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Implementation of Problem-Based Learning Based on Mathematical Literacy to Improve Student's Higher-Order Thinking Skills

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Abstract

HOTS are high-level thinking skills that are important to have in the era of globalization to solve complex problems. However, many students still have relatively low HOTS, especially when the issue is relevant to everyday life. This study aims to see how implementing Problem-Based Learning (PBL) based on mathematical literacy improves students' HOTS in class X MP 2 students of SMK Negeri 5 Madiun. This study is classroom action research (CAR) carried out in two cycles, with 29 subjects from class X MP 2 SMK Negeri 5 Madiun. Each research cycle consists of four stages: planning, implementing actions, observation, and reflection. The main objective of this study is to determine whether implementing Problem-Based Learning (PBL) based on mathematical literacy can improve students' HOTS in mathematics learning. The study results showed a significant increase in students' HOTS after the implementation of PBL based on mathematical literacy. In the pre-cycle stage, students' HOTS were at 56.6%. After the actions were carried out in cycle I, students' HOTS increased to 71.8%, although it had not reached the expected completion criteria. In cycle II, another increase in students' HOTS to 79.2% met the success criteria.

Keywords: Higher-order Thinking Skills; Mathematical Literacy; Problem-Based Learning

1. Introduction

HOTS (Higher-order Thinking Skills) are an important component in problem solving because they involve analytical, evaluative, and creative skills that allow someone to understand problems in depth, consider various alternative solutions, and make the right decisions based on logical and critical considerations (Lusiana & Andari, 2020). HOTS involve complex thinking processes, such as explaining, criticizing, and creating solutions. HOTS thinking includes critical and creative thinking (Safitri et al., 2024) in problem solving (Gusteti & Neviyarni, 2022). HOTS, which was developed from Bloom's Taxonomy, is at the top level (Sa'adah et al., 2021)), so it is essential in the 21st-century era. HOTS helps students face complex problems through analysis and find various solutions (Yanti et al., 2022). HOTS-based questions encourage students to think critically, creatively, and communicatively, and help them view problems logically and objectively (Dinni, 2018). High-level thinking skills enable students to understand concepts, connect ideas, and apply knowledge effectively in various situations, improving their learning outcomes (Ultra Guesteti & Neviyarni, 2022). One effort to improve these abilities is to use innovative learning models (Lusiana et al., 2021; Launuru et al., 2021).

An effective learning model that allows students to develop creativity in solving problems is Problem-Based Learning (PBL) (Lusiana et al., 2021; Setiawan & Santosa, 2017). The PBL learning model is a learning model that aims to stimulate critical thinking (Husnidar & Hayati, 2021; Nurhayati et al., 2021) and creativity of students by using real problems (Febita et al., 2024) as a learning context. Students are invited to identify, analyze, and solve problems to develop high-level thinking skills and application of knowledge in real-life situations (Marlina et al., 2020). According to PISA (2012), mathematical literacy is a person's ability to formulate, apply, and interpret mathematics in various contexts (Madyaratri et al., 2019). PBL based on mathematical literacy helps students remember information better by connecting it to real contexts, while developing problem-solving, critical thinking, and communication skills through group work (Handayani, 2021).

According to Asriningtyas et al. (2018) PBL study results are suitable for use in the learning process and to improve students' HOTS. Than, research by Kurniawan & Khotimah (2022), mathematical literacy and numeracy influence problem-solving abilities in improving HOTS. Based on observations made by researchers at SMKN 5 Madiun, it was found that students' HOTS were still relatively low in mathematics learning. Many students still have difficulty analyzing and solving complex problems, which shows their low HOTS (Irmawati et al., 2022). The low HOTS of students can be caused by a lack of mathematical literacy skills in problem solving (Hasyim & Andreina, 2019), which does not support the development of critical and creative thinking. Learning that only focuses on memorizing formulas and practicing questions does not allow students to explore problems in depth, question assumptions, or create alternative solutions. In dealing with these problems, innovation and solutions are needed to improve student learning outcomes. One of the factors that influences learning outcomes is implementing the PBL learning model by integrating mathematical literacy in the form of contextual questions. Implementing this PBL learning model based on mathematical literacy can improve student learning outcomes by making the material more relevant and applicable and improving students' ability to reason and create (Tabun et al., 2020; Erria et al., 2023).

Based on the description above, no research still discusses this problem, so the researcher will conduct it with the title "Implementation of the PBL Model Based on Mathematical Literacy to Improve HOTS Abilities of Class X Students at SMKN 5 Madiun". This research is expected to positively impact student learning outcomes and improve students' higher-order thinking skills.

2. Method

This research is classroom action research (CAR) whose main objective is to determine whether the application of PBL based on mathematical literacy can improve students' HOTS in mathematics learning. The classroom action research was conducted by the researcher on students of class X MP 2 at SMK Negeri 5 Madiun and was carried out in several cycles. The research subjects consisted of 29 students from class X MP 2 at SMK Negeri 5 Madiun in the even semester of the 2024 academic year. The research model used in this study is the model proposed by Kemmis and Mc Taggart (Prihantoro & Hidayat, 2019), where in the CAR research is carried out in several cycles. The results of the research in the first cycle will form the basis for research in the second cycle, where the second cycle is an improvement from the first cycle based on the results of reflection, if it has not met the established success indicators. The data analysis techniques used in this study are quantitative descriptive and qualitative descriptive techniques. According to (Unaradjan, 2019) the method for describing numerical data uses mathematical calculations with hypothesis testing using accurate data. While the qualitative descriptive method is a technique used to study objects in a natural context with the aim of understanding or interpreting phenomena based on the meaning determined by the researcher (Lusiana, 2017). Researchers conducted classroom action research in several cycles following the stages according to Kemmis and McTaggart, namely planning, implementation, observation, and reflection (Muhammad Djajadi, 2019). The stages of the classroom action research cycle that the researcher carried out show at Figure 1.

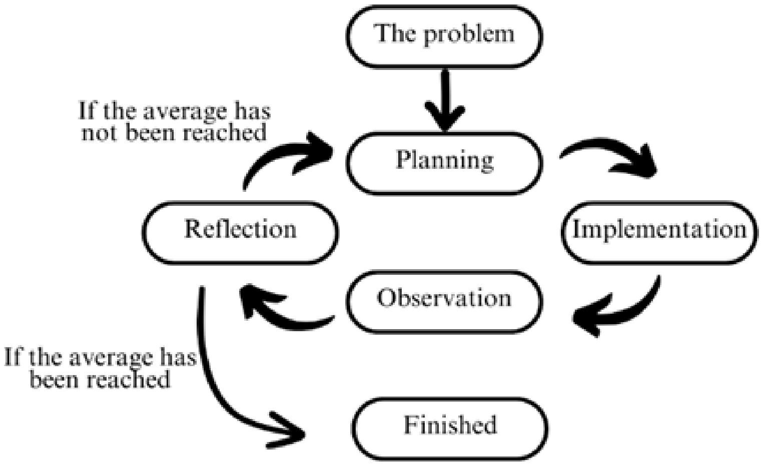

Figure 1. Stages of Classroom Action Research.

The instrument used in this study was a sial test adapted to the HOTS indicators (Sinaga, 2021).

Table 1. HOTS Indicator

HOTS Indicator	Ability
Analyze	Analyze information into its respective parts and determine the relationships between the parts.
Evaluate	Make your own decisions and assess things to achieve a goal based on specific criteria.
Create	Creating ideas/concepts, such as reorganizing existing parts to form a new structure, includes generating, planning, and producing.

The subjects of this study were 29 students of class X of SMKN 5 Madiun in the even semester of the 2023/2024 academic year. The researcher used the indicators in Table 1 to create a scoring guideline, which was compiled based on the indicators listed in Table 1. The scoring guideline can be seen in Table 2.

