subject S5 did not fulfil this indicator due to the influence of memorisation. Without comprehending how the idea was used to solve contextual difficulties, the individual merely committed the notion of SPLDV to memory. This finding is in line with the views expressed by (Mulyani et al., 2018) and (Maryanti & Zulfarazi, 2022) which show that students' inability to understand mathematical concepts and respond to learning problems can be related to their lack of understanding of the material being taught. This is among the elements that affect how hard it is for students to grasp a mathematical idea.

3. Transforming Concepts into Mathematical Representations
   Students must be able to translate ideas into mathematical representations in order to pass the third indicator. The problem's concepts must be presented by the students using a variety of mathematical representations. Students' skills in the third indication for questions a and b are described as follows:

The subject can convey the problem's ideas in a mathematical representation, according to the findings of the study of S1 and S2 responses. In problem alphabet

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a, S1 and S2 can represent data or information into mathematical form, namely tables. While question alphabet b, S1 and S2 can make a mathematical model of the information given which is one form of mathematical representation. This can be seen in the work of S1 and S2 which is reinforced by the following interview results.

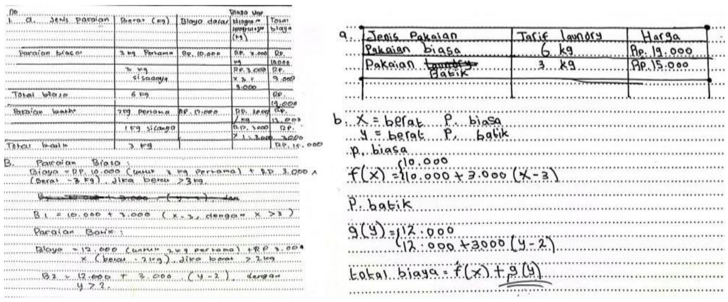

Figure 1. S1 and S2 Answers to Question Alphabets a and b

According to the findings of the analysis of S1 and S2 responses, which were supported by the findings of the interviews, in problem alphabet a S1 and S2 it can be seen that the subject did not write completely in representing into tabular form. In problem alphabet b, S1 immediately wrote down the mathematical model and did not write the memorisation. While S2 wrote down the memorisation but there were still errors. But during the interview, S1 and S2 could explain what was written on the answer sheet. So that S1 and S2 are able to fulfil the indicators of converting concepts into mathematical representations. This supports Wardono & Mariani's assertion that gifted students can effectively explain the problem-solving procedure and accurately assess the outcome (Wardono & Mariani, 2018).

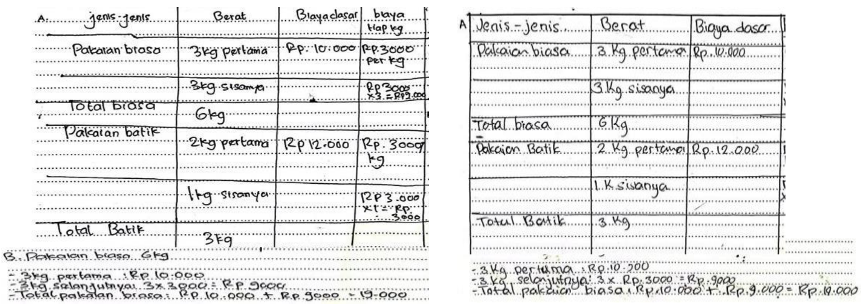

Figure 2. Answers of S3 and S4 Problem Alphabets a and b

According to the findings of the analysis of S3 and S4 responses, which were supported by the findings of the interviews, in question alphabet a S3 and S4 it can be seen that the subject does not write completely in representing into tabular form based on the information given. In question alphabet b, S3 and S4 represent the information given in verbal form or words. But during the interview, S3 and S4 can explain what is written on the answer sheet. So S3 and S4 are able to fulfil the indicators of converting concepts into mathematical representations.

Figure 3 describes that the results of the analysis of the answers of S5 and S6 which are strengthened by the results of the interview, in question alphabet a S5 did not write completely in representing into tabular form based on the information given. Meanwhile, S6 only rewrote the information given in the problem. In problem alphabet b, S5 and S6 could not represent mathematically the information or data given. Based on the results of interviews with S5 and S6, it is

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known that the subject cannot explain what is written on his answer sheet. So that S5 and S6 were unable to fulfil the indicator of converting concepts into mathematical representations.

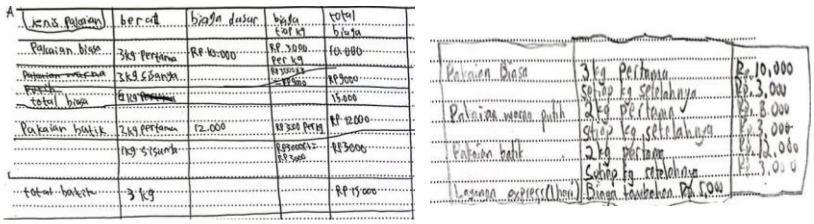

Figure 3. S5 and S6 Answers to Problem Alphabet a

The study of this indicator's results demonstrates that S1, S2, S3, and S4 in questions a and b are capable of accurately and exactly presenting the problem's notions in a mathematical representation. Although not exactly, S5 and S6 in alphabet a were able to accurately convey the problem's notions in a mathematical formulation. In question alphabet b, subjects S5 and S6 were unable to translate the problem's ideas into a mathematical representation. Based on the interview's findings, it is known that their inability to demonstrate an idea in another format stems from a lack of technical expertise.

Subjects are not used to understanding tools or methods for making representations such as graphs or tables so it is difficult to connect abstract concepts with more concrete representations. According to (Duval, 2017) the difficulty in linking different representations is because mathematics uses a variety of representations, such as symbols, graphs, diagrams, tables, and verbal language, which makes students' inability to connect these representations meaningfully hamper their mathematical representation skills.

4. Apply the relationship between concepts and procedures
   In the fourth indicator, in order to solve problems, students need to be able to understand how concepts relate to methods. Students are expected to correctly use the concepts and processes to solve the given problem. The following is a description of students' abilities in the fourth indicator for question alphabet c:

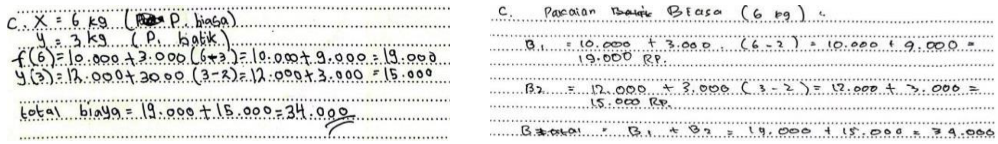

Figure 4. S1 and S2 Answers to Question Alphabet c

The results of the analysis on this indicator show that subjects S1 and S2 can apply concepts and procedures appropriately. This can be seen from the results of the work of subjects S1 and S2 in Figure 4. S1 and S2 can utilise and select the relationship between concepts and procedures of questions alphabets a, b, and c correctly. Meanwhile, subjects S3 and S4 were less careful in understanding the problem so that they were less precise in connecting concepts and procedures. This can be seen in the work of the study subjects in Figure 5 below.

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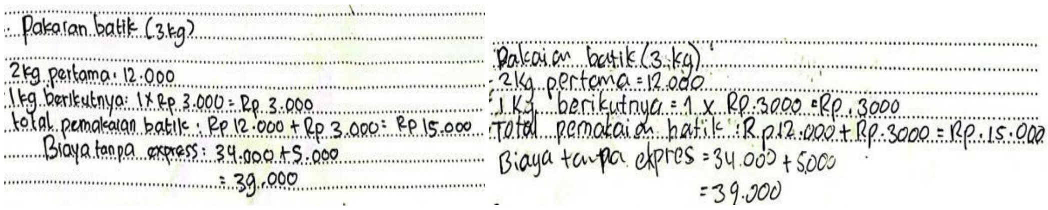

Figure 5. Answers of S3 and S4 Problem Alphabet c

According to the findings of the analysis of S3 and S4 responses, which were supported by the findings of the interviews, in question alphabet c S3 and S4 are less careful in understanding the problem so that they cannot connect concepts and procedures appropriately. This is in line with Azzahra's opinion (Azzahra, 2019) regarding the factors that cause student errors in solving problems, such as rushing to read the problem, lack of understanding of the contents of the problem, and forgetfulness of the right methods and steps to solve it.

Meanwhile, subjects S5 and S6 based on the results of the interview, it is known that the reason the subject has not fulfilled this indicator is that they have not practised conceptual problems often enough so that they are not automatically understood. This is in line with the opinion of Wardono & Mariani (Wardono & Mariani, 2018) that one of the factors causing low student scores in Indonesia is that Indonesian students are less trained in solving contextual problems. The difficulties students encounter when tackling problems involving SPLDV material include their incapacity to comprehend the information at hand, their incapacity to convert the problem narrative into a mathematical sentence structure, and their inability to comprehend the SPLDV concept, which makes it difficult for them to come up with a solution (Maspupah & Purnama, 2020).

5. Apply concepts for problem solving
   In the fifth indicator, students must be able to apply concepts for problem solving in mathematics problems. Students are given a problem about mathematics literacy in everyday life, then students are asked to apply a concept based on the right steps.

The results of the analysis on this indicator show that subjects S1 and S2 can apply concepts to problem solving based on appropriate and correct steps without any errors. This can be seen from the work of subjects S1 and S2 in Figure 6 below.

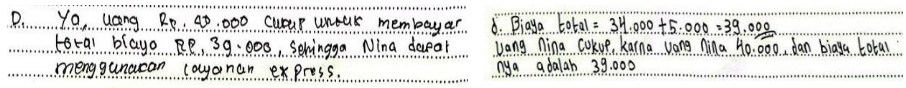

Figure 6. S1 and S2 Answers to Question Alphabet d

Subjects S3 and S4 in problem alphabet d made mistakes in applying concepts to problem solving. This can be seen from the results of the subject's work in Figure 5. Meanwhile, subjects S5 and S6 were unable to apply concepts for problem solving appropriately. Based on the results of the interview, it is known that the reason the subject has not fulfilled this indicator is that he is only used to working on routine problems so that it is difficult to think creatively if given contextual problems so that it is difficult to analyse the problem to determine which concepts are relevant.

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According to Sumarmo (Sumarmo, 2000) explains problem solving as a process that is carried out to overcome the obstacles faced with the aim of achieving the desired results. This study provides valuable insights into students' ability to apply mathematical concepts to problem-solving. While its strengths lie in clear evidence and theoretical support, weaknesses such as the limited sample size and subjective interpretations suggest the need for further study with larger scales and more rigorous methods.

The The level of understanding of mathematical concepts in general significantly influences students' ability to solve mathematical literacy problems. Students with a high level of understanding demonstrate the ability to understand and classify concepts, flexibility in mathematical representation, and systematic application of concepts to problem solving. Students with an average level of understanding show potential but still require guidance in conceptual analysis and rigor. Students with a low level of understanding experience fundamental obstacles due to a predominance of rote memorization and a lack of experience with contextual problems. These findings indicate the importance of mathematics instruction that focuses on conceptual understanding, the use of mathematical representations, and contextual problem-solving skills, particularly to help students with an average and low level of understanding improve their mathematical literacy.

4. Conclusions

Based on the analysis of 31 eighth-grade students at SMP Negeri 1 Lamongan, the level of mathematical conceptual understanding of the topic SPLDV was generally medium, with 64% of students in the medium understanding category, 26% in the high category, and 10% in the low category. Students with a high conceptual understanding demonstrated comprehensive abilities in all indicators of conceptual understanding, including grouping objects based on their properties, providing appropriate examples and non-examples, transforming concepts into various mathematical representations, connecting concepts to procedures, and applying concepts in contextual problem-solving. They were able to think critically and did not rely solely on memorization.

Students with a medium understanding were able to grasp most concepts, but still had difficulty providing conceptual reasoning (especially for non-examples), creating complete mathematical representations, and accurately connecting information to procedures. They tended to be less thorough and were not yet fully accustomed to non-routine problems. Students with a low understanding experienced fundamental obstacles because they tended to simply memorize definitions without understanding their meaning, resulting in an inability to accurately identify important components such as variables, coefficients, and constants. They also struggle to transform information into mathematical representations and fail to apply concepts in problem-solving due to their familiarity with routine problems and lack of analytical thinking skills.

Factors influencing poor understanding of mathematical concepts include: reliance on memorization, lack of mastery of representation techniques (such as tables and mathematical models), and limited experience solving contextual problems. Therefore, a learning approach is needed that strengthens conceptual understanding, facilitates the use of various representations, and improves mathematical literacy skills through real-world contexts.

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Author Contributions

The first author helped to formulate the study and design the instruments and study procedures. The first author also served as an observer, gathered and examined data, produced the first draft, and made revisions in response to input from the second and third authors. The second and third authors served as consultants, offering suggestions, making significant changes to the document, and approving the article's final draft. Additionally, the final draft of the work has been read and authorized for publication by all authors.

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Declaration of Competing Interest

The author states that there are no conflicts of interest related to this work that are disclosed in this paper.

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Raw Material Inventory Control Using The Period Order Quantity (POQ) Method to Reduce Stockout and Overstock Risks

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ABSTRACT

The rapid growth of coffee shops in Lampung has increased demand for Robusta Lampung, Arabica Kerinci, and Arabica Aceh Gayo, causing stockouts and overstocking at a coffee roastery. This study uses the Period Order Quantity (POQ) method to optimize inventory by ordering based on predictable demand periods, reducing order frequency and costs. Using demand data from the last six months of the year, POQ outperforms the manual inventory policy. Assuming a 5% holding cost and 90%–99% service levels (ensuring product availability), POQ reduces costs by 0.119%–0.163%, boosting profitability. Adopting POQ with real-time demand tracking can balance inventory and meet rising demand.

1. Introduction

The primary objective of every company is to achieve maximum profit. Profitability is largely influenced by operational costs, one of which is inventory-related expenditure (Zandra, 2016). In this sector, the availability and management of raw materials like coffee beans are essential for sustaining production flow and achieving consistent product quality. Managing raw material inventory, such as coffee beans, is crucial to maintaining smooth operations (Ilyas & Waluyo, 2024). Consequently, effective inventory management is essential to support

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uninterrupted production while minimizing operational costs. The inconsistency of market demand remains a critical concern in inventory management, frequently leading to operational inefficiencies such as product shortages or inventory surpluses (Rizqi & Khairunisa, 2020). Stockouts are often caused by insufficient raw material quantities, delays in delivery, and fluctuations (Chopra & Meindl, 2019).

Rubik Coffee Roastery is a small-scale business engaged in coffee processing, utilizing raw materials such as Robusta Lampung, Arabica Kerinci, and Arabica Aceh Gayo. The quality of coffee beans is highly sensitive to storage conditions and duration, poor inventory management can therefore lead to product degradation (Saolan et al., 2020). As such, inventory control not only ensures smooth operations but also safeguards product quality. To address these challenges, this study adopts the Period Order Quantity (POQ) method as an inventory control approach. POQ is a deterministic method that determines order quantities based on total demand over a specific time period, allowing companies to reduce order frequency and optimize inventory costs (Heizer et al., 2016). This method is especially suitable in environments with fluctuating yet predictable demand patterns, as typically encountered by small and medium enterprises (UMKM) in the coffee industry.

Inventory control of raw materials is a widely discussed topic in literature. For instance, (Trisno & Sunarso, 2024) explored inventory control using Material Requirement Planning (MRP) in a bread factory, demonstrating cost efficiency. Building upon this, the current study delves deeper by validating POQ's effectiveness in mitigating stockout and overstock risks for coffee processing SMEs. It compares inventory costs between manual systems and the POQ method, and crucially, analyzes how varying service levels (90% to 100%) impact total inventory costs. This aims to quantify potential savings, unlike the (Trisno & Sunarso, 2024) study which focused on non-perishable raw materials and didn't detail service level impact on cost efficiency.

2. Method

This research systematically outlines the methodology applied to analyze and optimize raw material inventory control at Rubik Coffee Roastery, a Micro, Small, and Medium Enterprise (UMKM). The approach employed in this study is specifically designed to address the complex characteristics of perishable raw materials and demand fluctuations at an SME scale within the coffee industry. This distinguishes it from previous research, such as the study by (Trisno & Sunarso, 2024), which tended to focus on the food industry with different raw material characteristics and did not delve into the sensitivity analysis of *service levels* on inventory costs. This research will comprehensively describe the data analysis procedures, commencing from the collection of historical data regarding raw material usage, ordering costs, and holding costs, up to the calculation of key inventory management parameters such as *safety stock*, *reorder point*, and *Period Order Quantity* (POQ).

This analysis aims to identify the root causes of *stockout* and *overstock* resulting from the UMKM's current manual inventory system. The success of the POQ method implementation will be quantitatively evaluated through a comparison of total inventory costs between the UMKM's existing policy and the results of the POQ method application, as well as an analysis of the range of cost savings

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obtained at various *service levels* (90% to 100%). These metrics will serve as the primary benchmarks for success in reducing costs and enhancing operational efficiency.