Table 2. Scoring Guidelines

HOTS Indicator	Score	Student Response
Analyze	1	Students cannot analyze problems based on mathematical literacy in the SPLDV material.
	2	Students can differentiate mathematical literacy-based problems in SPLDV material but cannot organize and connect mathematical literacy-based problems in SPLDV material.
	3	Students can differentiate and organize mathematical literacy-based problems in SPLDV material but cannot connect mathematical literacy-based problems in SPLDV material.
	4	Students can analyze problems based on mathematical literacy in the SPLDV material.
Evaluate	1	Students cannot evaluate mathematical literacy-based problems in the SPLDV material.
	2	Students can check mathematical literacy-based problems in SPLDV material but cannot criticize and interpret mathematical literacy-based problems in SPLDV material.
	3	Students can check and criticize mathematical literacy-based problems in SPLDV material; however, they cannot yet interpret mathematical literacy-based problems in SPLDV material.
	4	Students can evaluate problems based on mathematical literacy in the SPLDV material.
Create	1	Students cannot yet create new solutions to mathematical literacy-based problems in the SPLDV material.
	2	Students can compile mathematical literacy-based problems in SPLDV material but cannot plan and produce mathematical literacy-based problems from mathematical literacy-based problems in SPLDV material.
	3	Students can compile and plan mathematical literacy-based problems in SPLDV material but cannot produce new solutions to mathematical literacy-based problems in SPLDV material.
	4	Students can create new solutions to mathematical literacy-based problems in the SPLDV material.

The results of the students' Posttest test used to measure students' HOTS were analyzed using the following formula.

$$\text{Average} = \frac{\sum \text{Scores obtained in each aspect}}{\sum \text{Maximum Score for each aspect}} \times 100\%$$

Based on these results, they are then converted using HOTS criteria as in the table below.

Table 3. HOTS Categories

Presentation	Criteria
$90 < x \leq 100$	Very good
$80 < x \leq 90$	Good
$70 < x \leq 80$	Enough
$60 < x \leq 70$	Not enough
$0 < x \leq 60$	Very less

This research can be said to be successful if it meets several criteria, namely if the average HOTS percentage of class X MP 2 students reaches 75%.

3. Results and Discussion

The learning was carried out using a PBL learning model based on mathematical literacy for several cycles. However, before applying the PBL learning model based on mathematical literacy, researchers observed the students' initial conditions (precycle). This observation aims to provide an initial picture of the student's condition, so researchers can design appropriate actions to improve students' HOTS. Implementing PBL based on mathematical literacy can encourage students to think critically and develop high-level thinking skills through solving real problems (Asriningtyas et al., 2018; Hastawan et al., 2024).

After implementing the learning actions at the end of the meeting in each cycle, a post-test was conducted by giving one essay question based on mathematical literacy that matches the HOTS indicators to students. This test was given to measure students' HOTS abilities. The results of each cycle are as follows.

3.1 Results

3.1.1 Pre Cycle

The precycle stage is the initial stage before the Action (cycle I) begins, and it has an important purpose as a foundation for proper and data-based action planning. Learning activities at this stage are carried out according to plan, starting with triggering questions from the teacher to recall previous material. At the end, students take a post-test to measure their HOTS. The implementation of the Precycle activities consists of the following stages:

(1) Planning

The initial stage of Classroom Action Research (CAR) is careful planning, namely: determining learning objectives, Preparation of Teaching Modules, Designing Learning Scenarios, Determining Teaching Materials, compiling group/individual assignments, Providing Observation Sheets or Observations. The following is a post-test on pre-cycle activities.

Di sebuah kafe, terdapat dua jenis paket makan siang:
- **Paket A**: berisi 1 sandwich dan 2 jus dengan harga Rp 40.000.
- **Paket B**: berisi 2 sandwich dan 1 jus dengan harga Rp 50.000.

1. Buatlah model matematika dalam bentuk sistem persamaan linear dua variabel berdasarkan informasi di atas.
2. Tentukan jumlah masing-masing paket yang harus disiapkan kafe agar kebutuhan sarapan siswa tercukupi.
3. Setelah mengetahui harga sebuah sandwich dan sebuah jus, seorang pelanggan ingin membeli 3 sandwich dan 3 jus. Berapa total biaya yang harus dikeluarkan? Jelaskan proses perhitunganmu.

At a café, there are two types of lunch packages:
- Package A: contains 1 sandwich and 2 juices, priced at Rp 40,000.
- Package B: contains 2 sandwiches and 1 juice, priced at Rp 50,000.

1. Create a mathematical model in the form of a system of linear equations with two variables based on the information above.
2. Determine how many of each package the café should prepare to meet the students' breakfast needs.
3. After finding the price of one sandwich and one juice, a customer wants to buy 3 sandwiches and 3 juices. How much will it cost in total? Explain your calculation process.

Figure 2. Post-test Questions in the Pre-cycle.

(2) Implementation

The implementation stage involves implementing the plan that has been designed in detail. The planned actions are implemented in the classroom according to the strategies and methods that have been prepared. This activity aims to test the effectiveness of the learning plan in achieving the objectives. Implementation begins with a trigger question, continues with learning according to the learning plan, and ends with the provision of post-test questions that are worked on individually.

1. Apa yang terlintas di benak kalian saat mendengar kata "persamaan"?
2. Berdasarkan persamaan 2x + y = 10, ada berapa variable dari persamaan tersebut?
3. Apa bedanya antara persamaan dengan satu variabel dan dua variabel?
4. Ada berapa metode yang bisa kita gunakan untuk menyelesaikan SPLDV?

1. What comes to your mind when you hear the word "equation"?
2. Based on the equation 2x + y = 10, how many variables are in the equation?
3. What is the difference between an equation with one variable and an equation with two variables?
4. How many methods can we use to solve a system of linear equations with two variables (SPLDV)?

Figure 3. Post-Test Question.

(3) Observation

Observation aims to assess how the actions implemented achieve the stated objectives. At this stage, the researcher must explain each element used in detail; clarity in this observation is important so that the data collection process takes place systematically and the results can be analyzed accurately and comprehensively.

Based on the post-test results of 29 students, the average of their ability to analyze information into their respective parts and determine the relationship between the parts was 60.3%. Meanwhile, their average ability to make their own decisions was 57.7%, and their average ability to create their ideas/concepts only reached 51.7%. These figures indicate that students still have difficulty understanding and solving problems, which may be caused by the lack of relevance of the material to their daily lives. The percentage of students' HOTS in each indicator in the Precycle activities is as follows.

Table 4. Student's HOTS in Pre-cycle

Indikator HOTS	Average (%)	Caregories
Analyze information into its respective parts and determine the relationships between the parts.	60,3	Not enough
Make decisions and assess things to achieve a goal based on specific criteria	57,7	Very less
Creating ideas/concepts, such as reorganizing existing parts to form a new structure, includes generating, planning, and producing.	51,7	Very less

(4) Reflection

After the Action, reflection aims to identify weaknesses and deficiencies. Researchers analyze the implementation, record the results of observations, and evaluate learning, the results obtained before implementing the PBL learning model based on problem literacy. The results obtained were that students only achieved one HOTS indicator. The following are the results of the post-test to see HOTS from one of the students regarding problem solving.

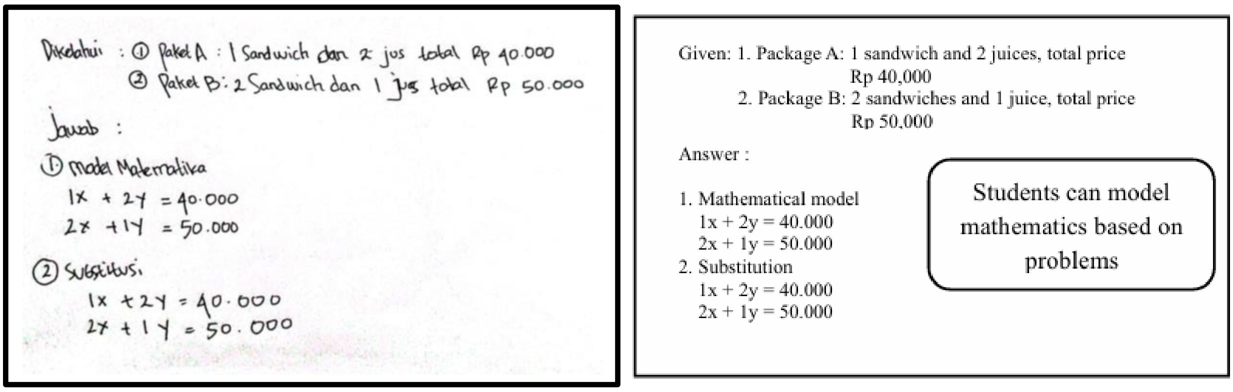

Figure 4. Example of Student Answer Results in the pre-cycle.

From the results of the students' work in Figure 3, it appears that the students have analyzed the given problem, as seen from the way the students form a mathematical model that matches the information in the question, indicating that the students have met the skill indicators in identifying important aspects for problem solving. However, in the second question, when students are asked to solve the problem, it is seen that they have difficulty following the proper steps and choosing the appropriate method. This difficulty indicates that students have not achieved the skill indicator in making independent decisions needed in the problem-solving process. Because students have not been able to solve the second question, similar difficulties are also seen in the next question, so students have not met the skill indicator in developing independent ideas or concepts needed to solve the problem.

3.1.2 Cycle 1

Learning activities are carried out according to the design that has been made. The activity begins with a trigger question, to remind students of the previous material. Then we continued with learning according to the stages of the Problem-Based Learning (PBL) learning model. Then at the end of the learning process, students are given post-test questions to measure students' HOTS. The implementation of Cycle I activities involves the following stages:

(1) Planning

Based on the results of reflection in the Pre-Cycle, it was found that students' HOTS were still relatively low, so in Cycle I, the researcher made a plan, namely determining learning objectives, compiling teaching modules, designing PBL learning scenarios (teachers design problem-based learning scenarios that involve students in problem solving, analysis, or evaluation related to the selected topic), determining teaching materials, compiling group/ individual assignments, providing observation or observation sheets. The following is the post-test in cycle I activities.

Untuk memperingati ulang tahun SMKN 5 Madiun sekolah mengadakan perlombaan membaca puisi dan bernyanyi, Osis yang kebetulan ditunjuk sebagai panitia kegiatan ingin menyiapkan paket hadiah yang akan diberikan kepada siswa yang memenangkan lomba. Terdapat dua jenis paket hadiah, yaitu Paket Hadiah 1 dan Paket Hadian 2. Paket Hadiah 1 terdiri dari 2 buah buku tulis dan 1 buah pensil, sedangkan Paket Hadiah 2 terdiri dari 1 buah buku tulis dan 3 buah pensil. Panitia hanya menyediakan hadiah total 10 buku tulis dan 10 pensil. Harga Paket Hadiah 1 adalah Rp30.000 dan harga Paket Hadian 2 adalah Rp40.000.

Selesaikan :

1. Tentukan model matematika dari masalah ini dalam bentuk sistem persamaan linear dua variabel.
2. Tentukan jumlah masing-masing paket Hadiah yang harus disiapkan oleh panitia agar sesuai dengan persediaan yang disediakan.
3. Setelah mengetahui jumlah masing-masing paket hadiah yang harus disiapkan, selanjutnya buktikan apakah jumlah paket Hadiah 1 dan paket Hadiah 3 sesuai dengan persediaan yang disediakan panitia, serta berapa total biaya yang dikeluarkan panitia untuk membuat paket Hadia tersebut.

To celebrate the anniversary of SMKN 5 Madiun, the school is holding a poetry reading and singing competition. The student council (OSIS), which has been appointed as the organizing committee, wants to prepare gift packages for the students who win the competition. There are two types of gift packages: Gift Package 1 and Gift Package 2. Gift Package 1 consists of 2 notebooks and 1 pencil, while Gift Package 2 of 1 notebook and 3 pencils. The committee only has a total of 10 notebooks and 10 pencils available. The price of Gift Package 1 is Rp 30,000, and the price of Gift Package 2 is Rp 40,000.
Solve the following:

1. Create a mathematical model for this problem in the form of a system of linear equations with two variables.
2. Determine how many of each type of gift package the committee should prepare to match the available supplies.
3. After determining the number of each gift package to prepare, verify whether the total number of Gift Package 1 and Gift Package 2 fits the available supplies, and calculate the total cost incurred by the committee to create the gift packages.

Figure 5. Post-test Questions in the Cycle 1.

(2) Implementation

The implementation stage involves implementing the designed plan, with actions in class according to the strategies and methods prepared. This stage aims to test the plan's effectiveness in achieving the objectives. Implementation begins with a trigger question, providing student worksheets (LKPD) for group work, followed by a presentation, and ending with individual post-test questions.

1. Jika kalian pergi ke supermarket dan membeli 2 jeruk dan 1 mangga dengan total harga tertentu, lalu kembali membeli 3 jeruk dan 4 mangga dengan harga yang berbeda, apakah mungkin menghitung harga satu apel dan satu pisang? Bagaimana cara kalian menentukan jawabannya?
2. Di kantin sekolah, 2 nasi dan 3 lauk seharga Rp45.000, sedangkan 4 nasi dan 2 lauk seharga Rp70.000. Berapa harga 1 nasi dan 1 lauk?

1. If you go to the supermarket and buy 2 oranges and 1 mango for a certain total price, then later buy 3 oranges and 4 mangoes for a different price, is it possible to calculate the price of one apple and one banana? How would you determine the answer?
2. At the school canteen, 2 portions of rice and 3 side dishes cost Rp 45,000, while 4 portions of rice and 2 side dishes cost Rp 70,000. What is the price of 1 portion of rice and 1 side dish?

Figure 6. Trigger Question in Cycle 1.

(3) Observation

Observation aims to assess how the actions implemented achieve the stated objectives. At this stage, the researcher must explain each element used in detail; clarity in this observation is important so that the data collection process takes place systematically and the results obtained can be analyzed accurately and comprehensively.

Based on the analysis of the post-test results of 29 students, the average of their ability to analyze information into their respective parts and determine the relationship between the parts was 74.1%. Meanwhile, the average of their ability to make their own decisions and assess something to achieve a goal based on specific criteria was 68.9%. The average of their ability to create their ideas/concepts, such as reorganizing existing parts to form a new structure, the process includes producing, planning, and producing, only reached 67.2%. This percentage shows that students have slightly improved in understanding and solving problems. The percentage of students' HOTS in each indicator in cycle one activities is as follows.

Table 5. Students HOTS in Cycle 1

Indikator HOTS	Average (%)	Caregories
Analyze information into its respective parts and determine the relationships between the parts.	74,1	Enough
Make decisions and assess things to achieve a goal based on specific criteria	68,9	Not enough
Creating ideas/concepts, such as reorganizing existing parts to form a new structure, includes generating, planning, and producing.	67,2	Not enough

(4) Reflection

Reflection is conducted after the Action, which aims to identify weaknesses and deficiencies. Researchers analyze implementation, record observation results, and evaluate learning to improve weaknesses in cycle one so that they can be applied in cycle two if the indicators have not been achieved. The research results conducted by researchers and students are given story problems related to everyday life to see how far students have HOTS. The following are the results of the post-test to see HOTS from one of the students in solving story problems.