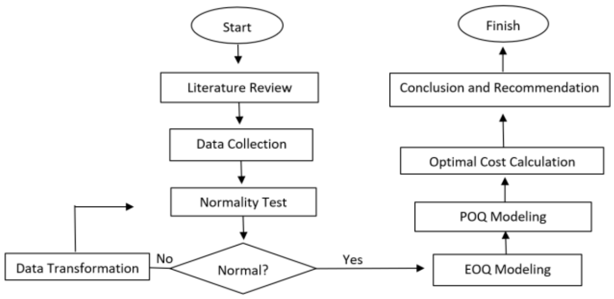

Figure 1. Research Flowchart

2.1. Normality Test

The normality test aims to determine whether the dependent and independent variables in the regression model follow a normal distribution (Irfan, 2019). If the maximum deviation observed is significant, the data are considered not normally distributed (Nasrum, 2018). This study employs the Kolmogorov-Smirnov test to assess normality. The process begins with formulating the hypotheses (Sondakh, 2020), where $H0$ states that the data are normally distributed, and $H1$ states otherwise. The significance level (α) is then determined, followed by calculating $F_o(X)$, which is derived from the z-table based on the cumulative distribution function of the standard normal probability distribution. Next, $S_n(X)$, the proportion of the cumulative frequency distribution of the observed data relative to the sample size, is calculated. The maximum deviation is then determined using the formula,

$$D = maximum\,|F\,(\mathrm{X}\,) - S_n(\mathrm{X}\,)| \quad (1)$$

Finally, hypothesis testing is conducted based on the criteria: if $D < D_{tabel}$, $H0$ is accepted, indicating that the data are normally distributed. Conversely, if $D > D_{tabel}$, $H0$ is rejected, suggesting that the data are not normally distributed (Supriadi, 2021).

2.2. Probabilistic Inventory Problem Model

Inventory is a term used by companies to refer to the goods stored in warehouses intended for future sales. It ensures that companies can optimize their operations in selling products to consumers (Karongkong et al., 2018). In the probabilistic inventory model, one of the issues is uncertainty. Uncertainty can arise from demand variability, lead time fluctuations, and supplier reliability (Simchi-levi et al., 2022). The consumer determines demand fluctuations through variations and standard deviation (S). The supplier, which may involve uncertainty in delivery times or lead times, inventory management in dealing with stockouts, and allowing the determination of the tolerable risk level (z_α). Inventory shortages often occur when market demand exceeds supply, a scenario commonly called the service level. The higher the service level, the less frequent stockouts become

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(Pangestu et al., 2021). The raw material usage data should follow a normal distribution to proceed with the investigation. This step is crucial to determine whether the dependent and independent variables in the regression model exhibit a normal distribution (Irfan, 2019).

2.3. Safety stock

Safety stock is a buffer inventory, where the primary purpose of maintaining this reserve is to protect against variations or fluctuations in demand during the replenishment lead time (L) (Brunaud et al., 2019), it is formulated as follows,

$$SS = Z_{\alpha} \times S \times \sqrt{L} \tag{2}$$

The safety stock (SS) is calculated based on several parameters, including the standard deviation of demand (S), the lead time (L), and the z-value (Z_{α}) from the standard normal distribution corresponding to the desired service level α, where α represents the probability of an inventory shortage. The factors determining the safety stock size are the average raw material usage, lead time, and associated costs (Lukmana & Y, 2015).

2.4. Economic Order Quantity (EOQ)

Economic Order Quantity (EOQ) is an inventory management method used to determine the optimal order quantity, with the primary goal of minimizing total inventory costs; it is formulated as follows (Heizer et al., 2016),

$$Q^* = (2KM/H)^{1/2} \tag{3}$$

The parameters used in the model are defined as follows: Q^* represents the optimal order quantity, M denotes the annual demand in units, K is the ordering cost per order, and H refers to the holding cost per unit per year.

2.5. Reorder Point

Reorder point is the minimum inventory level at which a company must place a reorder to avoid stockout and overstock (Pratama et al., 2023),

$$r = (d \times L) + SS \tag{4}$$

Where:
d : Average usage of goods
r : reorder point

2.6. Maximum Stock

Maximum stock is the level at which a maximum quantity of goods can be stored in inventory management,

$$MAX = SS + Q^* \tag{5}$$

Where:
SS : Safety Stock

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Q^* : Optimal order quantity

2.7. Period Order Quantity (POQ)

Period Order Quantity (POQ) is a method used to determine the order quantity over a specific period. In its application, POQ converts the order quantity into an order period, which differs from the EOQ (Aska Nadila Septyani et al., 2024). The method to determine the value of the order interval (T) is based on the EOQ framework and order periodicity principles (Silver et al., 2016):

1. Calculating the Economic Order Quantity (EOQ);
2. Calculate the ordering frequency (f) using the formula,

$$f = \frac{M}{Q^*} \tag{6}$$

3. Calculate the POQ by dividing the number of periods per year(P) by the ordering frequency (f),

$$T = P/f \tag{7}$$

The variables f represents the ordering frequency within a given period, M denotes the demand rate in one period, measured in units of goods, Q^*refers to the optimal order quantity, P indicates the length of the period and T stands for the order interval.

2.8. Total Cost

Total cost is the overall cost required to maintain raw material inventory over a specified period. The minimum total cost includes two components: total purchase and total inventory cost (Septyani et al., 2024). Inventory cost is part of inventory control techniques. Proper inventory control can reduce total inventory costs, thus maximizing profit for the company. Inventory costs include ordering and holding costs (Heizer et al., 2016). In general, the total cost can be expressed as follows,

$$B_T = B_L + T_S + T_P \tag{8}$$

Where,

$$T_S = \left(\frac{Q}{2} + SS\right)H \tag{9}$$

$$T_P = \frac{KD}{Q} \tag{10}$$

The variables used in the total cost calculation are defined as follows: B_T represents the total cost, B_L denotes the purchase cost, T_s is the holding cost, and T_p refers to the ordering cost. The order quantity per order is represented by Q (in units of goods), while K stands for the ordering cost per order, expressed in IDR. The demand rate within a single period is denoted by

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D (in units of goods), H represents the holding cost per period (in IDR), and SS indicates the safety stock level maintained to mitigate stockout risks.

3. Results and Discussion

Findings and in-depth analysis regarding the optimization of raw material inventory control using the *Period Order Quantity* (POQ) method at UMKM Rubik Coffee Roastery are comprehensively presented. Data provided include calculations for *safety stock*, *reorder point*, optimal order quantity, and ordering period for each type of coffee bean. These results are subsequently evaluated comparatively against the UMKM's actual inventory conditions, and their implications for *stockout* and *overstock* risks are analyzed. In contrast to prior studies that typically focus on comparing the general cost efficiency among various methods within conventional manufacturing contexts, this analysis specifically highlights POQ's effectiveness for perishable and fluctuating coffee bean inventory at an UMKM scale.

The discussion of results also encompasses a comprehensive analysis of the percentage of total cost savings achievable by varying the *service level* (90% to 100%). This comparison provides more detailed insights into the cost-service level trade-off, an aspect less specifically quantified in previous literature, thereby enriching the understanding of POQ application in the coffee UMKM context for maximum profitability. The use of the Period Order Quantity (POQ) method has been shown to significantly reduce total inventory costs across various types of raw materials in the food industry (Nasution et al., 2025).

3.1. Normality Test

The results of the Kolmogorov-Smirnov test for Robusta Lampung, Arabica Aceh Gayo, and Arabica Kerinci yielded D values of 0.117298, 0.10239, and 0.102639, respectively. These values are greater than the critical value D_{tabel}, which can be found in the normal distribution table, amounting to 0.100534093. This indicates that the data on the usage of Robusta Lampung, Arabica Aceh Gayo, and Arabica Kerinci do not follow a normal distribution. Therefore, data transformation is required, and the square root transformation was applied.

After performing the normality test again using the transformed data, the resulting D values were 0.04956, 0.049575, and 0.049575, respectively. These values are smaller than the critical value D_{tabel}, which is 0.100534093. This demonstrates that the transformed data for the usage of Robusta Lampung, Arabica Aceh Gayo, and Arabica Kerinci follow a normal distribution. Figure 2 is the raw material usage for Rubik Coffee Roastery.

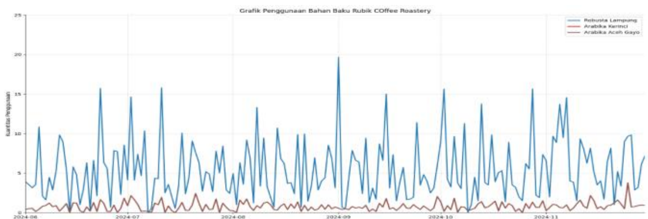

Figure 2. Raw material usage data for Rubik Coffee from June 1 to November 30

Over a six-month period, the total usage of Robusta Lampung raw material amounted to 1,193.6 kilograms, while Arabica Kerinci and Arabica Aceh Gayo

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were each used in quantities of 169.8 kilograms.

3.2. Safety Stock

After it was proven that the usage data for the three raw materials follows a normal distribution, the factors affecting inventory reserves can be determined, namely the lead time and standard deviation, which are calculated using the following formula,

$$S = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}} \tag{11}$$

Thus, the results are as Table 1.

Table 1. The Standard Deviation of Raw Materials

Raw Material Names	Lead Time (Days)	Standard Deviation	Standard Deviation (Transformation Scale)
Robusta Lampung	2	4.519805	0.907391647
Arabika Kerinci	5	0.655684	0.367989649
Arabika Aceh Gayo	7	0.655684	0.367989649

In formulating safety stock, it is important to consider the fluctuation level of raw material usage. The greater the fluctuation of a particular raw material, the larger the required safety stock. In mathematics, the fluctuation level of raw material usage can be measured using the standard deviation (σ) of the data. Lead time is also a key factor in determining safety stock. The service level used in the safety stock calculation is 95%, with an alpha (α) of 0.05. Based on the standard normal distribution table, the value of $z\alpha$ for an alpha of 0.05 is 1.645. Once the lead time and the standard deviation in the transformed scale are obtained, the safety stock can be determined. Since the raw material usage data does not follow a normal distribution, the safety stock is initially determined in the transformed scale, as shown in Equation 11,

$$S_{Transform} = Z_{\alpha}\ \sigma_{transform}\ \sqrt{L} \tag{11}$$

Based on the calculations, Table 2 is the results that are as follows Equation 11.

Table 2. The Safety Stock for each Raw Materials

Raw Material Names	Safety Stock (Kg)	Safety Stock Transformation Scale (Kg)
Robusta Lampung	4.46	2.11
Arabika Kerinci	1.83	1.35
Arabika Aceh Gayo	2.57	1.60

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3.3. Reorder Point

This calculation is performed by first calculating the average daily raw material. With an average daily usage of 6.52 kg for Robusta Lampung, and 0.93 kg each for Arabika Kerinci and Arabika Aceh Gayo. Using the previously explained formula, the reorder point for each raw material is calculated as follows:

a. Reorder point for Robusta Lampung:
   ROP = (6.52 × 2) + 4.46
   = 17.50 kg
b. Reorder point for Arabika Kerinci:
   ROP = (0.93 × 5) + 1.83
   = 6.48 kg
c. Reorder point for Arabika Aceh Gayo:
   ROP = (0.93 × 7) + 2.57
   = 9.08 kg

3.4. Maximum Stock

Maximum stock refers to the level at which the quantity of goods can be stored within inventory management. In the Economic Order Quantity (EOQ) method, maximum stock is defined as the sum of safety stock (S) and the EOQ value (Q^*). This relationship is formulated as shown in Equation 12,

$$S_{MAX} = S + Q^* \quad (12)$$

Determining the maximum stock level that can be accommodated in the warehouse is essential to avoid overstocking. Moreover, this practice is intended to minimize inventory-related costs in the context of inventory management. Therefore, the maximum stock is obtained as shown in Table 3 below.

Table 3. Maximum Inventory

Raw Material Names	Maximum Inventory (Kg)
Robusta Lampung	74.62
Arabika Kerinci	23.47
Arabika Aceh Gayo	25.43

3.5. Economic Order Quantity (EOQ)

From the known raw material usage data, the holding cost can then be calculated to determine the optimal order quantity per order (Q). The holding cost in Table 4 can be broken down as follows:

Table 4. Holding Cost

Raw Material Names	Raw Material Price	Holding Cost (%)	Annual Holding Cost
Robusta Lampung	IDR 97.000	5%	IDR 4.850
Arabika Kerinci	IDR 145.000	5%	IDR 7.250
Arabika Aceh Gayo	IDR 130.000	5%	IDR 6.500

After obtaining the holding cost per unit for six months, the value of Q, or the

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optimal order quantity per order, will then be calculated.

Table 5. The Economic Order Quantity (EOQ) Value for Raw Materials

Raw Material Names	Order Cost	Demand Level (Kg)	Holding Cost	EOQ (Kg)
Robusta Lampung	IDR 10.000	1193.6	IDR 4.850	71
Arabika Kerinci	IDR 10.000	169.8	IDR 7.250	22
Arabika Aceh Gayo	IDR 10.000	169.8	IDR 6.500	23

Table 5 shows the value of EOQ (Q^*), which represents the optimal order quantity per ordering cycle. This indicates that when the inventory level reaches the reorder point, Rubik Coffee Roastery should be ready to place a new order for each raw material in the amount of Q^*.

3.6. Period Order Quantity (POQ)

From the obtained raw material order quantities, the ordering frequency or the number of orders made in two months will be calculated to determine the value of T, or the period that a single order can cover. The total frequency and ordering periods obtained are as Table 6.

Table 6. Order Frequency and Period Order Quantity (POQ)

Raw Material Name	Ordering Frequency	T (Days)
Robusta Lampung	17.01	11
Arabika Kerinci	7.84	24
Arabika Aceh Gayo	7.43	25

Based on Table 6, the periods covered in a single order for Robusta Lampung, Arabica Kerinci, and Arabica Aceh Gayo are expressed in decimal numbers. Therefore, these values need to be rounded up to facilitate the determination of the number of days (periods) in each order cycle. As a result, the order periods for each raw material are 11 days, 24 days, and 25 days, respectively. This indicates that Robusta Lampung is ordered more frequently than the other raw materials, while Arabica Aceh Gayo has the longest interval between orders among the three.

3.7. Minimum Total Cost

The results of the calculation using the Period Order Quantity (POQ) method yield expenditure components that represent the minimum total cost in the inventory management system. This minimum total cost refers to the overall expenses that must be incurred by Rubik Coffee Roastery to fulfill raw material inventory needs over a six-month period. The minimum total cost consists of two main components, namely the total purchasing cost and the total inventory cost. The inventory cost includes both ordering and holding costs. The total costs incurred by Rubik Coffee Roastery are presented in the following table 7.

Table 7. Inventory Costs

Raw Material Name	Total Ordering Cost (IDR)	Total Holding Cost (IDR)	Purchase Cost (IDR)
Robusta Lampung	IDR 170.134	IDR 191.746	IDR 115.783.413
Arabika Kerinci	IDR 78.448	IDR 91.732	IDR 24.616.767

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Raw Material Name	Total Ordering Cost (IDR)	Total Holding Cost (IDR)	Purchase Cost (IDR)
Arabika Aceh Gayo	IDR 74.280	IDR 90.953	IDR 22.070.204

The inventory costs are then added to the total purchase costs to obtain the total cost. Based on the calculations, the total cost for each raw material can be seen in Table 8.

Table 1. Minimum Total Cost

Raw Material Names	Minimum Cost (IDR)
Robusta Lampung	IDR 116.145.295
Arabika Kerinci	IDR 24.786.947
Arabika Aceh Gayo	IDR 22.235.438

Table 8 shows that the total cost incurred by the company for the inventory of Robusta Lampung, Arabica Kerinci, and Arabica Aceh Gayo over a two-month period is IDR 163,167,680.

3.8. Variation in Service Level Value

After obtaining the values above, the minimum total cost incurred by Rubik Coffee Roastery in managing raw material inventory at each service level variation is as Table 9.

Table 9. Total Cost for each Service Level Variation

Service Level	Minimum Total Cost (IDR)
99%	IDR 163.219.570
98%	IDR 163.196.199
97%	IDR 163.183.467
96%	IDR 163.174.474
95%	IDR 163.167.681
94%	IDR 163.161.602
93%	IDR 163.157.855
92%	IDR 163.153.731
91%	IDR 163.150.331
90%	IDR 163.147.335

Table 9 illustrates the relationship between variations in service level and the minimum total cost incurred by Rubik Coffee Roastery in managing raw material inventory. It can be observed that the higher the targeted service level, the greater the total cost that must be borne.

3.9. Analysis of Total Cost Savings for Each Service Level Variation

Cost savings are obtained by calculating the difference in total costs using the POQ method compared to the total costs using the manual management system. The manual management system assumes that orders are placed once a week, with the order quantity determined by multiplying the average daily usage by 7 days. The results are as Table 10.

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Table 10. Total cost savings at each service level

Service Level	Total Cost with POQ	Total Cost with Manual System	Difference	Percentage of Savings
99%	IDR 163.219.571	IDR 163.413.857	IDR 194.286	0.119%
98%	IDR 163.196.199	IDR 163.413.857	IDR 217.658	0.133%
97%	IDR 163.183.467	IDR 163.413.857	IDR 230.390	0.141%
96%	IDR 163.174.475	IDR 163.413.857	IDR 239.383	0.146%
95%	IDR 163.167.681	IDR 163.413.857	IDR 246.176	0.151%
94%	IDR 163.161.602	IDR 163.413.857	IDR 252.255	0.154%
93%	IDR 163.157.855	IDR 163.413.857	IDR 256.002	0.157%
92%	IDR 163.153.732	IDR 163.413.857	IDR 260.126	0.159%
91%	IDR 163.150.331	IDR 163.413.857	IDR 263.526	0.161%
90%	IDR 163.147.336	IDR 163.413.857	IDR 266.522	0.163%

Table 10 is shown that the consistent application of the Period Order Quantity (POQ) method results in a lower total cost compared to the manual method. The POQ method generates cost savings, with the percentage of savings ranging from 0.119% to 0.163%. Although higher service levels lead to increased total costs, the method still provides overall cost savings and offers the potential for greater profitability.

4. Conclusions

The implementation of the Period Order Quantity (POQ) method at Rubik Coffee Roastery yielded optimal order quantity to average daily usage ratios of 1:10.8 for Robusta Lampung, 1:23.2 for Arabica Kerinci, and 1:24.6 for Arabica Aceh Gayo, at a 95% service level, with respective order intervals of 11, 25, and 24 days. These results confirm the effectiveness of the POQ method in minimizing both overstock and stockout risks. Varying the service level between 90% and 99% demonstrated potential cost savings of 0.119% to 0.163%, thereby supporting greater operational efficiency and profitability. Future studies are encouraged to integrate the POQ method with backorder systems and real-time inventory tracking to enhance decision-making precision and responsiveness.

Author Contributions

The first author was responsible for collecting, processing, and analyzing the data, as well as writing the scientific article. The second and third authors contributed by offering feedback and suggestions to improve the study, its analysis, and the overall manuscript.

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Declaration of Competing Interest

The author stated that there was no potential conflict of interest in this research.

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Development of Student Worksheets Using The Missouri Mathematics Model with Peer Feedback on Linear Programming Material

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ABSTRACT

This study aimed to develop a valid, practical, and effective student worksheet (LKS) for linear programming material based on the Missouri Mathematics Project (MMP) model with peer feedback. Using a Research and Development (R&D) design comprising definition, design, development, and dissemination stages, data were collected through validation sheets, questionnaires, and tests. The developed worksheet was assessed as valid by experts 80%, practical based on student and teacher responses 85%, and effective in improving learning outcomes. Effectiveness was indicated by 79% classical completeness and a significant improvement in Post test scores compared to Pre test results ($p < 0.05$). The findings show that the MMP-based worksheet with peer feedback meets the criteria for valid, practical, and effective learning tools.

1. Introduction

One important factor that can support more meaningful mathematics learning is the availability of adequate learning resources. Many learning resources can be used as guides in learning activities, one of which is student activity sheets. However, in reality, many mathematics teachers have not developed independent student worksheets according to student needs. The student worksheets used usually only contain a collection of materials and questions that are still conventional, without any innovative learning models that can create learning that

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can make students active in learning the subject. The lack of student involvement in building conceptual understanding results in students being less motivated and easily forgetting the material. Low learning motivation will have implications for learning outcomes, as stated by (Sardiman, 2012), namely that good motivation in learning will show good results.

Observing these conditions, a solution is needed to address this problem, namely the development of student worksheets with innovative learning models by curriculum demands that can increase student activity, motivation, and learning outcomes. According to (Juwita et al., 2019), student worksheets are one of the learning tools that support the optimal learning process. Student worksheets play a crucial role in guiding students' mindsets in discovering new knowledge and engaging students' creativity in finding various questions to solve problems (Novyani et al., 2020).

Selecting the right learning model can increase student learning activities and success (Basori, 2017). The implementation of learning with the Missouri Mathematics Project can help foster learning independence in students. The Missouri mathematics project learning model can make students play an active role in the learning process, both in discussion activities and individual exercises. In the implementation of the MMP Model, some processes or stages must be raised, namely (a) review; (b) development; (c) cooperative work (controlled exercises); (d) self-employment; and (e) assignment/closure (Rohman, 2023; Ummah & Sari, 2018) (Karim et al., 2023) (Syam et al., 2024). Students have the opportunity and flexibility to think independently or in groups to apply their understanding during cooperative work and independent work (seat work).

One of the important parts of the education process is feedback. According to Baerh and Bayerlein (Basuki & Hariyanto, 2017), quality assessment must meet the principle of improvement based on feedback from the assessment. The feedback provided as part of the formative assessment has the purpose of helping students become aware of the gap that exists between their desired goals and their current knowledge, understanding, or skills, and guiding them through the actions necessary to obtain their goals.

The learning process using peer feedback provides greater insight to students, interprets feedback, and supports mathematics learning (Reinholz, 2018). Peer feedback involves students in facilitating collaborative and social processes between students to help each other, so as to make the learning process more meaningful. By letting students take part in giving feedback, a student is trained to use and express themselves understandable way.

The innovation of the Missouri Mathematics Project model-oriented student worksheets with peer feedback is considered very important in mathematics learning, where students are required to learn cooperatively among each other to construct their knowledge in finding problem-solving solutions, and helping students actively participate in assessing and providing feedback on assignments independently. It found that developing student worksheets using the Missouri Mathematics Project model effectively improved students' mathematical conceptual understanding (Aufa et al., 2021) and effectively improved students' mathematics learning outcomes (Sofwani & Panggabean, 2023). The use of peer feedback at the Missouri Mathematics Project model stage guides students to assess each other and provide feedback on the results of their work. If this is a habit, it will improve students' abilities in mathematics.

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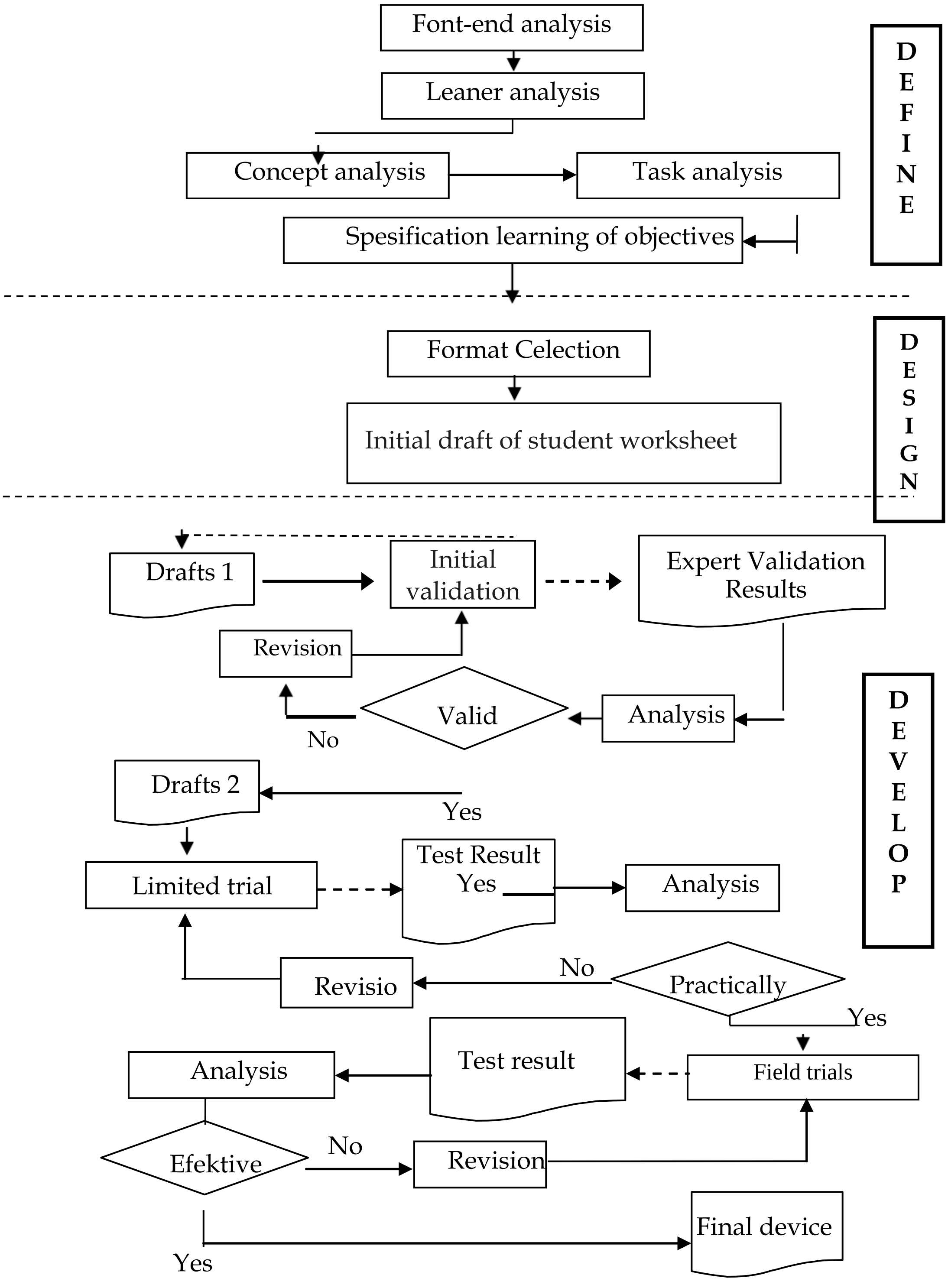
2. Method

The design of this research refers to the research and development (R&D) model of (Thiagarajan et al., 1974), consisting of four stages, namely: (1) define, (2) planning (design), (3) development, and (4) dissemination. However, due to time considerations, this research is limited to the third stage, namely: 1) definition, 2) planning, and 3) development. The steps of the development procedure are as follows.



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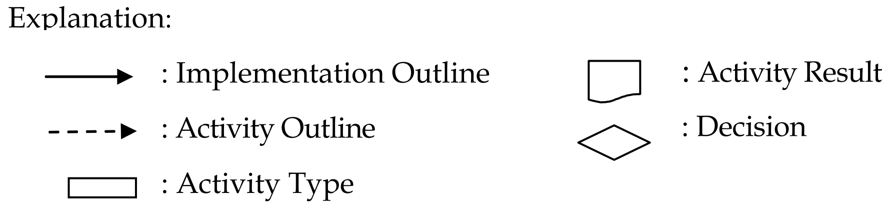

Figure 1. Development Model of 4-D Learning Tools
Source: (Thiagarajan et al., 1974)

The data collection instruments in this study consist of student worksheet validation sheets as well as teacher and student response questionnaires as well and linear program material test questions. The technical data analysis used in this study is as follows.

2.1. Validator Data Assessment Analysis

The validity test of the student worksheet is oriented to the Missouri mathematics model with peer feedback developed from material and media experts. After the data is collected, the data analysis is carried out using the formula,

$$TV = \frac{total\ score\ obtained}{maximum\ score} \times 100\% \qquad (1)$$

The TV is Validity Level. The interpretation of the validity data of the student worksheet can be seen in Table 1.

Table 1. Interpretation of student workshet Validity Data

No	Interval	Criterion
1	$81\% - 100\%$	Highly Valid
2	$61\% - 80\%$	Valid
3ce	$41\% - 60\%$	Quite Valid
4	$21\% - 40\%$	Less Valid
5	$0\% - 20\%$	Invalid

Source: (Riduwan, 2018)

2.2. Teacher and Student Response Test

The worksheet that has been validated by experts is then used in a limited trial of 15 students and 1 mathematics teacher with the aim of testing the practicality of the learning worksheet developed. The results of the practical test of the LKS that have been developed are analyzed using a formula (Riduwan, 2018),

$$P = \frac{TS_e}{TS_h} \times 100\% \qquad (2)$$

The variable P is percentage of practicality, TS_e is total empirical score, and TS_h full total score. The interpretation of the student worksheet practicality data can be seen in the Table 2.

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Table 2. Interpretation of student worsheet Practicality Data

No	Interval	Criterion
1	$81\% - 100\%$	Very Practical
2	$61\% - 80\%$	Practical
3	$41\% - 60\%$	Quite Practical
4	$21\% - 40\%$	Less Practical
5	$0\% - 20\%$	Impractical

Source: (Riduwan, 2018)

2.3. Effectiveness Test Analysis

The design of this study uses a one-group pretest-post test design. The research was carried out on only one group that was randomly selected. This one-group pretest-post test design is measured using pre test, treatment, and post test after treatment. The data analysis technique was carried out using normality tests, completeness tests, and paired sample t-tests. The quantitative research design of the one-group pretest-post test design can be seen in Table 3.

Table 3 Research Design: One-Group Pretest-Post test Design

Pretest	Treatment	Post test
O1	X1	O2

Information:
O1: Pre test done before being given treatment
O2: Post test done after being given treatment
X1: Learning with the Use of Model-Oriented student worksheet Missouri Mathematics Project with Peer Feedback

3. Results and Discussion

The Thiagrajan Development Model is called the 4-D model, with the development steps being Define, Design, Develop, and Disseminate, or adapted into the 4-P Model, namely Define, Design, Develop, and Disseminate, but in this development research, the Disseminate stage is not carried out.

3.1. Definition Stage

At the definition stage, there are several things that the researcher does, namely: font-end analysis, student analysis, task analysis, concept analysis, and specification of learning objectives.

3.3.1. Font-end analysis

This stage involved interviewing one of the mathematics teachers at Noemuti State High School. The analysis obtained from the interview revealed the following:

1) The curriculum used in Mathematics at Noemuti State High School still adheres to the 2013 Curriculum.
2) The learning challenge faced is that students are highly dependent on the teacher.
3) The learning resources used in class are 2013 Curriculum mathematics textbooks, which contain a mix of material from various subjects, resulting in minimal material, particularly mathematics.

At the final analysis stage, the development of Student Worksheets oriented

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towards the Missouri Mathematics Project model with peer feedback on linear programming material was carried out to enable students to learn actively, creatively, and independently in line with the existing curriculum objectives, motivating students to be directly involved in learning and assessment/evaluation activities.

3.3.2. Leaner Analysis

This analysis aims to determine the characteristics of 12th-grade students at Noemuti State Senior High School. Based on observations, it was found that:

1) 12th-grade students at Noemuti State Senior High School are aged 15 and above, with each student possessing varying levels of knowledge and diverse learning experiences. Based on Piaget's theory, this age group is at the formal operational level. This means that students are now able to understand abstract material.
2) Students are less effective in learning and wait for teacher explanations to understand the material. Most students lack the confidence to express their ideas.
3) Teachers have not developed innovative learning tools from various sources. The materials provided in the lessons come from textbooks published by specific publishers.

3.3.3. Concept Analysis

At this stage, a basic competency analysis is conducted related to the core material of the Linear Program. This stage also involves detailing and systematically organizing the concepts of the Linear Program material by creating a concept map of the material.

3.3.4. Task Analysis

At this stage, a basic competency analysis is conducted, and then learning indicators are outlined. Based on the analysis, a description of the tasks required in the learning process that align with the basic competencies is obtained.

3.3.5. Spesification Learning of Objectives

The learning objective specification aims to translate competencies derived from material analysis and task analysis into learning objectives to be achieved. The researcher's analysis of the learning competency specification indicates that through mathematics learning using the Missouri Mathematics Project-oriented worksheet with peer feedback, students are expected to:

1) Active, creative, and independent learning by existing curriculum objectives, enabling students to apply the learning and positive values to their daily lives.
2) Motivating students to be directly involved in learning activities and assessment/evaluation.

3.2. Planning Stage

At this stage, the researcher designed the student workksheet that are needed to support learning through. The learning tools needed to manage the teaching and learning process include a syllabus, lesson plan, teaching materials, student worksheets, evaluation instruments or learning outcome tests, and learning media (Trianto, 2011). The learning tool designed is a student worksheet implemented

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using the Missouri Mathematics Project model with peer feedback (Trianto, 2011). In addition to student worksheet, research instruments were also designed in this study, namely (1) Student worksheet validation sheet, (2) student and teacher response questionnaires. Design from student worksheet Missouri Mathematics Project model with Peer feedback can be seen in the image below.

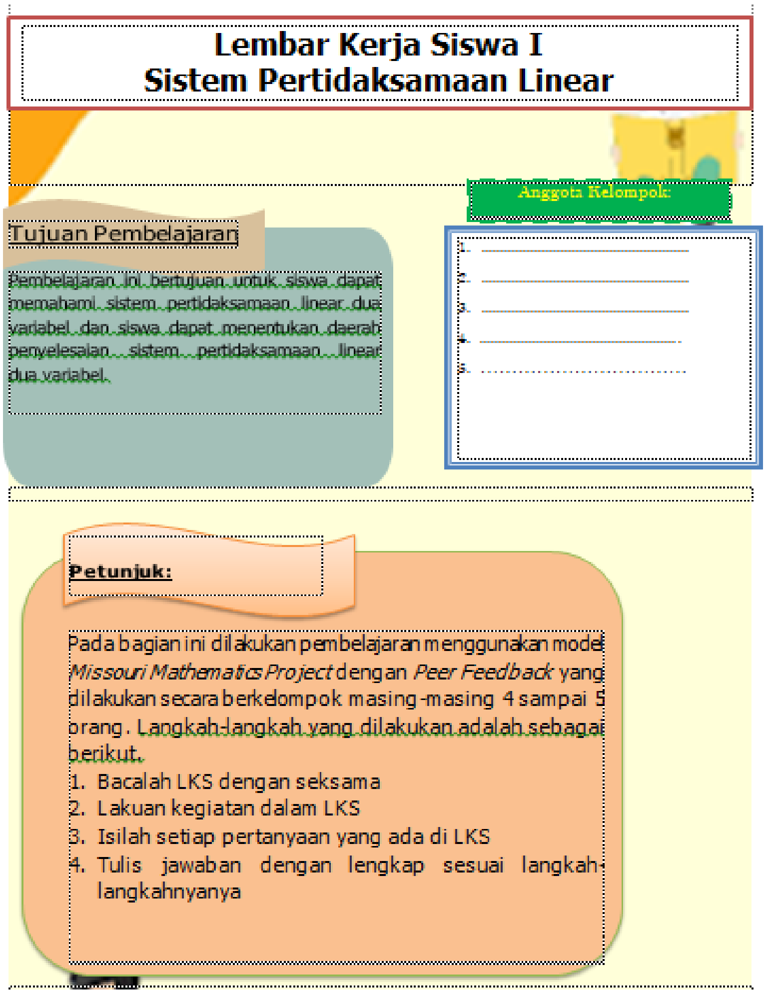

Figure 2. Design of the Missouri Mathematics Project Model-Oriented Worksheet with Peer Feedback, Preliminary Activities, and Exposure of Learning Materials