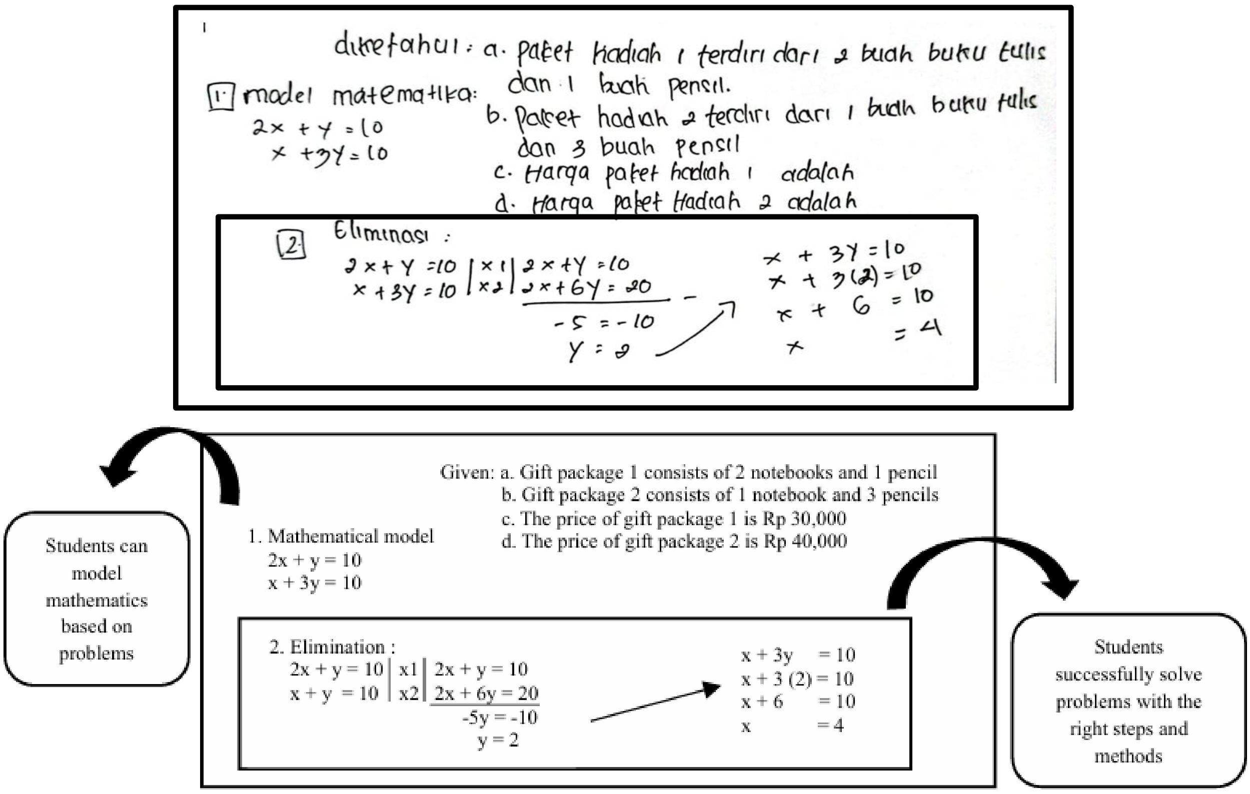

Figure 7. Example of Student Answer Results in Cycle 1.

Based on the results of the students' work in Figure 5, it can be seen that the students have analyzed the problems presented, this can be seen from the way the students for example the variables x and y, where the variable x is the number of Gift packages one purchased and the variable y is the number of Gift packages two purchased according to the information obtained from the question. Furthermore, students are asked to model the problem in mathematical form, and the answers given are based on expectations. Thus, students have achieved the indicators of the specifications of the aspects or elements needed in solving the problem. In the second question, students successfully solved the problem with the proper steps, understood the problem-solving process well, and met the indicators of skills in making independent decisions. However, in the third question, students had difficulty in proving the adequacy of supplies and calculating the total cost, which requires the ability to develop ideas independently. As a result, students have not achieved the indicators of skills in developing independent problem-solving ideas.

3.1.3 Cycle 2

Learning activities are carried out according to the design that has been made. The activity begins with a trigger question to remind students of the previous material. Then, they continued with learning according to the stages of the Problem-Based Learning (PBL) learning model. Then, at the end of the learning, students are given post-test questions to measure their HOTS. The implementation of Cycle 2 activities involves the following stages:

(1) Planning

Based on the results of reflection in cycle I, students still have not achieved the HOTS thinking ability indicators, so in Cycle 2 the researcher made a plan, namely determining learning objectives, compiling teaching modules, designing PBL learning scenarios (teachers design problem-based learning scenarios that involve students in problem solving, analysis, or evaluation related to the selected topic), determining teaching materials, compiling group/individual assignments, providing observation or observation sheets. The following is the post-test for cycle two activities.

Kantin Bu Ros yang ada di SMKN 5 Madiun, menyediakan dua jenis paket makan yang ditawarkan untuk siswa, yaitu Paket A dan Paket B. Paket A berisi 1 Nasi bungkus dan 2 Gorengan, sedangkan Paket B berisi 2 Nasi bungkus dan 1 Gorengan. Setiap hari, Bu Ros harus menyediakan 10 Nasi bungkus dan 8 Gorengan untuk memenuhi kebutuhan sarapan siswa. Harga satuan dari masing-masing paket adalah sebagai berikut :

- Harga Paket A adalah Rp6.000
- Harga Paket B adalah Rp8.000

Selesaikan :

1. Buatlah model matematika dalam bentuk sistem persamaan linear dua variabel berdasarkan informasi di atas.
2. Tentukan jumlah masing-masing paket yang harus disiapkan oleh kantin agar kebutuhan sarapan siswa tercukupi.
3. Setelah mengetahui jumlah masing-masing paket yang harus disiapkan, selanjutnya buktikan apakah jumlah paket A dan paket B dapat memenuhi kebutuhan siswa, serta berapa penghasilan Bu Ros jika menjual paket-paket makan tersebut.

Bu Ros's canteen at SMKN 5 Madiun offers two types of meal packages for students: Package A and Package B. Package A contains 1 wrapped rice and 2 fried snacks, while Package B contains 2 wrapped rice and 1 fried snack. Every day, Bu Ros must prepare a total of 10 wrapped rice and fried snacks to meet the students' breakfast needs.
The prices for each package are as follows:

- The price of Package A is Rp 6,000
- The price of Package B is Rp 8,000

Solve the following:

1. Create a mathematical model in the form of a system of linear equations with two variables based on the information above.
2. Determine the number of each package that the canteen must prepare to fulfill the students' breakfast needs.
3. After finding out how many of each package should be prepared, verify whether the quantities of Package A and Package B meet the students' needs, and calculate Bu Ros's total income from selling the meal packages.

Figure 8. Post-test Questions in Cycle 2.

(2) Implementation

The implementation stage involves implementing the designed plan, with actions in class according to the strategies and methods prepared. This stage aims to test the plan's effectiveness in achieving the objectives. Implementation begins with a trigger question, providing student worksheets (LKPD) for group work, followed by a presentation, and ending with individual post-test questions.

1. Jika Ridho memiliki uang Rp50.000 dan ingin membeli Buku dan Bolpoint. Ridho tahu harga Buku adalah Rp2.000 per batang, dan harga Bolpoint adalah Rp3.000 per buah. Berapa jumlah maksimal pensil dan penghapus yang bisa Ridho beli dengan uang Rp50.000?
2. Di koperasi sekolah harga 3 pensil dan 2 penghapus adalah Rp20.000, sementara harga 5 pensil dan 4 penghapus adalah Rp34.000. Berapa harga satu pensil dan satu penghapus?

1. Ridho has Rp 50,000 and wants to buy erasers and pens. He knows that the price of an eraser is Rp 2,000 each, and the price of a pen is Rp 3,000 each. What is the maximum number of erasers and pens that Ridho can buy with Rp 50,000?
2. At the school cooperative, the price of 3 pencils and 2 erasers is Rp 20,000, while the price of 5 pencils and 4 erasers is Rp 34,000. What is the price of one pencil and one eraser?

Figure 9. Trigger Question in Cycle 2.

(3) Observation

Observation aims to assess how the actions implemented achieve the stated objectives. At this stage, the researcher must explain each element used in detail; clarity in this observation is important so that the data collection process takes place systematically and the results can be analyzed accurately and comprehensively.

Based on the analysis of the post-test results of 29 students, the average ability of them to analyze information into their respective parts and determine the relationship between them was 81.8%. Meanwhile, their average ability to make their own decisions and assess something to achieve a goal based on specific criteria was 80.1%. Their average ability to create ideas/concepts, such as reorganizing existing parts to form a new structure, includes producing, planning, and reaching 75.8%. This percentage shows that students have experienced a significant increase in understanding and solving problems. This is because the material and questions are relevant to their daily lives. The percentage of students' HOTS in each indicator in cycle 2 is as follows.