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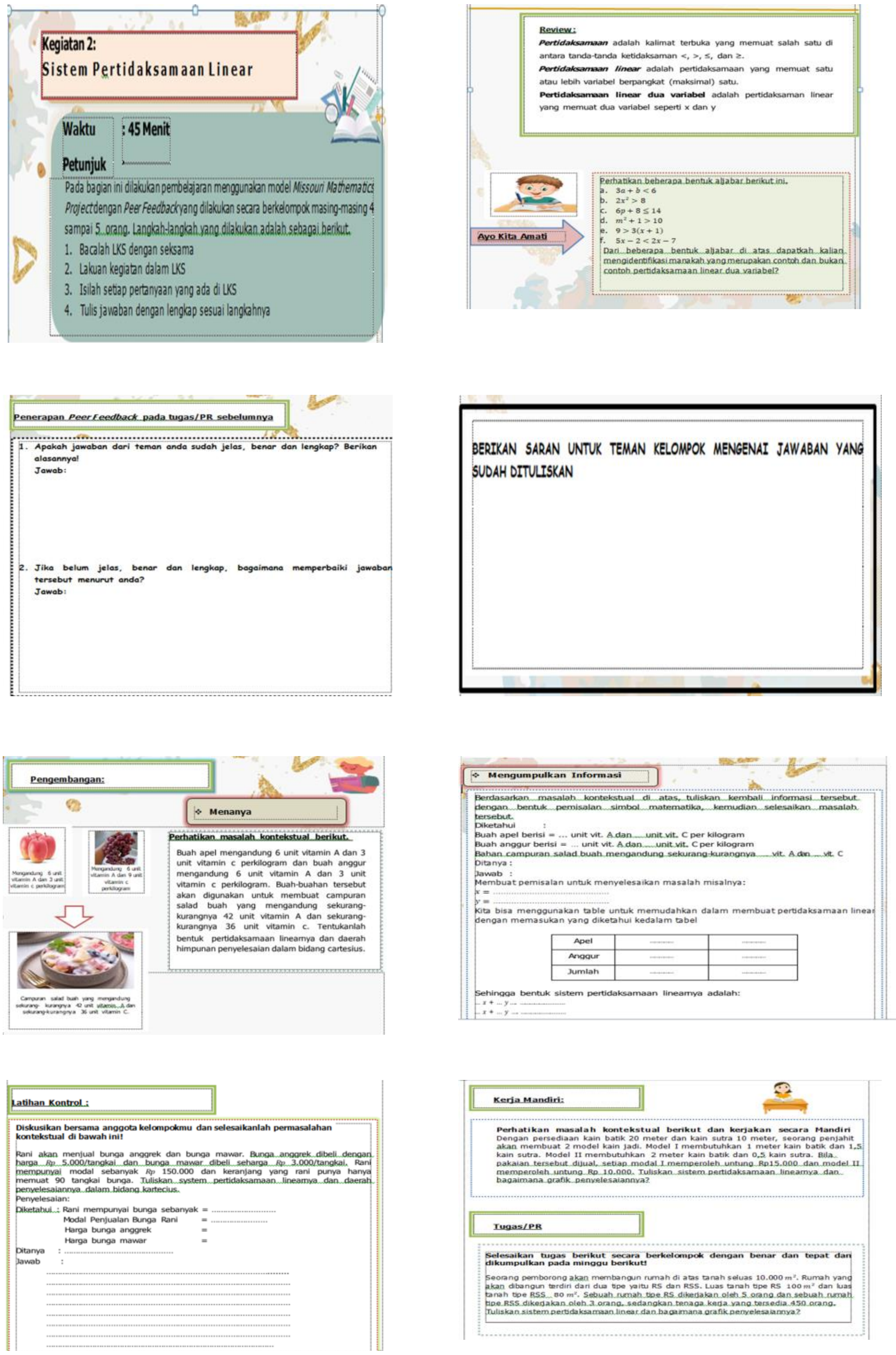

Figure 3. Missouri Mathematics Project Model Oriented Student Worksheet Design with Peer Feedback Learning Activities Section

3.3. Development Stage

3.3.1. *Characteristics of student worksheet Development*

The student workshet with the missouri mathematics project model with peer feedback contains things that can make students' time effective in learning, namely

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review of previous material, development of new ideas as an expansion of last mathematical concepts, provision of control exercises, assignments of independent assignments to students, and assignments of homework and assignments are corrected and assessed directly by the students themselves so that the remaining time is used with as effectively as possible to learn and engage directly in learning and assessment activities.

3.3.2. Validation of student worksheets

The assessment for the validation of the student workshet consisted of 2 validators, namely 1 media expert and 1 material expert. The media expert validation sheet consists of 10 indicators of assessment of student worksheet, consisting of aspects of appearance and accessibility. Based on the validation of media experts, the Missouri Mathematics Project Model-oriented Student Worksheet with Peer Feedback on Linear Program Materials obtained a validity score of 80%, with the category of Valid.

Suggestions and inputs from media expert validators are to pay attention to the page margins on the box containing sentences in the student worksheet. The following Figures 3 and 4 show the revision of the student workshet by media experts.

Figure 4. Student Worksheet View Before Validation

Figure 5. Student Worksheet View After Validation

The material expert validation sheet consists of 9 indicators for the assessment of of student worksheet, consisting of learning aspects and material content. The validity score for subject matter experts is 100% and is in the category of very valid. The suggestion and input from the material expert validator is to provide a place in the depiction of a graph in the form of a Cartesian diagram in the form of a grid so that the size on both coordinate axes is the same. The following figures 5 and 6 show the revision of the student worksheet from the subject matter expert.

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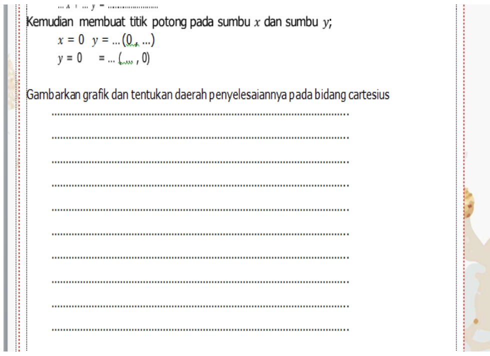

Figure 6. Student Worksheet View Before Validation

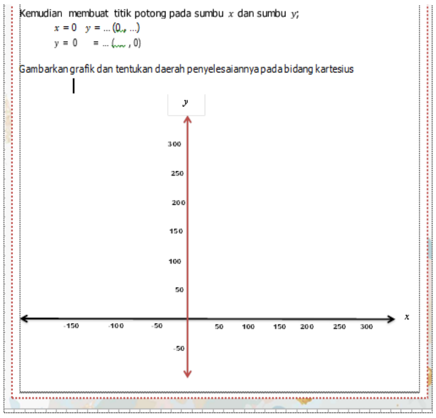

Figure 7. Student Worksheet View After Validation

The results of the validation activity show that the validator's assessment of the student worksheet is generally valid; however, there are still revisions related to the layout, graphics, symbols, and numerical errors as a result of typos. The results of the rational assessment by the validator provide the conclusion that the student worksheet is based on a strong theory, and the construction between its components consistently describes the learning model of the Missouri Mathematics Project, incorporating peer feedback. This is, by the opinion of (Sugiyono, 2017) that the validator's assessment of product design is carried out based on rational thinking, not facts in the field.

3.3.3. Practicality Test

The practical test of the development product was carried out in a small-scale (limited) trial, namely, 15 out of 24 students in grade XII MIPA 1 were selected as test subjects. For the 15 students, the researcher simulated the student worksheet, which were then asked to respond to the simulated student worksheet. In this simulation process, 1 mathematics teacher was also attended. Based on the results of the calculation of the small group test practicality questionnaire, a positive response from students to the student worksheet obtained a validity score of 82%, with a very practical category. And the teacher's positive response obtained a validity score of 88% with a very practical category.

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The average response of students and teachers reached 85%; If converted with the criteria of practical tools, the overall results of student and teacher responses are in the very practical category. The Missouri Mathematics Project's syntax, with its peer feedback, is very clear, making it very helpful for teachers in improving students' understanding of mathematical concepts. The steps students must take in this student worksheet to understand the concept are very clear. Learning does not feel boring. This is in line with the opinion of (Aufa et al., 2021) who found that students enjoyed the learning components through the Missouri Mathematics Project model. This is also supported by research (Febrian et al., 2023) demonstrated that the application of the Missouri Mathematics Project model, implemented through continuous practice, enabled students to gain experience in solving various problems.

3.3.4. Effectiveness Test

1. Thoroughness Test

The completeness test in this study consists of an average completeness test and a classical completeness test. The average completeness test was carried out to find out that learning outcomes oriented to the Missouri Mathematics Project model with peer feedback reached the minimum Completeness Criterion of 70. The hypothesis is as follows.

$H_0: \mu \leq 70$ (The average mathematics learning outcomes using the Missouri Mathematics Project model-oriented student worksheets with peer feedback are less than or equal to 70%.)

$H_1: \mu > 70$ (The average mathematics learning outcomes using the Missouri Mathematics Project model-oriented student worksheet with peer feedback of more than 70).

From the calculation using the t-test formula, a value is obtained for the price. Because it was rejected. So the results of this study can be concluded that the $t_{hitung} = 2{,}73 t_{tabel} = t_{(0{,}95)(23)} = 1{,}713 t_{hitung} > t_{tabel} H_0$ average mathematics learning outcomes using the student worksheet oriented to the Missouri Mathematics Project model, with peer feedback of more than 70, with an empirical average of 76.67

In this study, learning is said to be classically complete if at least 75% of all students taught using the Missouri Mathematics Project model-oriented with peer feedback reach a score of 70. The hypothesis used in this study is as follows.

$H_0: \pi \leq 75\%$ (The proportion of completeness of students taught using the Missouri Mathematics Project model-oriented worksheet with peer feedback is less than or equal to 75%)

$H_1: \pi > 75\%$ (The proportion of completeness of students taught using the Missouri Mathematics Project model-oriented student worksheet with peer feedback is more than 75%)

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From the calculation using the z-test formula, a value is obtained for the price. Because it was rejected. This means that the proportion of completeness of students taught using the student worksheet is oriented to the $z_{hitung} = 5{,}71;\ z_{tabel} = 1{,}64\ z_{hitung} > z_{tabel}\ H_0$ Iowa mathematics project model with peer feedback of more than 75%.

2. Average Difference test (Paired Sample t-test)

The average difference test in this study was carried out with the help of the SPSS application using a paired sample t-test with a real level of 5%. The hypothesis testing criteria are H_0 acceptable if the output sig value > is 5%. The hypotheses used in this study are:

$H_0: \mu_1 = \mu_2$ (Ere is no average difference between mathematics learning outcomes in Pre test and Post test data.
$H_1: \mu_1 \neq \mu_2$ (Ere is an average difference between the mathematics learning outcomes in the pre test and post test data

The prerequisite test that is carried out before the paired sample t-test is a normality test. The results of the normality test output can be seen in the following SPSS output.

Table 4. Output of Pre test and Post test Data Normality

One-Sample Kolmogorov-Smirnov Test		
		Unstandardized Residual
N		24
Normal Paremeters[a, b]	Mean	.0000000
	Std. Deviation	5.06492646
Most Extreme Differences	Absolute	.244
	Positive	.208
	Negative	-.244
Kolmogorov-Smirnov Z		1.194
Asymp. Sig. (2-tailed)		.116

a. Test distribution is Normal; b. Calculated from data

Based on the tests of normality output table above, in the Kolmogorov-Smirnov test section, a sig value for the pre test value and a post test value of 0.116 were obtained. Because the sig value of the two tests is greater than 5%, it can be concluded that the pre test and post test data are normally distributed and can be used for the paired sample t-test.

Table 5. Paired Sample T-Test Output

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of The Difference				
					Lower	Upper			
Pair 1	Pre test - Post test	-43.125	5.067	1.034	-45.265	-40.985	-41.691	23	.000

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The SPSS output result above was obtained with a sig (2-tailed) value of 0.000, then $H_0 < 0{,}05_0$ Was rejected, and H_1 was accepted, meaning that there was a real difference between the mathematics learning results in the Pre test and Post test data. Based on the results of the data tests that have been carried out, it can be said that the mathematics learning outcomes using the LKS oriented to the Missouri Mathematics Project model with peer feedback were developed to achieve learning completeness. This is because the Missouri Mathematics Project model with peer feedback provides a learning experience for students to learn through problems given by the teacher, where, through these problem-solving activities, students build new knowledge by relating the knowledge they have before. This is also supported by research by (Hidayah & Ningsih, 2021) that student worksheets using the Missouri Mathematics Project learning model are effective in the learning process. According to Ausubel's theory of learning that it is important for students to associate experiences, phenomena, and new facts with the knowledge they already have.

The use of peer feedback in the MMP model trains students to express themselves understandably. Students take part in giving feedback on the problems solved, students are trained to read their peers' work, reflect on its quality, and formulate constructive and useful feedback, so that students can think critically about what they read. This is by Piaget's theory that to help cognitive development, learning conditions need to be made as optimal as possible to allow students to conduct experiments, ask questions, answer, and compare their discoveries with those of friends. This is in line with (Patchan & Schunn, 2015) research, stating that students are involved in assessment and peer feedback, not to become experts like teachers, but to be involved in tasks so that they can be active in learning activities. This is supported by research by (Naimnule et al., 2020) saying that Peer feedback has the most important influence on student learning achievement.

4. Conclusions

The characteristic of this Student Worksheet is that its development is adjusted to the Missouri Mathematics Project Model with Peer Feedback, which is cooperative learning among others to construct students' knowledge in finding problem-solving solutions and helping students to be actively involved in assessing and providing feedback on assignments independently. The LKS of the Linear Program material developed was declared valid with an average percentage of validators reaching 80% and through the simulation of the LKS developed oriented to the Missouri Mathematics Project Model with Peer Feedback on 15 students of grade XII MIPA-1 of Noemuti State High School and attended by 1 mathematics teacher, the response and response of teachers and students to the LKS and the process was declared very good (very practical) with the average response of the teacher and students reached 85%. From the research carried out, it can be seen that there are real differences. This is seen from the value of Sig. (2-tailed) is 0.001 < 5%. So that the use of the LKS developed is oriented towards the Missouri Mathematics Project Model with Peer Feedback in learning mathematics of linear programming materials effectively.

Author Contributions

The first author researches the implementation of activities, collects and processes

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data, and compiles them in an article manuscript. The second and third authors helped research the implementation of activities and made significant contributions to the process of writing and developing the research

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Declaration of Competing Interest
The authors declare that there are no conflicts of interest.

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Mathventure SPLDV: Developing an Educational Math Game to Improve Students' Critical Thinking Skills

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ABSTRACT

This study aims to develop and evaluate Mathventure SPLDV, an Android-based educational game to enhance eighth-grade students' critical thinking on Systems of Linear Equations in Two Variables. The study used the ADDIE model in a Research and Development (R&D) approach. Data were collected using questionnaires and essay tests, and analyzed using a paired samples t-test after meeting normality and homogeneity assumptions. Validation from media and material experts showed high validity (87.78% and 93.63%), while student and teacher responses showed high practicality (89.26% and 96%). A significant improvement in critical thinking was found ($t = 2.638 > 1.6698$), indicating H_0 rejection. Based on the results, Mathventure SPLDV is recommended for classroom use as an effective tool to support students' critical thinking.

1. Introduction

In the 21st century, critical thinking is an essential skill that every individual must possess due to its important role in learning (Özelçi, 2023). This ability enables someone to effectively solve problems that arise in daily life as well as in the field of education (Setiana et al., 2021). Someone with critical thinking skills can quickly identify and formulate problems, analyze them from various perspectives, and deeply evaluate each step taken in the problem-solving process (Maričić et al., 2016). When faced with complicated issues, critical thinking abilities help students make more thoughtful and logical judgments by enabling them to properly examine, evaluate, and synthesize information. (Ennis, 2011; Laar et al., 2019). Students trained in critical thinking can apply their knowledge in real-world

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contexts and develop the ability to solve more complex problems with more innovative and effective solutions (Halpern & Dunn, 2021). With these skills, students will be able to identify relevant information and make appropriate decisions in various situations. Hence, it is essential for educators to consistently enhance instructional practices that emphasize critical thinking, as such skills are foundational competencies that students need in order to navigate real-life challenges effectively. (Efendi, 2022).

However, the reality is that students' critical thinking skills in Indonesia are still relatively low. Based on the PISA 2022 results released by the OECD, the average mathematics proficiency score of Indonesian students was recorded at 366, while the global average score was 472 (OECD, 2023). This result remains consistent with the PISA 2018 findings, which indicate that Indonesia continues to demonstrate low academic performance while maintaining a high level of equity. Additionally, the average performance of Indonesian students in mathematics, reading, and science remains below the OECD standards. Only 18% of Indonesian students achieve the minimum level 2 competency in mathematics, while the OECD average is 69%. Most Indonesian students are at level 1a, which means they can solve simple math problems with clear information but struggle to use critical and creative thinking to solve more complex problems (Trisnani et al., 2024). These findings are in line with national studies reporting that students' critical thinking skills are still far below the expected level (Agustiani & Jailani, 2023; Martyanti, 2018).

The limited critical thinking skills of students in Indonesia are reflected in their difficulties in solving problems effectively (Firdaus & Kailani, 2015). Mathematics is a discipline that contributes to the development of critical thinking skills because of its well-defined structure and the interconnectedness of its concepts (Aizikovitsh & Amit, 2010). In mathematics education, critical thinking becomes an important aspect that is honed through the ability to reason and analyze deeply, so that students can apply this understanding in problem-solving and everyday life (Munawaroh et al., 2018). Furthermore, critical thinking skills are essential for achieving success in mathematics learning. (Popova et al., 2024). Skills are essential in mathematical activities, especially in the problem-solving process (Khusna et al., 2024), as well as for solving problems rationally and making accurate decisions (Verschaffel et al., 2020). Therefore, critical thinking and problem-solving skills are interconnected (Susandi et al., 2019). A subject that demands critical thinking abilities is the Systems of Linear Equations in Two Variables (SLETV), because solving it requires the ability to analyze, understand the relationships between variables, and interpret solutions in various problem contexts.

Findings from observations and interviews with eighth-grade teachers at SMP Negeri 2 Jaten indicate that students' critical thinking abilities in the topic of SLETV are still encountering significant challenges. Daily test results on this topic showed that most students scored below the Minimum Completeness Criteria. In addition, a pretest designed to assess students' critical thinking on SLETV yielded an average score of 56.84, which falls into the low category. These findings are consisten with the study by (Maghfiroh & Dasari, 2023), which stated that classroom learning still face various obstacles that hinder the achievement of learning objectives. These obstacles include the use of less appropriate learning models, strategies, or approaches, as well as a lack of practice questions specifically designed to develop students' mathematical critical thinking skills. Similarly,

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(Pramasdyasari et al., 2024) revealed that the critical thinking skills of eighth-grade students still require significant improvement.

The students’ low critical thinking skills are reflected in their tendency to memorize solution patterns for contextual problems without fully understanding the fundamental concepts. This is caused by a non-student-centered learning approach, making them more passive and only learning through rote memorization. Additionally, the lack of critical thinking training, the dominance of low-cognitive-level questions, and the habit of teachers providing example questions before tests cause students to struggle with different variations of questions (Astuti et al., 2019; Efendi, 2022). When encountering difficulties in solving math problems, students are often given direct answers instead of being encouraged to find solutions on their own. This obstructs the growth of their critical thinking skills in solving problems. (Fadhilah et al., 2021). The still conventional teaching methods also contribute to the low critical thinking skills of students. Students are not encouraged to think more deeply when learning materials are used insufficiently and passively. On the other hand, creating a more fun and exciting learning environment requires the use of interactive and engaging learning materials (Qureshi et al., 2023). Therefore, innovation in learning media and more effective use of technology are needed to enhance students' critical thinking skills.

In modern education, technology as a learning medium plays an important role in enhancing the effectiveness of the teaching and learning process. One of the most popular learning media among students is game-based learning, as it provides entertainment that makes students feel happier and more motivated while studying. Through games, students can more easily understand the material and undergo the learning process in a more enjoyable atmosphere. (Ebner & Holzinger, 2007; Fatimah & Santiana, 2017). In mathematics education, game-based learning has the potential to improve students’ academic performance simultaneously (Ersen & Ergul, 2022).

Research has shown that the use of educational games is effective in supporting mathematics learning (Tristanti et al., 2021). Android-based games have been widely studied implemented in mathematics education. (Lestari et al., 2019; Qohar et al., 2021; Sarifah et al., 2022). The study by Qohar et al. (2021) indicates that the Android-based educational game they developed demonstrates a high degree of practicality, positioning it as an effective tool for mathematics instruction. Game-based learning models are considered an effective approach to fostering critical thinking skills (Yang & Chang, 2013; Cicchino, 2015). Furthermore, (Vos et al., 2011) argue that digital game-based learning fosters an environment that encourages students to engage in active critical thinking.

Based on the explanation above, the researcher is interested in developing a valid and practical educational mathematics game for eighth-grade students to be used as a learning medium. It is also expected to be effective in training and enhancing students’ critical thinking skills in mathematics learning, particularly in the topic of SLETV.

2. Method

2.1. Participants

The research and development of the educational game media Mathventure

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SPLDV involved eighth-grade students from SMP Negeri 2 Jaten as participants. The study population comprised all eighth-grade students at the school. Two classes were selected as the sample through a simple random sampling method. Class VIII-G, consisting of 32 students, served as the experimental group, while Class VIII-F,also with 32 students, functioned as the control group.

2.2. Research Design and Procedures

This research uses a Research and Development (R&D) approach by developing Android-based educational game media. It utilizes the ADDIE development model(Frydenberg, 2011) which includes five stages: analysis, design, development, implementation, and evaluation. In the analysis phase, problem and needs identification are conducted to determine the type of product to be developed. The design stage aims to design various aspects necessary for product development, including creating the storyline and game flowchart, while the development stage encompasses the realization of the product design, including validation by subject matter experts and media experts, with the goal of producing a product prototype. In the implementation stage, the validated product is tested in schools through a math educational game to evaluate its practicality, with limited trials and large-scale trials. Following the trial, the evaluation stage is conducted to ascertain whether the product can enhance students' critical thinking abilities by evaluating its effectiveness in both the experimental and control groups.

2.3. Instruments

This study utilized data collection instruments in the form of tests and non-tests. The test instrument developed by the researcher was a critical thinking ability test, arranged as essay-based pretest and posttest items, referring to critical thinking indicators within the topic of Systems of Linear Equations in Two Variables (SLETV). The critical thinking indicators used in this study included understanding the problem, generating ideas relevant to the problem, determining appropriate problem-solving strategies, and rechecking the solution by providing reasons or conclusions. The topic focused on solving contextual problems related to SLETV accurately through various methods. In addition, the researcher prepared a validation questionnaire to evaluate the educational game's content, covering aspects such as content feasibility, presentation, and language. The media expert validation questionnaire included assessments of appearance, programming aspects, and ease of product use. A student response questionnaire was also used for data collection, providing a series of questions to the respondents. Additionally, a teacher response questionnaire was used to gather feedback from educators. The collected data were analyzed through processes of organization, classification, description, and conclusion drawing. A descriptive approach was employed to interpret participants' responses from tests, questionnaires, interviews, and observations.

2.4. Data Analysis

The data analysis techniques in this study consist of validity analysis, practicality analysis, and effectiveness analysis of the educational math game media. Data validation is conducted using a questionnaire that assesses the feasibility of the educational game in terms of content and media. The assessment of media

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feasibility is conducted by media expert validators, who evaluate aspects of appearance, programming, and product usage. Meanwhile, the validation of material feasibility is carried out by subject matter expert validators by assessing the aspects of content, presentation, and language. In addition to the game products, the test instruments are also validated. The mean score obtained from the validators' evaluations is subsequently transformed into a percentage to assess the feasibility and appropriateness of the learning media and test instruments for practical implementation. The next step is the practicality test of the media, which is conducted by distributing questionnaires to gather responses from students and teachers. This questionnaire assesses how easy it is to use and operate the educational game, as well as the section that provides recommendations for improvement. The data obtained is analyzed to understand user responses, including the weaknesses and shortcomings of the media. The results of the trial can be used as a basis for modifying the media to make it better for learning. The survey results are calculated using the following percentage formula,

$$P = \frac{TSe}{TSm} \ x \ 100 \ \% \qquad (1)$$

Notation *TSe* refers to the total empirical score obtained, while *TSm* represents the maximum possible score. The collected data is then converted into percentages and analyzed according to validity and practicality criteria developed based on the characteristics of the assessment instrument. These characteristics are categorized into four groups. A percentage score ranging from 85.01% to 100% indicates that the product is very valid or very practical. Scores between 70.01% and 85.00% are classified as valid or practical. If the score falls between 50.01% and 70.00%, the product is considered less valid or less practical. Meanwhile, a percentage score between 1.00% and 50.00% indicates that the product is not valid or not practical.(Akbar, 2013)

An effectiveness test was conducted to show that the educational games used in this study are capable of enhancing students' critical thinking skills. Before starting the effectiveness test, it is important to ensure that the distribution of the dependent variable values is normal and homogeneous. This study involves two groups, the experimental class and the control class, each given a pretest to ensure that there are no significant differences between them. Effectiveness is assessed by comparing the scores after the critical thinking skills test between the experimental class, which received treatment with educational game media during teaching, and the control class, which did not use such media. A product is deemed effective if the average critical thinking score of the experimental class is higher than that of the control class. Based on these findings, it can be concluded that the product meets the criteria of validity, practicality, and effectiveness.

3. Results and Discussion

3.1. Analysis Stage

At the analysis stage, the identification of the needs and problems of eighth-grade students was carried out through interviews with teachers and the administration of questionnaires. According to the findings of the interview with the math teacher for the eighth grade, the teaching still only makes use of the school's textbooks, and there is still very little media utilized. The learning media used is still

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conventional, relying only on the blackboard to deliver the material. The teacher doesn't have time to create other learning media because it takes time and money, as well as the limited facilities of the school. During the learning activities, students tend to be less active and often encounter difficulties in solving mathematical problems. The teacher noted that the students' critical thinking skills require further development. This is reflected in the low assignment results, especially in solving math problems, including the topic of SLETV. Students' knowledge, particularly on this topic, is still limited. This is evident from the average score of the last daily test results, which is still below the minimum completeness criteria. In fact, 87.5% of students scored below the minimum mastery criterion of 70, indicating that most students have not yet mastered the topic of SLETV.

Students are only able to memorize concepts without truly understanding them. Students tend to rely on memorization and example solutions to answer questions and are not yet able to handle problems that require analysis or evaluation, depending on example solutions first before exams, making it difficult for them when given questions in a different format. Moreover, students' motivation to learn mathematics is very low, as evidenced by the presence of students chatting during lessons. Some students often do not focus on the lessons because the media used is less engaging for them. As a result, some students still struggle to understand the concept of SLETV.

According to the results from a questionnaire given to the students at SMP Negeri 2 Jaten, the instructors frequently employ the lecture format and have not yet incorporated a variety of instructional media. These findings are reinforced by observations during the learning process where the math teacher used group discussion methods followed by presentations, after which the teacher explained the material. The frequency that is too often acknowledged makes students feel bored and less enthusiastic. All students desire the presence of varied and innovative learning media as a medium for learning mathematics.

At this stage of the analysis, it is also stated that the initial research was undertaken by administering a test to students to establish their baseline ability in critical thinking skills. The critical thinking test was administered to 32 eighth-grade students at SMP Negeri 2 Jaten, focusing on the prerequisite material for SLETV, namely the one-variable linear equation topic. It was found that 15.63% of the students met the indicator for understanding the problem. Students still face difficulties in writing down what they know and identifying what the question is asking, based on this indicator. Regarding the indicator of generating ideas relevant to the problem, only 21.88% of students were able to meet this criterion. In this aspect, many of their abilities are still not optimal in creating mathematical models according to the context of the problem, such as writing equations that describe the relationships between variables in the question. Meanwhile, for the aspect of determining problem-solving, there are 15.63% of students. Only a portion completed all stages of the math problem-solving process in a sequential and systematic manner. For the indicator of rechecking by providing reasons/conclusions, it was found that 12.50% of students met this indicator. In this aspect, on average, students do not write the conclusion of the solution correctly.

3.2. Design Stage

Following the completion of the analysis stage, the researcher proceeded to the

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second phase of the ADDIE development model, namely the design stage. The product developed is an Android-based educational game intended to support eighth-grade mathematics learning, specifically focusing on the topic of SLETV. This game, titled *Mathventure SPLDV*, is designed as an adventure game. The design stage involved preparing the content material, creating the storyline, and developing the game flowchart, all aligned with the learning objectives and expected competencies related to SLETV.

On the initial screen, players are introduced to a character known as the material gatekeeper. The game consists of three levels, each starting with players interacting with in-game characters to unlock chests containing contextual problems. Players then explore the environment with the mission of solving these problems and collecting keys obtained from character checkpoints. The visual display was created using Canva, while audio features such as cheerful background music and sound effects were added to enhance the gameplay experience. Unity was selected as the development platform for building the application. At this stage, the researchers also developed various instruments for evaluating the educational game, including validation, practicality, and effectiveness assessment sheets in the form of questionnaires and test instruments.

3.3. Development Stage

At the stage of game product development using the Unity application, the initial game screen displays an adventurer character who will explore a village. Instructions are provided to control the character's movement using the left, right, and up directional buttons. The left button moves the character to the left, the right button moves it to the right, and the up button allows the character to jump. This screen also includes an info menu that contains the profile of the educational game developer. The material menu display, in which part of Image 2, presents the learning content available in this educational game. The content includes a summary of the SLETV material, encompassing learning objectives, essential concepts, sample problems, and solution strategies, such as the substitution, elimination, and combination methods.

On the game adventure page, in this section, the character explores a village after encountering a problem or challenge from the previous chest. Players must complete all stages by interacting with characters at each checkpoint. There are four posts, namely post 1 to post 4. Each character at each post presents a challenge to the player, which involves solving problems related to SLETV sequentially at each stage. Each character post represents one stage, from "Fact Exploration" to "Critical Conclusion." If the player's answer is correct, the character will give a key. Players must collect all the keys from each checkpoint to advance to the next level.

During the exploration, players will encounter several obstacles. On this page, there are also three heart symbols in the top left corner, indicating the player's three chances. If the player answers incorrectly or hits an obstacle, then the opportunity will be reduced by one. If the player's chances run out, the game will end (game over). Additionally, there is a map menu that keeps a record of previous character paths, such as cases to be solved and every answer given at previous checkpoints. This helps players track their progress and gain further insights into their journey in completing the game. The display of the educational game "Mathventure SPLDV" is shown in Figure 1.

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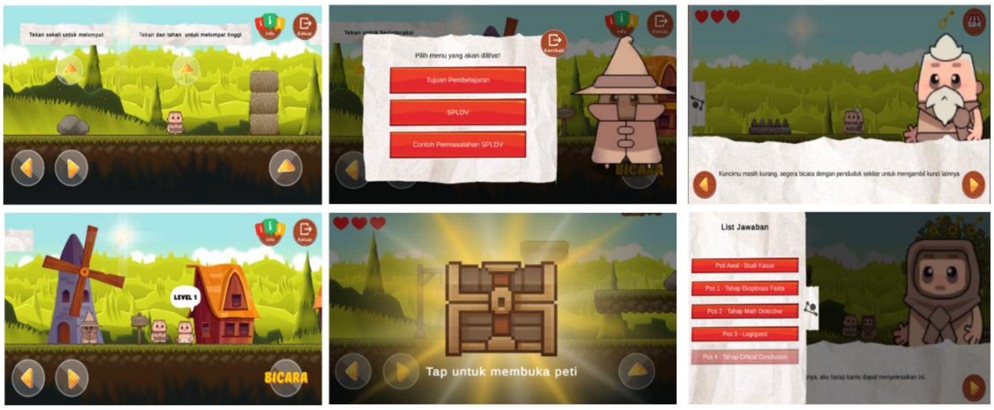

Figure 1. Display of the Educational Game "Mathventure SPLDV"

After the game media was developed, the researchers then conducted validation. Validation is part of the implementation phase in the ADDIE development model, aimed at obtaining feedback from experts regarding the validity of the learning media, both in terms of content and media. This validation is conducted through the distribution of questionnaires to media experts and content experts.

The evaluation conducted by media experts using a questionnaire addressing appearance, programming, and usability aspects resulted in an average validation score of 87.78%, categorizing the media as "very valid." Meanwhile, the assessment results from content experts through a questionnaire evaluating the aspects of content feasibility, presentation, and language show an average validation percentage of 93.63%, also categorized as "very valid."

3.4. Implementation Stage

In the implementation stage, the validated product was tested in the school on eighth-grade students to evaluate its practicality. The trial phase in this development included a limited-scale trial (group trial) and a field trial. The group trial was conducted with 32 students from class VIII-G at SMP Negeri 2 Jaten. The practicality assessment of the educational game product was obtained through response questionnaires from teachers and students. Following the implementation of the learning process using the game-based media, students were asked to complete response questionnaires to evaluate their perceptions and experiences. Meanwhile, the mathematics teacher at SMP Negeri 2 Jaten completed the teacher response questionnaire.

Based on the results of the student response questionnaires, a practicality score of 89.26% was obtained, while the teacher's response score was 96%. Thus, it was concluded that the educational game product met the criteria of being very practical. Therefore, the practicality indicators of the game were fulfilled, as evidenced by the student and teacher response questionnaires. In the field trial, after obtaining valid and practical results, a large-scale trial was conducted. The field trial was conducted with class VIII-G as the experimental group, comprising 32 students, and class VIII-F as the control group, also with 32 students. The experimental group utilized the educational game media during learning, whereas the control group did not use the educational game media.

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3.5. Evaluation Stage

For the purpose of determining how effectively the product has improved students' critical thinking abilities, evaluation is the final stage in the development process. An effectiveness test was conducted on the developed educational game media following the completion of the trial phase. Prerequisite tests, such as homogeneity and normality tests, were performed beforehand. According to the normality test results, data from both the experimental class (L-count = 0.118 < L-table = 0.159) and the control class (L-count = 0.136 < L-table = 0.159) were normally distributed. The homogeneity test, conducted using Excel's F-test, yielded an F-calculated value of 1.380, which is less than the F-table value of 1.822, indicating that the data were homogeneous. Next, an equivalence test was conducted to ensure that the initial scores (pretest) between the experimental and control classes were comparable. The results indicated no significant difference at the beginning of the learning process. After confirming that all prerequisites were met, learning activities proceeded with the experimental class using the educational game media, while the control class employed conventional methods. Following the learning sessions, normality and homogeneity tests were performed again on the posttest data, confirming that the data remained normally distributed and homogeneous.

To evaluate the effectiveness of the educational game, a one-tailed t-test was performed. The analysis yielded a t-observed value of 2.638, which lies within the critical region (DK= $\{t \mid t > 1.6698\}$), leading to the acceptance of H_1. Therefore, a significant difference exists between the experimental and control groups, demonstrating that the Mathventure SPLDV educational game media effectively improves students' critical thinking skills.

The enhancement in these skills is closely related to the design and characteristics of Mathventure SPLDV, which is specifically designed as an adventure-based educational game to encourage students to actively solve contextual problems related SLETV. This game integrates four critical thinking indicators: understanding the problem, considering ideas according to the problem, determining problem-solving and rechecking by providing reasons/conclusions. The four indicators are integrated into the game flow through four thematic stations: *Fact Exploration*, *Math Detective*, *LogiQuest*, and *Critical Conclusion*.