Table 6. Student's HOTS in cycle 2

Indikator HOTS	Average (%)	Caregories
Analyze information into its respective parts and determine the relationships between the parts.	81,8	Good
Make decisions and assess things to achieve a goal based on specific criteria	80,1	Enough
Creating ideas/concepts, such as reorganizing existing parts to form a new structure, includes generating, planning, and producing.	75,8	Enough

(4) Reflection

Reflection is conducted after the Action, which aims to identify weaknesses and deficiencies. Researchers analyze the implementation, record the results of observations, and evaluate learning to improve weaknesses in the second cycle so that they can be applied in the third cycle if the indicators have not been achieved.

The research results conducted by researchers and students are given story problems related to everyday life to see how far students have HOTS. The following are the results of the post-test to see HOTS from one of the students in solving story problems.

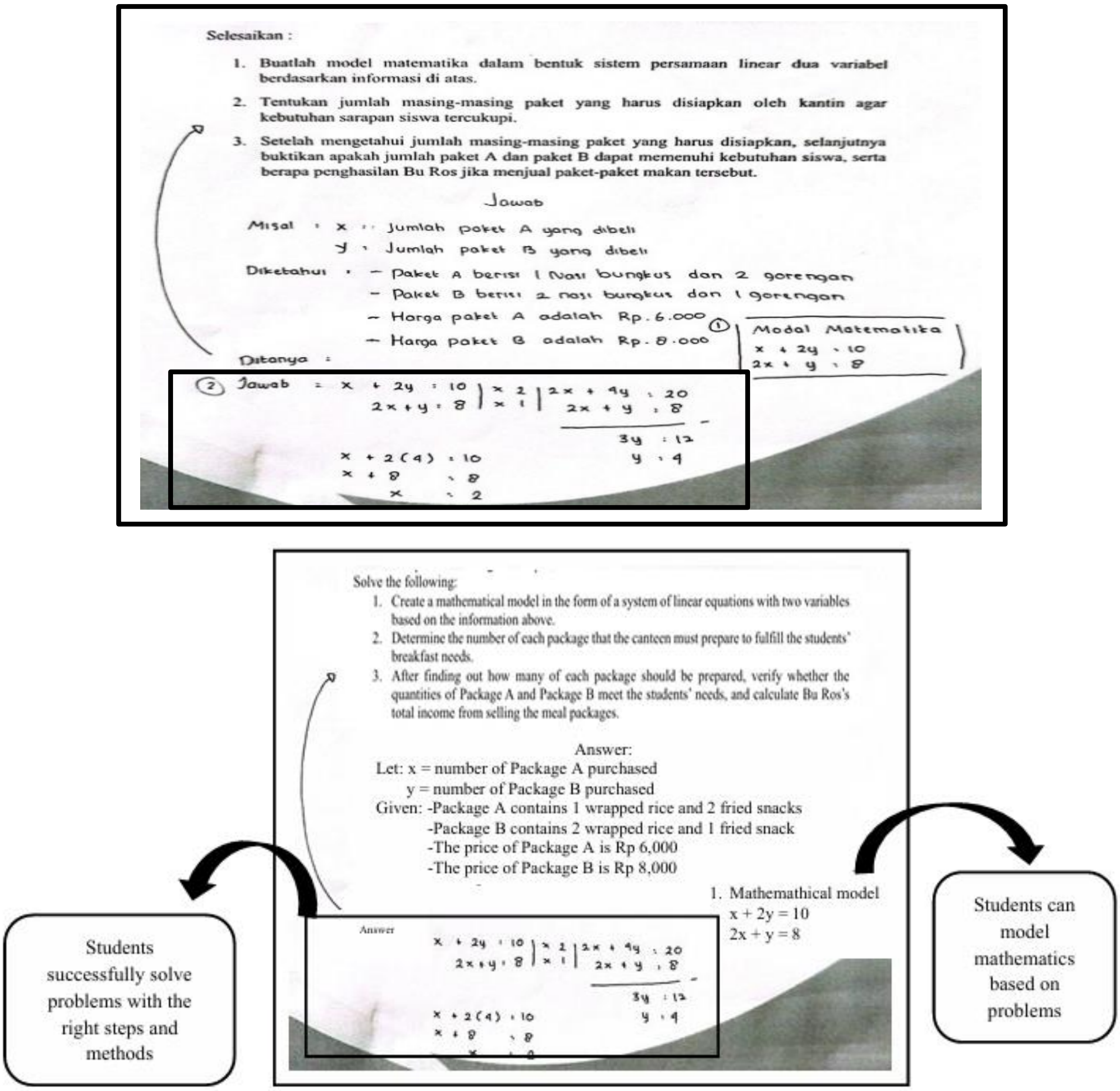

Figure 10. Example of Student Answer Results in Cycle 2.

Based on the students' work results in Figure 7, the students have analyzed the problems presented. This can be seen from how the students assume the variables x and y, where the variable x is the number of packages A purchased, and the variable y is the number of packages B purchased, according to the information obtained from the question. Furthermore, students are asked to model the problem in mathematical form, and the answers given are based on expectations. Thus, students have achieved the indicators of the specifications of the aspects or elements needed in solving the problem. Furthermore, in the second question, students are asked to solve the problem given. It can be seen that students have been able to solve the problem by using the appropriate solution steps and following the correct sequence. In this way, students show they have understood the problem-solving process correctly. Therefore, students have succeeded in making their own decisions and assessing something to achieve a goal based on specific criteria needed in the problem-solving process.

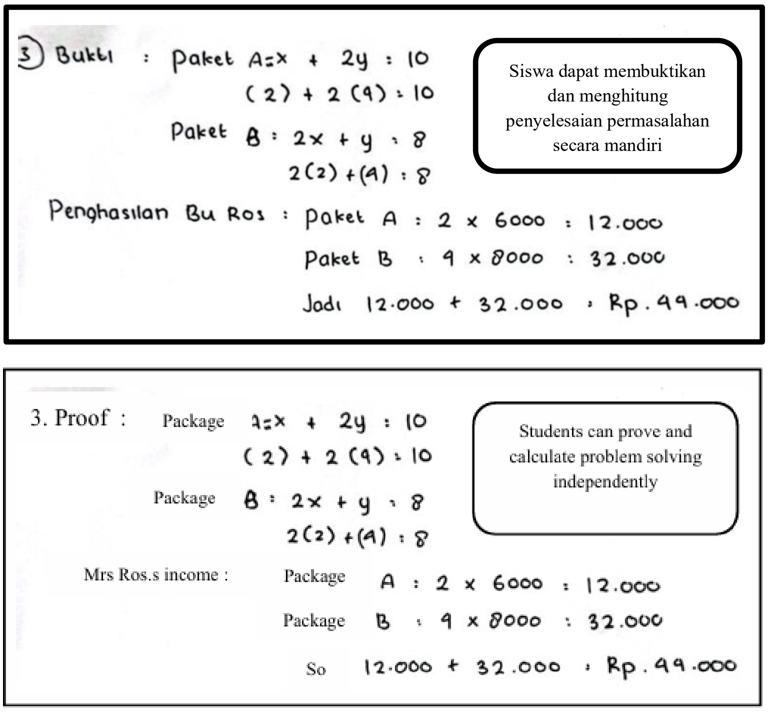

Figure 11. Example of Student Answer Results in cycle 2 (question 3).

In the third question, students can solve the problem, this is proven by the students being able to prove and calculate the expenses needed to make Gift Package 1 and Gift Package 2. Therefore, students have achieved the indicators in developing independent ideas or concepts needed in the problem-solving process.

Table 7. Recapitulation of Research Results

HOTs Indicator	Precycle (%)	Cycle 1 (%)	Cycle 2 (%)
Analyze information into its respective parts and determine the relationships between the parts.	60,3	76,7	81,8
Make decisions and assess things to achieve a goal based on specific criteria	57,7	71,5	80,1
Creating ideas/concepts, such as reorganizing existing parts to form a new structure, includes generating, planning, and producing.	51,7	67,2	75,8
Average	56,6	71,8	79,2
Category average	Very less	Enough	Enough

Based on the recapitulation table, the following is a recapitulation diagram of the research results to improve students' HOTs in each indicator and the average for each category.

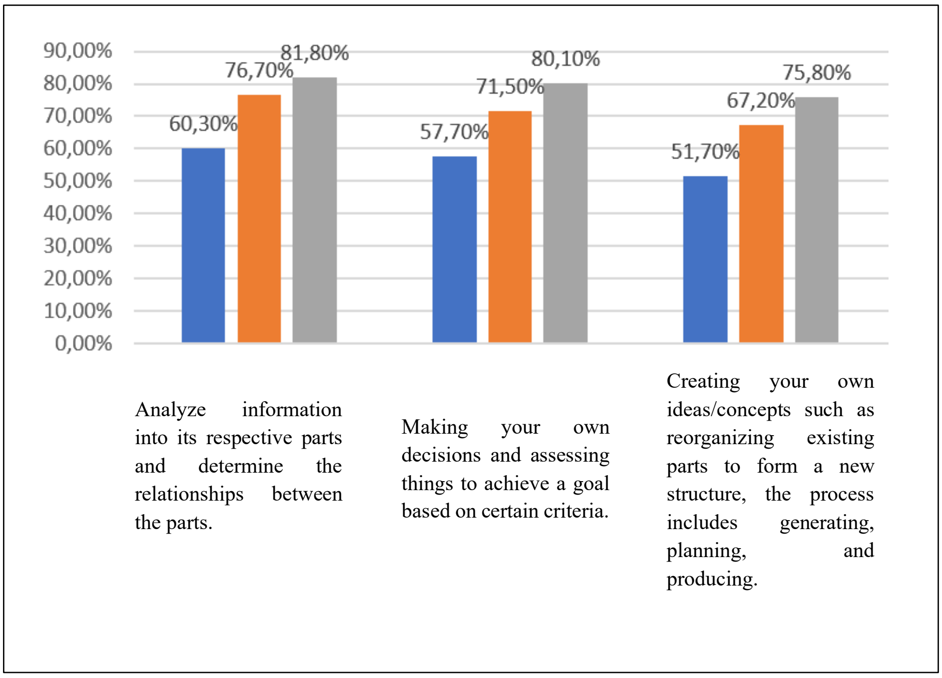

Figure 12. Recapitulation diagram of research results.

3.2 Discussion

This classroom action research (CAR) aims to improve students' HOTS in mathematics learning through learning with the Problem-Based Learning learning model based on mathematical literacy in class X MP 2 SMK Negeri 5 Madiun. By integrating the Problem-Based Learning learning model based on mathematical literacy into mathematics learning, it can create an environment that allows students to develop a deeper understanding of mathematical concepts and at the same time improve their HOTS in dealing with mathematical problems in real life (Utami, 2023; Wulandari & Badjeber, 2023).

The research showed students' HOTS in solving mathematical problems was still relatively low. In the precycle stage, students' abilities were far below the expected level of success, with an average completion of only 56.6%. After the Action was taken in the first cycle, there was a significant increase, but the results still did not reach the set completion criteria, with an average of 71.8%. Then learning was continued in the second cycle, where a significant increase occurred again, and this time students managed to achieve the completion criteria, with an average of 79.2%. These data show positive developments in students' HOTS after going through two learning cycles. This is in line with research (Husnidar & Hayati, 2021) that the Problem-Based Learning (PBL) learning model can stimulate students' critical and creative thinking by using real problems (Hirda Yanti, 2017). Research by Antonio & Prudente (2023) also states that with HOTS abilities, students are invited to identify, analyze, and solve problems, so that they can develop high-level thinking skills and application of knowledge in real-life situations.

4. Conclusion

Based on the research results, it can be concluded that the application of the Problem-Based Learning learning model based on mathematical literacy in solving mathematical problems in class X MP 2 SMK Negeri 5 Madiun has proven effective in improving students' HOTS. The implementation of PBL based on mathematical literacy helps students relate relevant mathematical concepts to real life, making it easier to understand and apply in the context of problem solving. This research was only conducted in one class and in two cycles. Therefore, it is suggested that further research be conducted in more than one class or across levels to see the consistency of the results more broadly.

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Mathematical Literacy Problems in Exponential Material Based on Vocational Students' Self-Regulated Learning

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Abstract

This study explores the mathematical literacy challenges faced by students at SMK Negeri 2 Bawang, Banjarnegara Regency, in learning exponential concepts, which are analyzed through the lens of the Independent Regular Learning (SRL) level. Using a descriptive qualitative approach, this study involved three student subjects representing high, medium, and low SRL categories. Data was collected through mathematical literacy tests, SRL questionnaires, and interviews. The research findings indicate that variations in SRL levels significantly influence the types of difficulties students experience. Students with low SRL face various challenges, including understanding the context of the problem, building mathematical models, and interpreting results. Students with moderate SRL demonstrate the ability to understand problems but have difficulty selecting appropriate problem-solving strategies and accurately representing contextual situations in mathematical form.

Meanwhile, students with high SRL exhibit systematic and reflective thinking but encounter obstacles connecting mathematical outcomes to real-life contexts. These findings underscore the role of SRL in shaping students' mathematical literacy challenges. Further research is recommended to investigate additional internal factors that influence mathematical literacy in order to develop more adaptive and targeted teaching strategies.

Keywords: Exponential; Learning Challenges; Mathematical Literacy; Self-Regulated Learning; Vocational School Students

1. Introduction

In the era of globalization and the Industrial Revolution 4.0, mathematics education is not only expected to be able to convey basic concept, but also develop students' mathematical literacy skills. Mathematical literacy is a vital competency that reflects an individual's ability to formulate, apply, and interpret mathematics in a variety of real-life contexts (Apriliska et al., 2025). This ability is closely related to 21st-century competencies such as logical reasoning, representation, connections, communication, and mathematical problem-solving (Putri et al., 2022). Therefore, strengthening mathematical literacy through relevant, contextual, and future-oriented learning approaches serves as an essential foundation for preparing students to face complex challenges in the modern world.

Students' mathematical literacy goes beyond procedural problem-solving and includes more complex processes. This includes how students interpret the meaning of a given context, transform information into a mathematical model, interpret the results, and reflect on the problem-solving process. Many students have difficulty identifying relevant information, choosing appropriate solution strategies, and connecting calculation results to real-world contexts (Cardoso Espinosa, 2021). Burkhardt et al. (2024) emphasize that mathematics education should enable students to understand the relevance of mathematics in real-life situations, rather than simply memorizing procedures or formulas. Students' inability to connect mathematical concepts to real worls contexts highlights conceptual and contextual problems in mathematical literacy. This is in line with the perspective of Cardoso Espinosa's (2021) perspective, who emphasized that mathematical literacy serves as a foundation for developing quantitative thinking skills, including the ability to represent information through graphs, tables, and mathematical models that are important for decision-making.

Based on PISA's framework, mathematical literacy is defined as an individual's ability to apply, interpret, and engage with mathematics in various real-life contexts. This competency is vital not only for academic performance but also for making well-informed decisions in social, economic, and professional environments. As highlighted by Indonesian media, the official release of the 2022 PISA results took place on December 5, 2023. The report revealed that Indonesia ranked 68th, with scores of 379 in mathematics, 398 in science, and 371 in reading. These results indicate that Indonesian students have consistently struggled with mathematical literacy over the years. Furthermore, the OECD (2023) noted that Indonesia's average mathematics score declined from 379 in 2018 to around 368 in 2022, marking one of the lowest scores recorded since 2003. Only 18% of Indonesian students reached at least Level 2 proficiency, compared to 69% across OECD countries, and almost none achieved the highest proficiency levels (Level 5–6) in mathematics.