Each station challenges students to solve problems step by step with an approach aligned with critical thinking stages. In playing, students become accustomed to evaluating information, making decisions, and drawing conclusions based on relevant arguments. Thus, the learning process becomes not only meaningful but also gradually fosters critical thinking skills. This is in line with the findings of Ismail et al. (2022) ,who assert that critical thinking skills are more effectively developed through contextual problem-based mathematics learning relevant to real life, as it helps students connect concepts with their experiences. This is also supported by the explanation of (Ailiyyah et al., 2024), who noted that contextual mathematical problems can encourage students to engage in critical thinking during learning. Furthermore problem-solving in mathematics also trains logical, analytical, and critical thinking skills(Trisnani et al., 2024).

This research developed an educational game called Mathventure SPLDV, aimed at improving the critical thinking skills of eighth-grade students at SMP

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Negeri 2 Jaten, particularly on the topic of SLETV. The game was evaluated for its validity, practicality, and effectiveness, with results showing that it met all three criteria, indicating its feasibility for classroom implementation. These findings are consistent with various previous studies. Research by Lestari et al. (2019) shows that Android-based educational games can enhance students' critical thinking skills. According to Angelelli et al. (2023), the integration of game elements into instructional practices can significantly enhance students' abilities in critical thinking, reasoning, and problem-solving. Similarly, Game-Based Learning (GBL) provides simulated real-world environments within a safe setting, allowing learners to explore various strategies, receive immediate feedback, reflect on their decisions, and further strengthen their critical thinking skills) (Mao et al., 2022). Moreover, educational games with an adventure concept have been proven effective in developing creativity and decision-making abilities in the context of problem-solving (Efendi, 2022).

Mathventure SPLDV is a well-designed adventure-based educational game that systematically integrates critical thinking indicators into contextual problem-solving activities. Its structured stages, real-world relevance, and engaging gameplay format make it a powerful tool to foster students' critical thinking skills in mathematics. However, the scope of the game is limited to a single mathematical topic. Therefore, further research is recommended to expand the game content to other mathematical concepts in order to maximize its applicability and impact in broader educational settings.

4. Conclusions

This development resulted in an educational mathematics game designed to enhance students' critical thinking skills. The final product, titled Mathventure SPLDV, was found to be valid, practical, and effective. The validity of the game was established based on evaluations by media and subject matter experts, with average scores categorized as very valid. The practicality of the media was assessed through questionnaires administered to both students and teachers, which indicated that the game was considered very practical. The effectiveness of the product was evaluated using a hypothesis test that compared the mean scores of effectiveness data between the experimental class and the control class. The results revealed a significant difference between the two groups, indicating that the implementation of Mathventure SPLDV had a positive impact on improving students' critical thinking skills. Therefore, it can be concluded that Mathventure SPLDV is an effective learning media and is suitable for use as a supplementary tool in the mathematics learning process.

Author Contributions

The first author was responsible for collecting, processing, and analyzing the data; designing and developing the product; and preparing the initial draft of the scientific article. The second and third authors provided input and suggestions in refining the research, data analysis, and manuscript writing.

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Declaration of Competing Interest
There are no conflicts of interest to declare.

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Mathematical Reasoning Ability in Terms of Self-Efficacy in the CORE Learning Model Assisted by Liveworksheet

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ABSTRACT

This study aims to analyze the quality of the CORE learning model assisted by Liveworksheet and examine the effect of self-efficacy on students' mathematical reasoning. A quantitative method with a posttest-only control group design was used. Instruments included a reasoning test, self-efficacy questionnaire, student response questionnaire, and observation sheet. The sample consisted of eighth-grade students at SMPN 16 Semarang, selected through cluster random sampling. Data analysis involved planning, implementation, evaluation, and simple linear regression. The results showed the CORE model with Liveworksheet was of good quality, and self-efficacy significantly influenced mathematical reasoning, contributing 71.6%. It is recommended that the interactive CORE model be further developed along with differentiated teaching tools to ensure learning becomes more adaptive to students' needs.

1. Introduction

The rapid progress that has occurred in the world of science and technology is closely related to the essential contribution of mathematics, which serves as the main foundation in various disciplines and applied fields. Well-mastered mathematical skills will be an important asset for every individual to face challenges, make the right choices, and adapt to an ever-changing world (Herman et al., 2024). One of the crucial aspects that every student must master in mathematics learning activities is mathematical reasoning ability. If knowledge about reasoning is integrated into the curriculum, it will undoubtedly have a positive impact on mathematics learning (Basir et al., 2022).

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Mathematical reasoning is a crucial competency that enables students to internalize and apply mathematics substantively through the construction of original ideas. This process facilitates the drawing of logical and valid mathematical conclusions based on the analysis of available data, facts, or statements (Masriyah et al., 2024). Mathematical reasoning ability is a process of systematic and logical thinking, comprehensively analyzing information, generating valid conclusions along with evidence, and applying mathematical concepts in various problem contexts (Lithner, 2008). This is supported by findings in studies conducted by (Jariyah et al., 2024) and (Kusumawardani et al., 2018), which reveal that mathematical reasoning is a cognitive skill that relies on a sequential thinking process to produce logical and accountable conclusions based on verified evidence. Based on the various perspectives presented, it can be concluded that mathematical reasoning is a form of logical and structured thinking process used to understand information, analyze relationships between concepts, and draw valid conclusions based on evidence and data whose accuracy can be accounted for.

Findings from various previous studies indicate that students' mathematical reasoning abilities are low. The study by (Nabila & Marlina, 2022) found that the mathematical reasoning abilities of eighth-grade junior high school students in Karawang are still low. The cause of this condition is that there are still a number of students who do not fully understand the content or meaning of the questions presented, are not careful enough in analyzing and interpreting the content of the questions, resulting in students answering carelessly and having difficulty solving problems because they do not use their reasoning skills properly.

Similar findings were obtained in seventh grade junior high school students that mathematical reasoning ability is still in the low category, many students face obstacles when trying to solve a contextual problem that contains mathematical reasoning indicators, students find it difficult if the exercise problem is different from the example problem (Yerizon et al., 2024). If students lack mathematical reasoning skills, they tend to face obstacles in understanding and solving mathematical problems (Nasir et al., 2023). Therefore, mathematical reasoning skills in mathematics learning must be continuously trained and honed through teachers who regularly provide challenging problems requiring higher-order thinking skills (HOTS) (Sari et al., 2023)(Sumartini, 2015). In addition to mathematical reasoning skills, one of the affective factors that plays a crucial role in predicting students' success in solving mathematics problems is self-efficacy (Smit et al., 2023).

Self-efficacy refers to an individual's belief in their personal capacity to organize and carry out various strategic actions needed to achieve the desired level of performance or results (Dinther et al., 2011)(Badura, 1997). The characteristics of self-efficacy are specific to certain fields and influenced by context, meaning that an individual's belief in their abilities will vary depending on the situation they are facing. Individuals in the learning process who have high self-efficacy tend to demonstrate better academic performance, as they possess strong intrinsic motivation and persistence in taking appropriate actions. Conversely, individuals with low self-efficacy tend to show vulnerability to feelings of despair, resignation, and avoidance of assigned tasks (Kul et al., 2024).

Self-efficacy is related to mathematical reasoning ability; a lack of mathematical reasoning ability may be due to a lack of self-efficacy among

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students efficacy (Smit et al., 2023). This is reinforced by research conducted by (Hadiat & Karyati, 2019) which found that the higher the level of self-efficacy among students, the higher their mathematical reasoning abilities. (Jumiarsih et al., 2020) stated that this is because students with high levels of self-efficacy tend to be more confident in facing mathematical challenges. They are more active in engaging in the learning process, attempting to solve difficult problems, and not easily giving up when faced with difficulties. Conversely, students with low self-efficacy are more likely to feel anxious or afraid of failure, which can hinder them from practicing and developing their mathematical reasoning abilities.

Students' self-efficacy can be enhanced through the implementation of active learning, especially when such learning involves everyday problems closely related to students' lives (Hanifah et al., 2021). Therefore, a learning model is needed that not only promotes the development of cognitive abilities such as mathematical reasoning but also strengthens students' self-confidence or self-efficacy in the learning process. One of the relevant learning models to address this need is the Connecting, Organizing, Reflecting, Extending (CORE) learning model.

The CORE learning model is one of the alternative learning models that aims to activate students in constructing their own understanding (Latifah et al., 2025). Through the stages of connecting, organizing, reflecting, and expanding, this learning model facilitates students in integrating, organizing, exploring, and developing the information they have obtained (Rahmadhani et al., 2024). Therefore, the clearly structured stages in the CORE learning model have the potential to make learning a more valuable experience and help students achieve learning objectives more effectively (Muhammadiah et al., 2023). Additionally, in order to optimize the implementation of the CORE learning model, which emphasizes active and constructive student involvement, support from digital learning media that can effectively facilitate this process is required. The presence of interactive media not only strengthens the implementation of the stages in the CORE model but also significantly contributes to facilitating students' understanding of complex and challenging learning topics, such as mathematical concepts. One form of digital learning media innovation relevant to this need is Liveworksheet.

Liveworksheet, as a free online platform, empowers educators to create or utilize interactive Electronic Student Worksheet, transforming conventional worksheets, such as Student Worksheet, which are typically printed, into more personalized and challenging digital learning activities for students (Rosidah et al., 2023)(Le & Prabjandee, 2023). The use of Liveworksheet can help make learning more effective, as this model encourages direct student participation in teaching and learning activities, thereby reducing passive attitudes during the learning process (Sugandi et al., 2024). When integrating complex problems into Electronic Student Worksheet based on Liveworksheet, it can facilitate a deeper understanding of mathematical concepts and significantly develop students' mathematical reasoning skills. This is supported by research conducted by (Ahmar & Soro, 2023; Atiyah & Priatna, 2023) which shows that the implementation of the CORE learning model and the use of Liveworksheet-based Electronic Student Worksheet can improve mathematical reasoning skills.

The research results show that the average reasoning ability of students in the experimental class is higher than that of students in the control class. This is because in the CORE learning model, students are actively involved through four

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stages, namely: Connecting, where students connect new knowledge with existing knowledge. Organizing, where students are encouraged to organize the information they have learned so that they can understand the structure and relationships between concepts. Reflecting, where students reflect on their learning process, enabling them to evaluate their understanding and the strategies they have used. Extending, where students are encouraged to expand their knowledge by applying the concepts they have learned in a broader context or in new situations.

This study is similar to the research conducted by (Hadiat & Karyati, 2019), which found that mathematical connection skills, curiosity, and self-efficacy are collectively related to mathematical reasoning skills, contributing 46.3% to the overall outcome. Furthermore, based on the findings in the study by (Sari et al., 2021), it was found that self-efficacy has a positive effect on mathematics learning outcomes. (Wiharso & Susilawati, 2020) concluded in their study that improving students' connection skills through CORE learning shows advantages over conventional learning. (Mahanani et al., 2023) concluded in their study that implementing liveworksheets in learning activities contributes positively to improving students' mathematics learning outcomes. Based on the above discussion, previous studies have indeed addressed similar topics related to mathematical reasoning ability, self-efficacy, the CORE learning model, and Liveworksheet.

This study presents a unique approach by integrating all four aspects simultaneously, thereby offering novelty compared to previous research. Based on the previous explanation, this study aims to achieve the following: (1) to determine the quality of the CORE learning model assisted by Liveworksheet? (2) To determine the influence of students' self-efficacy on their mathematical reasoning abilities in the CORE learning model supported by Liveworksheet. In light of this, this study is expected to provide concrete benefits in expanding the scope and strategies of mathematics education, which are not solely focused on developing mathematical reasoning abilities but also simultaneously build students' self-efficacy in learning activities. Through the application of the CORE learning model supported by interactive media such as Liveworksheet, this study is expected to serve as a reference for teachers in designing more meaningful, adaptive, and responsive learning activities to meet the learning needs of students in the digital age.

2. Method

This study uses a quantitative method based on positivism philosophy, in which numerical data is used in the research process on a specific population or sample group, collected through instruments, then analyzed statistically to test hypotheses and conclude the results of the study (Sukestiyarno, 2021). This study uses a Posttest-Only Control Group Design, in which there are two randomly assigned groups, namely the experimental group and the control group. The following is an illustration of the Posttest-Only Control Group Design model.

Group	Treatment	Posttest
R_1	X_1	O
R_2	X_2	O

Figure 1. Posttest-Only Control Group Design Model

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The population in this study included all eighth-grade students at SMP Negeri 16 Semarang. Sampling was conducted using the Cluster Random Sampling technique, which resulted in an experimental group and a control group, namely eighth grade classes C and D. The techniques used in data collection included tests to measure mathematical reasoning ability, self-efficacy questionnaires, observation sheets on the implementation of learning, and questionnaires to assess students' responses to the learning process. Data collection was carried out systematically using several instruments according to the research needs.

First, a mathematical reasoning ability test was used to obtain quantitative data on the mathematical reasoning abilities of students after the treatment was given. Second, a self-efficacy questionnaire was used to measure the level of students' self-confidence in their ability to complete mathematical tasks. The results of this questionnaire were used to determine the effect of self-efficacy on mathematical reasoning abilities. Third, an observation sheet on the implementation of learning was used to measure the quality of the implementation of the CORE learning model assisted by Liveworksheet in the experimental class. Observations were made by observers during the learning process to ensure objectivity and consistency of implementation. Finally, a questionnaire on students' responses to the learning process was distributed after the treatment was given.

This instrument aims to determine students' perceptions and responses to the learning model applied. Data analysis was conducted through four stages: (1) analysis of learning planning data, analyzing learning tools and assessment instruments by expert validators; (2) analysis of learning implementation data, assessing the implementation of learning activities during the learning process by observers; (3) learning evaluation data analysis, analyzing data through prerequisite tests in the form of normality tests, homogeneity tests, followed by hypothesis tests in the form of one-tailed t-tests to test the average completeness, one-tailed z-tests to test the proportion of completeness, and two-sample mean tests to test the difference in means; (4) To measure the effect of self-efficacy on mathematical reasoning ability in the CORE model assisted by Liveworksheet, simple linear regression analysis was used. This analysis aims to determine the extent to which the self-efficacy variable contributes to predicting students' mathematical reasoning ability. The collected data was analyzed in three stages. This study refers to the following learning quality achievement (Khardita et al., 2023).

Table 1. Learning Quality Achievement

Stage	Achievement
Planning	Valid and at least categorized as good
Implementation	At least categorized as good
Assesment	Learning is effective if (1) Average score is satisfactory (2) ≥ 75% of students are satisfactory (3) Experiment score >control (4) Completion rate with CORE learning > Problem Based Learning (PBL) (5) *Self-efficacy* is influential

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3. Results and Discussion

This section presents the results of research highlighting the quality of learning implementation by applying the CORE model supported by the use of Liveworksheet. In addition, it also explains the extent to which students' self-efficacy contributes to their mathematical reasoning abilities while participating in learning with the CORE model assisted by Liveworksheet.

3.1. CORE Learning Quality Assisted by Liveworksheet

Quality mathematics learning is characterized by interactive and inspiring processes that motivate students to participate actively. An effective learning environment is also challenging, enjoyable, and provides adequate opportunities for the development of students' initiative, creativity, and independence (Siregar et al., 2021). The quality of learning has three stages, namely: Planning, Implementation, and Assessment. Quantitatively, the quality of learning is evaluated based on two main criteria: first, the performance of the experimental group is significantly superior to that of the control group; second, the achievement of learning completeness by students.

3.1.1. Planning

During the planning stage, researchers designed teaching modules, Liveworksheet-based E-LKPD, mathematical reasoning tests, interview guidelines, and self-efficacy questionnaires. The learning tools were then validated by two lecturers from the UNNES Postgraduate Mathematics Education Study Program who are experts in the field of mathematics education, as well as a mathematics teacher from class VIII at SMP Negeri 16 Semarang. The following is an expert evaluation of the learning instruments that have been designed.

Table 2. Average Results of Expert Assessment of Learning Device Quality

Learning Tools	Overall Average
Teaching Modules	4.8
Liveworksheet-based Electronic Student Worksheet	4.7
Mathematical Reasoning Ability Test (MRAT)	4.8
Interview Guidelines	4.8

Referring to Table 2, it can be seen that the average overall score from the validation stage for the teaching module device is 4.8. The average Electronic Student Worksheet score is 4.7. The average MRAT score is 4.8. The average interview guideline score is 4.8. Based on the average overall validation scores, all learning devices received a rating in the “very good” category. Therefore, it can be concluded that these learning devices are suitable for use.

3.1.2. Implementation

The learning activities were conducted in four sessions. During the learning activities, which used the CORE model supported by Liveworksheet in the experimental class, the observer observed the learning process in accordance with the assessment listed in the learning implementation assessment sheet. The following is the observer's assessment of the learning implementation.

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Table 3. Average Observer Assessment of Learning Implementation

Meeting	Overall Average
1	4.11
2	4.21
3	4.47
4	4.68
Total Average	4.37

Referring to Table 3, the average implementation of learning in the first meeting was recorded at 4.11 and was classified as good. In the second meeting, there was an increase in the average score to 4.21, which was classified as very good. The third session showed an average of 4.47, also in the very good category. Furthermore, the fourth session recorded an average of 4.68, which is still in the very good category. Overall, the total average of the observation results for learning implementation was 4.37. These findings indicate that learning using the CORE model with the assistance of Liveworksheet is classified as very good and is running well.

In addition, from the analysis of the response questionnaire filled out by students after the learning process using the CORE model combined with Liveworksheet, which consisted of 17 statements with a rating scale of 1 to 5, the average total score was 4.21. This result shows that the score falls into the excellent category. This finding reflects that the implementation of the learning process has been carried out with good quality.

3.1.3. Assesment

The assessment stage aims to evaluate the effectiveness of learning using the CORE model with the help of Liveworksheet on mathematical reasoning abilities. Before conducting the effectiveness test, a prerequisite test was first conducted. The prerequisite tests used were normality and homogeneity tests. The following are the results of normality and homogeneity tests.