Most previous research on mathematical literacy has focused more on improving students' skills through various learning models without comprehensively addressing the root causes of the difficulties or challenges students face in learning mathematics. For example, Maysarah et al. (2023) examined the effectiveness of the Project-Based Learning (PjBL) model in improving mathematical literacy, showing significant improvements in students' abilities to identify facts, formulate problems, and interpret solutions. However, their studies focused solely on improving literacy outcomes without investigating the underlying factors contributing to students' difficulties. Similarly, Aritonang and Safitri (2021) explored the impact of blended learning during the COVID-19 pandemic, reporting a 30% increase in students' mathematical literacy compared to a 2.44% increase using traditional methods. While these studies highlight effective strategies for literacy improvement, they do not investigate the underlying challenges students experience.

Research by Anggraeni et al. (2020) identifies that learning difficulties in mathematics stem from both internal and external factors. Internal factors include students' negative attitudes towards mathematics, low interest in learning, weak motivation, and limited sensory abilities. On the other hand, external factors include the less than optimal role of teachers, inadequate learning facilities, and minimal support from family and society. Among these factors, one of the internal factors relevant to mathematical literacy is self-regulated learning (SRL), which plays an important role in shaping students' ability to manage and optimize their learning process independently.

Supporting this, a systematic literature review by Apriliska et al. (2025) identified three dominant internal factors affecting mathematical literacy in Indonesian students: learning motivation, self-regulated learning, and prior mathematical ability. Among these, learning motivation was the most influential, followed closely by SRL and initial mathematical competence. Students with low motivation often solve problems procedurally without analyzing context, while those with high motivation demonstrate deeper engagement and better literacy outcomes. Furthermore, students with strong SRL skills were more likely to meet higher-level literacy criteria, including the ability to reason abstractly, model mathematically, and solve non-routine problems. Although prior mathematical ability played a lesser role, it still served as a foundation for higher-level literacy development.

SRL is the ability of students to manage their learning process independently, including planning, monitoring, and reflecting on learning activities. Students with low SRL often have difficulty with learning strategies, time management, and evaluating their mistakes (Afrizal, 2023). As a result, they face challenges in understanding the context of problems, building appropriate mathematical models, and drawing accurate conclusions, all of which are important components of mathematical literacy. In contrast, students with strong SRL can plan solutions to math problems, monitor their understanding as they solve them, identify difficulties, adjust strategies if initial plans fail, and evaluate whether their solutions align with the problem context. SRL provides a framework for students to control their mathematics learning through goal setting, problem-solving strategies, reflection, and continuous improvement (Afrizal, 2023; Indriani & Wahyuni, 2022).

Mathematical literacy and self-regulated learning (SRL) are interrelated constructs that significantly contribute to students' capacity for effective mathematical reasoning and problem-solving. According to Gabriel et al. (2020), SRL which encompasses motivation, metacognition, and emotional regulation plays a vital role in improving students' mathematical literacy. Their findings indicate that perseverance, as a core aspect of SRL, enhances students' self-efficacy, which in turn has a strong positive effect on mathematical literacy outcomes. Similarly, Wang and Sperling (2020) reported that students with higher academic achievement tend to use a broader array of learning strategies and apply SRL techniques more frequently than their lower-achieving peers, highlighting the positive association between SRL and academic performance in mathematics.

Mathematical literacy involves not only applying but also interpreting mathematical concepts in real-world situations, while SRL encompasses goal setting, monitoring progress, and employing strategic approaches to learning (Sumarni et al., 2025). Without adequate SRL skills, students may face difficulties in solving mathematical problems, reflecting on their learning, or adapting strategies when encountering challenges. Research highlights that students with strong SRL tend to exhibit better problem-solving performance and resilience in mathematical tasks (Sumarni et al., 2025).

Findings by Yanti et al. (2022) also strengthens this interconnection, showing that students' mathematical literacy performance in solving higher-order thinking problems on matrix material is closely related to their abilities in communicating, mathematizing, and applying strategies. Their study found that students with low literacy levels not only struggled with symbolic representation but also in contextualizing mathematical problems, indicating the need for deeper cognitive and metacognitive engagement elements fostered through self-regulated learning (SRL). In line with this, Sapulete et al. (2023) highlight that students' problem-solving abilities in mathematics are influenced by their levels of SRL and self-efficacy. Although their study revealed that the quantitative contribution of SRL to problem solving was limited, it highlighted qualitative gaps in students' learning behavior, such as lack of planning, weak persistence, and use of surface-level strategies. This pattern of behavior reflects the core challenges in mathematical literacy as described in previous literature.

The concept of exponentials poses a significant challenge for vocational high school students because of its abstract yet practical application. In mathematical literacy assignments, students must not only understand formulas but also apply exponential concepts to real-world scenarios, such as population growth or asset depreciation.

This study identifies a critical gap in previous studies, most of which have focused on improving mathematical literacy and have not explored the root causes of students' difficulties in understanding mathematics, especially from the perspective of learning processes and SRL abilities. To address this gap, this study examines the mathematical literacy challenges faced by vocational high Scholle students with varying levels of SRL, especially in exponential material. Therefore, this study seeks to uncover the appropriate and fundamental issues, which form the basis for designing contextual and personalized learning intervention.

2. Method

This study employs a qualitative approach with a descriptive design. This methodology was chosen because it allows researchers to explore in depth students' experiences, strategies, and thought processes in solving mathematical literacy problems related to exponential material. Descriptive design is used to describe students' mathematical literacy systematically and accurately, particularly regarding differences in self-regulated learning (SRL) when solving exponential problems.

The population of this study consisted of all 36 students in Class X TE 5 at SMK Negeri 2 Bawang, Banjarnegara Regency, who had studied exponential material as part of the mathematics curriculum. The sample was selected using a purposive sampling technique, considering variations in students' levels of self-regulated learning.

This study used a purposive sampling method to select three representative samples categorized based on the level of Self-Regulated Learning (SRL): high (T1), medium (S1), and low (R1). One student from each category was selected as a representative sample, following the method used in the study by Rizqa et al. (2023) to examine differences in mathematical literacy abilities across SRL levels. This approach facilitates an in-depth qualitative case study, enabling a comprehensive understanding of each SRL category. However, the limited sample size restricts the generalizability of the findings to the broader population, making the results exploratory in nature and highlighting the need for further research with larger sample sizes to validate the findings.

Data collection for this study involved various instruments and techniques. The primary instrument was a mathematical literacy test, validated by the supervisor, designed to evaluate problem-solving abilities and the application of mathematical concepts using an approach grounded in mathematical literacy. The test questions, centered on exponential material, were developed to address three key literacy indicators based on OECD (2019) guidelines: (1) Formulate, which involves translating real-world problems into mathematical models; (2) Employ, which refers to applying mathematical concepts to solve problems; and (3) Interpret, which requires reinterpreting mathematical results, solutions, or conclusions in the context of the problem.

The Self-Regulated Learning (SRL) questionnaire was administered to assess students' levels of learning independence and to categorize them into high, medium, and low SRL groups. This instrument was adapted from validated questionnaires, particularly from Azwar as cited in Afrizal (2023). The SRL questionnaire utilizes a Likert scale ranging from 1 to 4, comprising both positive and negative statements. The scoring structure for the SRL scale items is detailed in the table below.

Both the mathematical literacy test and the SRL questionnaire were validated by experts or adapted from previously validated instruments, such as those developed by Azwar (Afrizal, 2023). This process ensures the credibility and reliability of the data collected in this study. The scoring arrangement for the SRL scale items is outlined in the following Table 1.

Table 1. SRL Scale Item Scoring Structure

Answer Categories	Positive	Negative
Strongly Disagree (STS)	1	4
Disagree (TS)	2	3
Agree (S)	3	2
Strongly Agree (SS)	4	1

Source: Adapted from Azwar (Afrizal, 2023)

The following is an example of a question related to exponents:

A workshop produces certain components of a Motorcycle. On the first day (day 0), the workshop successfully produces 10 components. It turns out that every day the number of components produced increases exponentially with a growth factor a (with a>1).

The exponential function is expressed as:
$f(x) = P0 \cdot \alpha^x$ where:
- F (x) = number of components produced on day x
- α = daily growth factor (where a>1)
- x = number of days after the first day.