Table 4. Normality Test Results

Group	Sig. Shapiro Wilk	α
Experimental	0.450	0.05
Control	0.527	0.05

Based on the results of the normality test using Shapiro Wilk, the significance value for the experimental class is $\text{sig} = 0.450 > 0.05 = \alpha$, while the significance value for the control class is $\text{sig} = 0.527 > 0.05 = \alpha$, so H_0 is accepted, meaning that the data comes from a normally distributed population.

Table 5. Homogeneity Test Results

Sig. Levene Statistic	α
0.868	0.05

Based on the results of the homogeneity test using Levene's statistic, a value of $\text{sig} = 0.868 > 0.05 = \alpha$ was obtained, so H_0 was accepted, indicating that the variances of the two classes (experimental and control) were the same or homogeneous. The data showed that the experimental class and the control class had normal and homogeneous distributions. Before continuing with the

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hypothesis test, the Batas Tuntas Aktual (BTA) was first determined. The following is the formula for determining the BTA,

$$BTA = \bar{X} + 0.25\,SD \tag{1}$$

Explanation:
$\bar{X}$: initial MRA average
SD : standard deviation

The next test was conducted on the average achievement by applying a t-test at a significance level of α = 0,05. It was concluded that $t_{count} = 5.348 \geq 1.692 = t_{table}$, in other words, the average mathematical reasoning ability of students in the experimental class had reached BTA = 60. The classical completeness test using the z-test resulted in $z_{count} = 1.837 \geq 1.65 = z_{table}$, meaning that the proportion of students' mathematical reasoning ability using the CORE learning model assisted by Liveworksheet reached more than 75%. The results of the two-sample mean test prove that $t_{count} = 3.0919 > t_{table} = 1.668$. This finding indicates that the average mathematical reasoning ability of students in the experimental class is significantly higher than that of students in the control class. The proportion difference test yielded $z_{count} = 2.049 \geq 1.65 = z_{table}$, meaning that the proportion of mathematical reasoning ability mastery in the CORE model assisted by Liveworksheet is higher than the proportion of mathematical reasoning ability mastery in PBL learning.

Based on the results of the above analysis, it can be seen that the application of the CORE learning model assisted by Liveworksheet is effective in improving mathematical reasoning skills. During the learning process, there were changes in classroom interaction, activities, and student enthusiasm for learning through the use of new models and media. Learning began with the connecting stage, where teachers linked PLSV concepts to real-life situations, such as calculating the total cost of shopping at a minimarket, dividing daily pocket money, or determining the remaining money after purchasing several items.

Students became more interested because the problems no longer felt abstract but were closely related to their daily lives. Many students began actively answering and sharing personal experiences related to the problem situations. During the organizing stage, students were guided to group important information from the problems and outline solution steps using Liveworksheet. This interactive medium presents problems in the form of stories. Students show high enthusiasm, actively discussing in groups and checking their work. The classroom atmosphere is lively; students are not only solving problems but also beginning to understand the patterns of solutions and the logical reasoning behind their steps. In the reflecting stage, students are asked to explain their thought processes and compare their answers with their peers. They discuss, correct, and even give each other suggestions.

Students who are usually quiet began to dare to express their opinions, especially after gaining confidence from successfully answering questions correctly. This stage shows that the learning process encourages students to think critically and believe in their own abilities (self-efficacy). In the extending stage, students are given enrichment questions in the form of stories, such as determining the width of a swimming pool after knowing its length and circumference. These

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questions not only require students to apply basic formulas but also involve an understanding of geometry and algebra concepts to solve them. Students need to analyze the information provided and formulate equations based on the given conditions.

The students' responses were very positive, with some even requesting additional problems because they felt challenged and wanted to try more exercises through Liveworksheet. This is supported by research by (Widiastuti et al., 2022), which shows that the average mathematical reasoning ability of students in classes using the CORE learning model is superior to the average in classes using expository learning. Additionally, this is supported by the findings of (Ahmar & Soro, 2023), who found that Electronic Student Worksheet based on Liveworksheet in mathematics learning can influence students' mathematical reasoning abilities. This is also evident from the average scores of both classes, where the class using Electronic Student Worksheet based on Liveworksheet had a higher average of 6.807 points.

3.2. The Influence of Students' Self-Efficacy on Mathematical Reasoning Ability in the CORE Learning Model Assisted by Liveworksheet

Self-efficacy is an important factor that can influence students' mathematical reasoning abilities. To determine this, a simple linear regression test was used to examine the influence of students' self-efficacy on their mathematical reasoning abilities in the CORE learning model assisted by Liveworksheet. In the linear regression test with interval questionnaire data using the Method of Successive Intervals (MSI), which was then tested using SPSS 22.0, several test results were obtained, namely the linearity test of the regression equation, the regression significance test, the correlation test, and the calculation of the coefficient of determination.

Table 6. Results of Linearity Test and Regression Significance Test

	Sig.	α
Deviation from Linearity	0.301	0.05
Regression	0.0000	0.05

Based on the output results in table 4, the linearity significance value of 0.301 exceeds $\alpha = 0.05$. Thus, the regression equation $\hat{Y} = 7.673 + 0.865X$ can be declared linear. Furthermore, based on the regression significance test results listed in the ANOVA Table, a significance value of 0.000 was obtained, which is smaller than the significance level $\alpha = 0.05$. This shows that self-efficacy has a significant effect on students' mathematical reasoning ability.

Table 7. The Result of Correlation Test

		MRAT	**SE**
Pearson	MRAT	1.000	0.846
Correlation	SE	0.846	1.000
Sig.	MRAT	.	0.000
	SE	0.000	.

Based on the output results in Table 5, the significance value is $0.000 < 0.05$, which means there is a significant relationship between self-efficacy and mathematical reasoning ability. In other words, the higher the self-efficacy of students, the better

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their ability to do mathematical reasoning.

Table 6. Coefficient of Determination

R	R Square
0.846	0.716

Based on the output in the summary table, the R Square (r^2) value = 0.716, is obtained, which is converted into a percentage becomes $D = 0.716 \, x \, 100\% = 71.6\%$. This means that 71.6% of the variability in students' mathematical reasoning ability can be explained by the self-efficacy variable, while the remaining $100\% - 71.6\% = 28.4\%$ is influenced by other factors outside self-efficacy, such as learning strategies, cognitive background, learning environment, and intrinsic motivation.

Based on the findings of this study, it is known that self-efficacy has a positive effect on mathematical reasoning ability. Discussion and group work activities were actively participated in by the majority of students, but there were also some students who did not show optimal participation in these activities. Students with high levels of self-efficacy tend to be active in the learning process in class and in completing mathematical tasks (Imaroh et al., 2021). When they encounter difficulties in understanding the teacher's explanations, they do not hesitate to ask questions to gain a better understanding of the material. In addition, they are also able to consistently solve the problems given with good results.

The learning situation in the classroom shows that students with high self-efficacy also demonstrate high mathematical reasoning abilities, and the opposite is true for students with low self-efficacy. This is because students with high self-efficacy have self-confidence, are confident in the results of their work, which is considered more difficult, and are willing to take risks so that learning objectives are achieved achieved (Amir et al., 2021). Thus, the higher the level of self-efficacy among students, the greater their mathematical reasoning ability, and vice versa (Negara et al., 2024). This is due to the important role of students' self-confidence in determining how they manage the learning process, understand concepts, and face challenges. This belief encourages students to keep trying to solve the problems they face, thereby sharpening their reasoning skills.

Based on the research results, it is recommended that the CORE learning model continue to be developed as an effective approach to improving mathematical reasoning skills, especially when combined with interactive media such as Liveworksheet. The integration of digital learning technology needs to be expanded to support higher-order thinking processes among students. In addition, it is important for teachers to design learning activities that can increase self-efficacy, as this has been proven to have a significant effect on mathematical reasoning. This research also opens up opportunities for application at different levels and in different contexts to test the consistency of results. It is also recommended that differentiated instructional tools be developed to make learning more adaptive to students' needs. Finally, collaboration between researchers, teachers, and policymakers is necessary to ensure that learning innovations can be widely and sustainably implemented.

4. Conclusions

Based on the results and discussions of the research described above, it was found

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that the CORE learning model supported by Liveworksheet media has excellent quality in terms of students' mathematical reasoning abilities. The quality of the instructional planning phase received very good ratings from validators, with an overall average score for each instructional tool, such as the instructional module (4.8), Electronic Student Worksheet (4.7), mathematical reasoning test (4.8), and interview guidelines (4.8). The quality of the implementation stage, with the average observation of learning implementation, showed an increase from the first meeting (4.11) to the fourth (4.68), with an overall average of 4.37, and student responses received very good results with an average score of 4.21.

The quality of the assessment stage revealed that the CORE model assisted by Liveworksheet was effective in improving mathematical reasoning skills, with the average mathematical reasoning ability of students in the experimental class reaching BTA = 60, the proportion of students' mathematical reasoning ability with the CORE model assisted by Liveworksheet reached more than 75%, the average mathematical reasoning ability of students in the experimental class was significantly higher than that of students in the control class, and the proportion of mathematical reasoning ability mastery in the CORE model assisted by Liveworksheet was higher than the proportion of mathematical reasoning ability mastery in PBL learning.

Self-efficacy was found to have a significant effect on students' mathematical reasoning ability, as shown by the results of simple linear regression, which indicated a significance value of $0.000 < 0.05$ with a coefficient of determination R Square (r^2) = 0.716. This means that 71.6% of the variation in mathematical reasoning ability can be explained by the level of self-efficacy, while the remaining 28.4% is influenced by other factors.

Author Contributions

The first author carried out the task of collecting data, processing it, analyzing the results, and compiling scientific articles. The second and third authors played a role in providing constructive suggestions and input to develop the study, strengthen the analysis, and improve the content of the manuscript.

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Declaration of Competing Interest

There are no indications of potential conflicts of interest disclosed by the authors.

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Panel Data Regression Modeling of North Sumatra Province's Gross Regional Domestic Product for 2019-2023

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ABSTRACT

Regional economic growth is influenced by various factors that need to be analyzed accurately to support the formulation of effective policies. This study aims to analyze the influence of economic factors on the Gross Regional Domestic Product (GRDP) in North Sumatra Province. The main issue raised is the need for an appropriate model to understand the relationship between economic variables and GRDP. This study uses panel data from 33 districts/cities during the period 2019–2023 obtained from official sources. Through Chow, Hausman, and Lagrange Multiplier tests, the Fixed Effect model was selected. The results indicate that population size, number of poor people, and Human Development Index (HDI) significantly influence RDP.

1. Introduction

Development is a continuous process aimed at improving the quality of life of the community, which requires synergy between local government and the community as the main actors (Musolesi, 2025). Economic development is characterized by long-term increases in per capita income and the creation of more jobs (Nandita et al., 2019). as well as reductions in poverty rates and improvements in well-being (Silalahi et al., 2014). In this context, Regional Domestic Product (RDP) was selected as the focus of the panel data regression model because it is the primary indicator for measuring the success of regional economic development (Adityaningrum, 2024). RDP reflects the total gross value added of all economic units in a region, providing a comprehensive overview of regional economic performance (Zebua, 2022). for example, the GRDP of Medan City in 2020 was recorded at 153,669.83 billion rupiah, down from 156,780.58 billion rupiah in the

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previous year due to the impact of the COVID-19 pandemic (Hasibuan et al., 2022). This decline has had widespread effects on socio-economic aspects such as increased poverty and unemployment, necessitating in-depth studies on the factors influencing economic growth in Medan City as the economic center of North Sumatra Province (Hasibuan et al., 2022).

Economic growth and poverty analysis using a panel data regression approach is considered appropriate because it can capture the dynamics of data in two dimensions, namely between individuals (cross-section) and over time (time series) (Castro, 2024; Amaliah, 2020). Unlike ordinary regression models, which only analyze data statically and often ignore differences between observation units or the influence of time, panel data regression is able to reveal more complex and realistic relationships between variables. In panel data regression, there are three main models commonly used, namely the Common Effect Model (CEM), Fixed Effect Model (FEM), and Random Effect Model (REM) (Gujarati, 2021). Selecting the most appropriate model is crucial to ensure that the analysis results reflect real-world conditions (Hidaka, 2024). and for this purpose, the Chow, Hausman, and Lagrange Multiplier tests are used (Hutagalung, 2022). This method has been widely applied in regional economic studies to identify the determinants of economic growth (Ratnasari, 2023). Therefore, panel data regression is relevant for analyzing the relationship between GRDP and other economic variables in North Sumatra Province (Hasibuan et al., 2022).

Previous research has provided an important foundation for understanding the relationship between GRDP and poverty levels, such as the study by Zebua (2022)" which showed that GRDP had a negative and significant effect on poverty in North Sumatra during 2011–2020, meaning that an increase in GRDP can reduce poverty levels. This finding aligns with the view that strong economic growth can be a key instrument in poverty alleviation (Elviera & Irawan, 2020). However, economic growth alone is insufficient if it is not accompanied by income distribution and inclusive job creation. Amaliah (2020) also emphasize the need for a more in-depth analysis of other factors that influence GRDP and its impact on poverty. Previous studies have suggested including additional socioeconomic variables such as unemployment and labor force participation in further research. Unfortunately, there are still limitations in studies that specifically develop panel data regression models based on GRDP at the provincial and city/district levels in North Sumatra, particularly in Medan City, which has unique and strategic economic characteristics.

Based on the above, the researcher intends to conduct a study titled "Panel Data Regression Modeling of Regional Domestic Product in North Sumatra Province from 2019 to 2023." This study will focus on applying panel data regression methods to analyze the relationship between GRDP and several socioeconomic indicators. The dependent variable in this study is GRDP at constant prices (ADHK), while the independent variables consist of population size, number of poor people, human development index (HDI), open unemployment rate (OUR), and labor force participation rate (LFPR). The data used are secondary data obtained from the Central Statistics Agency (BPS) and related agencies, covering 33 districts/cities in North Sumatra Province during the period 2019 to 2023. By utilizing panel data, this study is expected to provide a more accurate and dynamic picture of regional economic development. Additionally, the results of the regression analysis will be used to determine the

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best estimation model among CEM, FEM, and REM. The selection of the model is based on statistical tests that have been validated in econometric literature. It is hoped that the findings of this study will contribute to data-driven and more targeted economic policy-making.

This study also aims to further analyze how economic growth reflected in GRDP can be used as a tool to address poverty issues, particularly in Medan City. Using a panel data regression approach, it is expected to identify which variables significantly influence GRDP and the direction and magnitude of their effects. Through this understanding, local governments can design more effective policies to enhance economic growth while reducing poverty rates sustainably.

As the provincial capital, Medan plays a vital role in driving economic growth in North Sumatra, so development strategies in this city will greatly determine the direction of regional development. This study is also expected to serve as a reference for other researchers in developing studies on regional economic dynamics using an econometric approach. By looking at the estimation results and the selection of the best model, this study can provide an empirical basis for inclusive and equitable economic development planning. The research findings can also be utilized by other stakeholders, such as academics and regional planning institutions, to support evidence-based policy-making. Therefore, this study holds strategic value in efforts to promote sustainable economic development in North Sumatra Province.

2. Method

2.1. Panel Data Regression

Panel data regression is a type of regression based on panel data used to observe the correlation between one dependent variable and one or more independent variables (Nguyen, 2023). The variables that have an impact are called independent variables, while the variables that are affected are called dependent variables. Panel data regression is an expansion of multiple linear regression. When panel data is the type of data, such as time series and cross-sectional data, panel data regression is used (Tohir & Utomo, 2023).

2.2. Panel Data Regression Model

In determining the panel data regression model, there are several alternative models that can be solved with panel data of Equation 1 (Elviera & Irawan, 2020),

$$Y_{it} = \beta_0 + \sum_{k=2}^{J} \beta_j X_{jit} + \varepsilon_{it} \quad (1)$$

Description:
i = $1,2,\dots,N$
t = $1,2,\dots,T$
N = number of cross-section units
T = number of time series data
Y_{it} = dependent variable for cross section i and time series t
x_{it} = independent variable j for cross section i and time series t
β_{it} = estimated parameter
ε_{it} = population disturbance element
J = number of estimated parameters

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2.3. Common Effect Model (CEM)

The CEM method is the simplest approach in determining panel data regression model estimates, because this approach combines all data, both cross section data and time series data (Delmar, 2022). CEM assumes that the intercept and slope in the cross section and time series units are the same. Generally, the model equation (Hasibuan et al., 2022) is written as shown Equation 2 (Kosmaryati et al., 2019),

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_j X_{jit} + \varepsilon_{it} \quad (2)$$

Explanation:
Y_{it} = dependent variable for cross section i and time series t
β_0 = intercept model
β_j = slope regresi to-j
X_{jit} = independent variable to-j for cross section i and time series t
J = number of independent variables to- j ; $j = 1,2, \dots, k$
i = regional unit to e- i ; $i = 1,2, \dots, n$
t = time period to t ; $t = 1,2, \dots, p$

2.4. Fixed Effect Model (FEM)

The FEM assumes that the slope coefficient is constant but the intercept is not constant. The method that can be used to estimate the model in FEM is the Least Square Dummy Variable method, often referred to as LSDV (Verlita, 2022). In the LSDV method, estimation is performed by inserting a dummy variable used to explain the different intercept values due to differences in unit values (Zebua, 2022). The regression model equation in FEM is written as Equation 3 and the explanation of this equation is the same as the Equation 2,

$$Y_{it} = \beta_{0it} + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_j X_{jit} + \varepsilon_{it} \quad (3)$$

2.5. Random Effect Model (REM)

There are two methods that can be used to estimate REM, namely the LSDV method and the Generalized Least Square (GLS) method (Heydari, 2021). Because the LSDV method adds variables, this results in a large number of variables in the equation compared to the amount of data. In addition, the degree of freedom is not fulfilled, so the LSDV method cannot be used. Therefore, it is necessary to perform estimation using the GLS method, as this method performs estimation directly without adding dummy variables (Silalahi et al., 2014). Several model equations in REM are described as Equation 4,

$$Y_{it} = \beta_{0it} + \beta_1 X_{1it} + \beta_2 X_{2it} + \cdots + \beta_j X_{jit} + (\mu_i + \varepsilon_{it}) \quad (4)$$

2.6. Gross Regional Domestic Product (GRDP) at Constant Prices

Gross Regional Domestic Product (GRDP) reflects the total value of goods and services produced in a region, both by local residents and foreigners living in that regio (Szwacka-Mokrzycka, 2020) and is used to measure the economic contribution of a region to the national economy. In this study, RDP based on constant prices (ADHK) is used because this method eliminates the influence of inflation, thereby reflecting real economic growth more accurately (Kosmaryati dkk., 2019 ; Brzozowska-Rup, 2020). GRDP is calculated using three approaches:

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income, expenditure, and production, and serves as the primary indicator for assessing the economic progress of a region (Kosmaryati et al., 2019).

This study uses PDRB data for North Sumatra Province from 2019 to 2023, covering 33 districts/cities with unbalanced characteristics, as some regions have a much more dominant economic contribution than others, such as Medan City. This sample representation imbalance has the potential to influence the results of the model implementation, making a focus on Medan City particularly important to identify the main factors influencing GRDP in the context of poverty (Priyatno, 2023).

3. Results and Discussion

3.1. Descriptive Statistical Analysis

An overview of the variables used in this study, including minimum, maximum, average, and standard deviation values. The data show significant variations in variables such as GDP, population, number of poor people, human development index (HDI), open unemployment rate (OUR), and labor force participation rate (LFPR) in Medan City during the period 2019-2023, as presented in Table 1.

Table 1. Descriptive Statistical Analysis

Variable	Minimum	Maximum	Mean	Standar Deviasi
PDRB (Y)	850.79	173445.69	17.175,03	29.070,25
JP (X1)	48935.00	2494512,00	452.752,0	510.947,6
JPM (X2)	4.01	193,03	38.89176	34.2143
IPM (X3)	61.14	82,19	71,31921	4.509589
TPT (X4)	0.19	11,50	4.814061	2.739589
TPAK (X5)	51.83	88,95	72.93885	7.9737008

3.2. Multicollinearity Test

The multicollinearity test was conducted by examining the Variance Inflation Factor (VIF) value, where a VIF value greater than 10 indicates multicollinearity in the model. The results of the multicollinearity test are shown in Table 2.

Table 2. Multicollinearity Test

Variable	VIF
X_1	7.773710
X_2	7.006006
X_3	1.607456
X_4	2.327282
X_5	1.882673

Table 2 informs that the variable X_1, X_2, X_3, X_4, and X_5 have a VIF value < 10. This indicates that there is no multicollinearity problem between the independent variables in the Regional Domestic Product (RDP) in North Sumatra in 2019-2023. These results indicate that the data used can provide reliable estimates without distortion due to multicollinearity.

3.3. First Stage Panel Data Regression Estimation

Panel data regression estimation will be estimated using three models, namely CEM, FEM, and/or REM. The parameter estimation process for each model has

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been described previously.

3.3.1. *Common Effect Model (CEM)*

The panel data regression model for CEM that produces estimates is presented in Table 3.

Table 3. Common Effect Model (CEM)

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-81.72	16.54	-4.93	0.00
X_1	0.02	0.00	6.02	0.00
X_2	427.11	54.75	7.80	0.00
X_3	1142.3	198.99	5.74	0.00
X_4	-646.56	394.14	-1.64	0.10
X_5	-90.58	121.79	-0.74	0.45

The panel data regression model estimation for CEM of Table 3 can be written in Equation 5,

$$\hat{Y}_{it} = -81.725 + 0.023283X_{1it} + 427.11_{2it} + 1142.3X_{3it} + -646.56X_{4it} + -90.585X_{5it} \quad (5)$$

3.3.2. *Fixed Effect Model (FEM)*

Panel data regression model for FEM that produces estimates as shown in Table 4.

Table 4 Fixed Effect Model (FEM)

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-25.90	15.55	-1.66	0.09
X_1	0.01	0.00	3.36	0.00
X_2	442.7	82.55	-0.53	0.59
X_3	669.7	184.8	3.62	0.00
X_4	-85.58	154.2	-0.55	0.57
X_5	-0.22	29.97	-0.00	0.99

The panel data regression model estimation for FEM gives Equation 6,

$$\hat{Y}_{it} = -25.900_i + 0.01271X_{1it} + 442.7_{2it} + 669.7X_{3it} + -85.58X_{4it} + -0.2276X_{5it} \quad (6)$$

3.3.3. *Random Effect Model (REM)*

Panel data regression model for REM that produces estimates as Table 5.

Table 5. Random Effect Model (REM)

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-70.22	13.17	-5.33	0.00
X_1	0.02	0.00	6.59	0.00
X_2	312.22	56.51	5.52	0.00
X_3	909.88	180.58	5.03	0.00
X_4	-89.57	162.68	-0.55	0.58
X_5	7.77	32.214	0.24	0.80

The panel data regression model estimation for REM has mathematical equation

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as Equation 7,

$$\hat{Y}_{it} = -70.220 + 0.022583X_{1it} + 312.22_{2it} + 909.88X_{3it} + -89.576X_{4it} + 77759X_{5it} \quad (7)$$

3.4. Best Model Approach Phase One

After obtaining three different approach models, the next step is to determine which model is most suitable for the data among the three models. Model selection tests are conducted using the Chow test, Hausman test, and Lagrange Multiplier test.

3.4.1. Chow Test

The Chow test is used to select the best model between FEM and CEM. After obtaining an initial estimate by estimating FEM, the next step is to perform the Chow test. The hypothesis is as follows,

$H_0 : \beta_{01} = \beta_{02} = \cdots = \beta_{0n} = 0$ (the best model is CEM)
H_1 : at least one $\beta_{0i} \neq 0$ (the best model is FEM)

The test results obtained F_{count} is 177.73. Meanwhile, the value of F_{table} with degrees of freedom N1 = 32 and degrees of freedom N2 = 127 at the actual level (a = 0.05), is 1.628. Therefore, reject H_0 because $F_{count} > F_{table}$. Therefore, the Chow test results prove that the best model selected is Fixed Effect Model (FEM). With this, the testing process continues to the Hausman Test.

3.4.2. Hausman Test

The Hausman test is used to select the best model between FEM and REM. This test is performed if the previous Chow test results indicate that FEM is the best model. The hypothesis uses,

$H_0 : corr\left(X_{it,}\varepsilon_{it}\right) = 0$ (REM are better),
$H_1 : corr\left(X_{it,}\varepsilon_{it}\right) \neq 0$ (FEM are better)

The results of the Hausman test conduces that the value of W is 33.398. To obtain the table value X^2 can be seen in the Chi-Square table with degrees of freedom at the significant level (a = 0.05), then the value obtained is X^2_{table} = 11.070. Thus, it is obtained that $W > X^2_{table}$ therefore reject H_0 which means that the FEM model is better.

3.4.3. Lagrange Multiplier Test

The Lagrange Multiplier test was used to select the best model between CEM and REM. With the help of R software, this study used the Lagrange Multiplier test (LM_{lag}). The hypothesis for the Lagrange Multiplier test is as follows,

$H_0 : \sigma_1^2 = \sigma_2^2 = \cdots = \sigma_n^2 = \sigma^2$ (CEM are better)
H_1 : there is at least one $\sigma_i^2 \neq \sigma^2$(REM are better), $i = 1,2,\ldots,n$

The result of the Lagrange Multiplier Test has $p - value$ which is 0.0000. This result obtained $p - value < a$ so that reject H_0 which means that the better

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estimation model is the Random Effect Model (REM). According to the Chow Test, Hausman Test, and Lagrange Multiplier Test, it was obtained that the best model is the Fixed Effect Model (FEM). The best equation obtained is,

$$\hat{Y}_{it} = -25.900_i + 0.01271X_{1it} + -44.27_{2it} + 669.7X_{3it} + -85.58X_{4it} + -0.2276X_{5it} \quad (8)$$

3.5. Significance Test of First Stage Model Parameters

3.5.1. Simultaneous Regression Coefficient Significance Test (F test)

The F test is used to determine the linear relationship between all independent variables and the dependent variable. The hypothesis uses,

$H_0 : \beta_1 = \beta_2 = \cdots = \beta_k = 0,$
H_1 : at least one $\beta_p \neq 0$ with $p = 1,2, \ldots, k$

The test results were obtained $F_{count} = 30.909$ as large as and for $F_{table} = F_{(a,k-1,n-k)} = F_{0,05;5,127} = 2.29$. The FEM output has that $p - value(0.0000) <$ actual level ($a = 0.05$). The value obtained is $F_{count} = 30.909 > F_{table} = 2.29$ therefore it is concluded to reject H_0 which means that there is at least one independent variable that has a significant effect on the dependent variable.

3.5.2. Partial Regression Significance Test (t-test)

The t-test is used to determine the causal relationship between independent variables individually and the dependent variable. The results of the partial model significance test are shown in Table 6.

Table 6. Result of t-test

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-25.90	15.55	-1.66	0.09
X_1	0.01*	0.00	3.36	0.00
X_2	- 442.7	82.55	-0.53	0.59
X_3	669.7*	184.8	3.62	0.00
X_4	-85.58	154.2	-0.55	0.57
X_5	-0.22	29.97	-0.00	0.99

The t-test of Table 4 shows that variable X_1 (Number of Residents), X_3 (Human Development Index) have a value $p < 0{,}05$, so that both variables have a significant effect on GRDP partially. The variable X_2 (Number of Poor People) X_4 (Open Unemployment Rate) and X_5 (The Labor Force Participation Rate has a value of $p > 0.05$, so that it does not significantly affect the dependent variable. Therefore, the variable X_2, X_4, and X_5 can be considered for exclusion from the advanced regression model.

3.6. Second Stage Panel Data Regression Estimation

Similar to the first stage panel data regression estimation, the second stage follows the same process as the first stage.

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3.6.1. *Common Effect Model (CEM)*

The panel data regression model for CEM is presented in Table 7.

Table 7. Common Effect Model (CEM)

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-46.82	14.27	-3.28	0.00
X_1	0.05	0.00	28.01	0.00
X_3	576.30	204.58	2.81	0.00

The panel data regression model estimation for CEM stage two can be written in Equation 9,

$$\hat{Y}_{it} = -46.828 + 0.050584X_{1it} + 576.30_{2it} \quad (9)$$

3.6.2. *Fixed Effect Model (FEM)*

The panel data regression model for CEM is presented in Table 8.

Table 8. Fixed Effect Model (FEM)

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-33.190	11.150	-2.873	0.004753
X_1	0.01286	0.003735	3.443	0.000775
X_3	721.5	168.8	4.276	0.0000366

The panel data regression model estimation for the second stage of the FEM, as derived from the FEM results presented above, is expressed in Equation 10.

$$\hat{Y}_{it} = -33.190_i + 0.01286X_{1it} + 721.5_{2it} \quad (10)$$

3.6.3. *Random Effect Model (REM)*

The panel data regression model for REM is presented in Table 9.

Tabel 9. Random Effect Model (REM)

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-43.967	12.808	-3.3547	0.0007946
X_1	0.031356	0.0030856	10.1620	0.00000000000000022
X_3	644.23	181.55	3.5484	0.0003875

The panel data regression model estimation for the second stage of REM, as shown in Table 9, is expressed in Equation 11.

$$\hat{Y}_{it} = -43.967 + 0.031356X_{1it} + 644.23_{2it} \quad (11)$$

3.7. *Best Model Approach Phase Two*

After obtaining three different approach models, the next step is to determine which model is suitable for the data among the three models. The model selection test is conducted using the Chow test, Hausman test, and Lagrange Multiplier test.

3.7.1. *Chow Test*

The Chow test is used to select the best model between FEM and CEM. After obtaining an initial estimate by estimating FEM, the next step is to perform the

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Chow test. The hypothesis uses,

$H_0 : \beta_{01} = \beta_{02} = \cdots = \beta_{0n} = 0$ (the best model is CEM)
$H_1 :$ at least one $\beta_{0i} \neq 0$ (the best model is FEM

The test results indicate that F_{count} is 253.31. Meanwhile, the value F_{table} with degrees of freedom N1= 32 with degrees of freedom N2=130 pada actual level ($a = 0.05$), is 1.533. Thus, reject H_0 because $F_{count} > F_{table}$. Therefore, the Chow test results prove that the best model selected is Fixed Effect Model (FEM). With this, the testing process continues to the Hausman Test.

3.7.2. Hausman Test

The Hausman test is used to select the best model between FEM and REM. This test is performed if the previous Chow test results indicate that FEM is the best model. The hypothesis uses,

$H_0 : corr\left(X_{it,}\varepsilon_{it}\right) = 0$ (REM are better),
$H_1 : corr\left(X_{it,}\varepsilon_{it}\right) \neq 0$ (FEM are better)

The Hausman test results yield a value of $W = 76.283$. To obtain the critical chi-square value, the Chi-Square table is consulted with degrees of freedom equal to 2 and a significance level of $a = 0.05$. The value obtained is $X^2_{table} = 5{,}991$. Thus, we obtain $W > X^2_{table}$ so that reject H_0 which means that the FEM model is better.

3.7.3. Lagrange Multiplier Test

The Lagrange Multiplier test was used to select the best model between CEM and REM. With the help of R software, this study used the Lagrange Multiplier test (LM_{lag}). The hypothesis uses,

$H_0 : \sigma_1^2 = \sigma_2^2 = \cdots = \sigma_n^2 = \sigma^2$ (CEM are better)
$H_1 :$ there is at least one $\sigma_i^2 \neq \sigma^2$(REM are better), $i = 1,2, \ldots, n$

The Lagrange Multiplier Test yields a value of 0.0000, indicating that the p-value is less than α, leading to the rejection of the null hypothesis in favor of the REM. According to the Chow Test, Hausman Test, and Lagrange Multiplier Test, it was found that the best model was the FEM. The best equation obtained was,

$$\hat{Y}_{it} = -33.190_i + 0.01286X_{1it} + 721.5_{2it} \tag{12}$$

3.8. Significance Test of Model Parameters in Stage Two

3.8.1. Simultaneous Regression Coefficient Significance Test (F test)

The F test is used to determine the linear relationship between all independent variables and the dependent variable. The hypothesis is as follows,

$H_0 : \beta_1 = \beta_2 = \cdots = \beta_k = 0,$
$H_1 :$ at least one $\beta_p \neq 0$ with $p = 1,2, \ldots, k$

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The Lagrange Multiplier Test result is 0.0000, indicating that the p-value is less than α. This leads to the rejection of the null hypothesis, suggesting that the REM is not the preferred specification. Considering the outcomes of the Chow Test, Hausman Test, and Lagrange Multiplier Test collectively, the FEM is identified as the most appropriate estimation model. The best equation obtained was,

$$\hat{Y}_{it} = -33{,}190_i + 0.01286X_{1it} + 721{,}5_{2it} \quad (13)$$

3.8.2. *Partial Regression Significance Test (t-test)*

The t-test is used to determine the causal relationship between independent variables individually and the dependent variable. The results of the partial model significance test can be shown in Table 10.

Table 10 Partial Regression Significance Test (t-test)

Variable	Parameter Estimates	Standard Deviation	t-value	p-value
C	-33.190	11.150	-2.873	0.004753
X_1	0.01286*	0.003735	3.443	0.000775
X_3	721.5*	168.8	4.276	0.0000366

The actual level used is 0.05. The partial regression significance test (t-test) from Table 10 shows that variable X_1 (Population), X_3 (Human Development Index) has a value of $p - value < 0.05$. It can be said that each of these independent variables has a significant effect on GRDP.

3.9. *Coefficient of Determination (R^2)*

The panel data regression model for the multiple R-squared values is presented in Table 11. The coefficient of determination (R^2) is shown in Table 11.

Tabel 11. Coefficient of Determination (R^2)

multiple R-squared	
CEM	0.86
FEM	0.9974
REM	0.47103

The test results yield a multiple R-squared value of 0.9974, indicating that the independent variables explain 99.74% of the variation in the dependent variable, while the remaining 0.26% is attributed to factors not included in the model. The best model is selected based on the highest R-squared value, the FEM is chosen as the most appropriate specification.

In applying models to simulation processes, a number of substantive challenges often arise, particularly those related to data imbalance. This imbalance has the potential to cause bias in parameter estimation, which can ultimately reduce the accuracy of the analysis results. Therefore, selecting the right analysis method is essential, given that not all statistical approaches are capable of handling data complexity and dynamics optimally. For example, panel data regression models may have limitations in fully representing temporal variation. Additionally, hardware and software limitations can also pose significant challenges, especially when dealing with large volumes of data and complex data structures. Therefore, a comprehensive methodological and technical evaluation is necessary before simulation implementation to ensure the validity and reliability

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of the results obtained.

4. Conclusion

The Chow, Hausman, and Lagrange Multiplier test results collectively indicate that the FEM is the most appropriate model for this study. The panel data regression model with FEM estimation is,

$$\hat{Y}_{it} = -33{,}190_i + 0.01286X_{1it} + 721{,}5_{2it}$$

In the panel data regression modeling stage, it was found that several variables had a significant effect on Gross Regional Domestic Product (GRDP), namely: Population X_1, Number of Poor People X_2, and Human Development Index X_3. Meanwhile, the Open Participation Rate (OPR) variable X_4, and Labor Force Participation Rate (LFPR) X_5, not significant to GRDP in the model used.

Contributions

The first author is responsible for the process of collecting, processing, analyzing data, and compiling the results into a scientific paper. Meanwhile, the second and third authors acted as advisors who provided guidance during the writing of this article.

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Conflict of Interest Statement

As the author, I declare that there are no conflicts of interest or other interests that conflict with this research. All research results are compiled objectively and free from the influence of any party that could affect the validity or independence of the findings.

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