Question:
a) Explain how you would construct a mathematical model to describe the growth of component production in this workshop? Explain why α >1?
b) Suppose α = 1.2 (meaning a 20% increase every day). Use the formula $f(x) = 10 \cdot (12)^x$ to calculate how many components are produced on the 5th day. Show your calculation steps clearly.

Based on your calculation results, draw a graph of the growth in production volume over 7 days and explain the growth pattern seen based on the graph.

Figure 1. Example Questions.

To categorize students' levels of Self-Regulated Learning (SRL), positive and negative scores obtained from the SRL questionnaire are analyzed based on predetermined intervals. The range of positive and negative scores is calculated using the maximum and minimum data values. The difference between these scores is the main indicator for determining a student's SRL category. SRL levels are classified into three categories: high, medium, and low, as outlined by Wijayanto, et al (2024). Next, the data collection technique is through In-depth Interviews. These interviews aim to explore, in detail, students' problem-solving strategies, obstacles encountered, and thought processes. This technique has been demonstrated to be effective in studies examining mathematical literacy and Self-Regulated Learning (Afrizal, 2023).

Data analysis was conducted using a qualitative descriptive approach, adhering to systematic stages to ensure comprehensive and meaningful findings. The qualitative analysis process involved three key steps: data reduction, data presentation, and conclusion drawing. These steps, as outlined by Qomaruddin and Sa'diyah (2024), were implemented using four identified analysis techniques to provide a thorough understanding of the research phenomenon. The first stage, data reduction, involved filtering and grouping data collected from questionnaires, tests, and interviews based on their relevance to mathematical literacy indicators and students' SRL levels. Reduced data were then presented systematically in a narrative format, highlighting problematic patterns.

Subsequently, the researcher interpreted the data by connecting the findings to mathematical literacy theory. This step identified the core challenges students face in their mathematical literacy processes on exponential material and formulated recommendations to address these issues. Finally, conclusion drawing was performed through a triangulation process, comparing data obtained from various collection methods (tests and interviews) to ensure reliability and validity.

Additionally, the principles for developing mathematical literacy proposed by Cardoso Espinosa (2021) served as a foundation for this study, particularly emphasizing the integration of technology and innovative learning strategies to enhance students' mathematical literacy. Below are the questions used to assess students' mathematical literacy skills on exponential material.

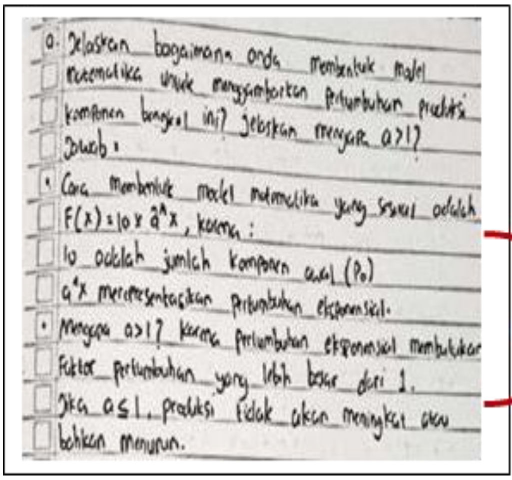
3. Results and Discussion

3.1 Results

This study aims to describe the forms of students' mathematical literacy problems based on high, medium, and low self-regulated learning (SRL) categories. Each student category is analyzed using the results of mathematical literacy tests and in-depth interviews, specifically focusing on the indicators of formulating, applying, and interpreting within the context of exponential material.

3.1.1 Students with high self-regulated learning (T1)

The following are the result of the students answers with high self regulated learning.


a. Jelaskan bagaimana anda membentuk model matematika untuk menggambarkan pertumbuhan produksi komponen bengkel ini? Jelaskan mengapa a>1?
Jawab:
• Cara membentuk model matematika yang sesuai adalah F(x)=10 × a^x, karena:
10 adalah jumlah komponen awal (P0)
a^x merepresentasikan pertumbuhan eksponensial.
• Mengapa a>1? karena pertumbuhan eksponensial membutuhkan faktor pertumbuhan yang lebih besar dari 1.
Jika a≤1, produksi tidak akan meningkat atau bahkan menurun.

Formula, namely formulating real problems mathematically

a. Explain how you would construct a mathematical model to describe the growth in production of this workshop component? Explain why $a > 1$?

Answer:

- The way to form a suitable mathematics model is $F(x) = 10 \times a^x$, because:
  10 is initial number komponen
  a^x presentation exponential growth.
- Why $a > 1$? Because exponential growth requires greater growth factor than 1.
  If $a \leq 1$, production will not increase or even decrease.

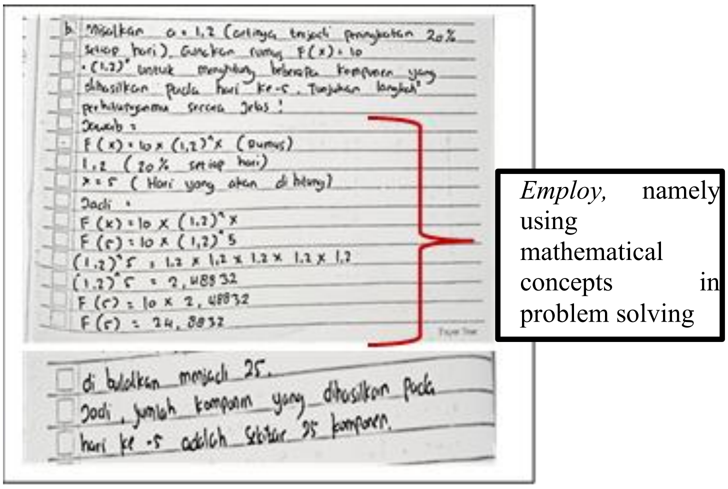
Figure 2. Subject T1's Answer.

Based on Figure 2, the mathematical literacy process of students with high Self Regulated Learning, students do not experience problems in formulating problems. This is shown through the preparation of accurate mathematical models and clear reasons for choosing exponential models, such as the growth factor a>1 which is relevant to the context of the problem. In terms of applying the concept (employ), students also do not show any obstacles in writing exponential formulas to calculate the number of components on the 5th day in detail and systematically, including in the process of calculating numbers.

In the interpreting and communicating indicator, students have no difficulty in describing the growth graph of the number of components accurately and explaining the exponential growth pattern descriptively. However, the problem that appears is that students do not create the right scale in visualizing the graph so that the graph points look rather linear even though they are exponential.

Based on the interview results, student T1 also did not show any problems in solving exponential problems. The interview results showed that student T1 had a systematic approach in solving exponential problems. At the stage of formulating the problem, students stated that they had no difficulty in understanding the context of the problem and could identify important elements, such as the daily growth factor (a) and its relationship to changes in the number of component production each day. Students also showed how to integrate the information in the problem with relevant mathematical concepts, and explained the relationship between the parameter a>1 and exponential growth in a real context without any difficulty. The following is a transcript of the interview with T1.

Researcher : "Tell me what was the first thing you did when you read the question?"
Subject : "I read the question carefully to understand what was asked. I noticed that the question asked to calculate the amount of production on a certain day using the exponential formula. Then, I noted down important information such as the initial value of production and the daily growth factor, ma'am."



b. If $a = 1,2$ (meaning an increase every day). Use formula $F(x) = 10.(1,2)^x$ to calculate some of the components produced on the 5th day. Show the steps of the calculation clearly!
Answer:
$F(x) = 10 \times (1,2)^x$ (rumus)
1,2 (20% every day)
$x = 5$ (day to be counted)
So,
$F(x) = 10 \times (1,2)^x$
$F(5) = 10 \times (1,2)^5$
$(1,2)^5 = 1,2 \times 1,2 \times 1,2 \times 1,2 \times 1,2$
$(1,2)^5 = 24,8832$
Rounded up to 25
The number of components produced on the 5th day is approximately 25 components.

Figure 3. Subject T1's Answer.

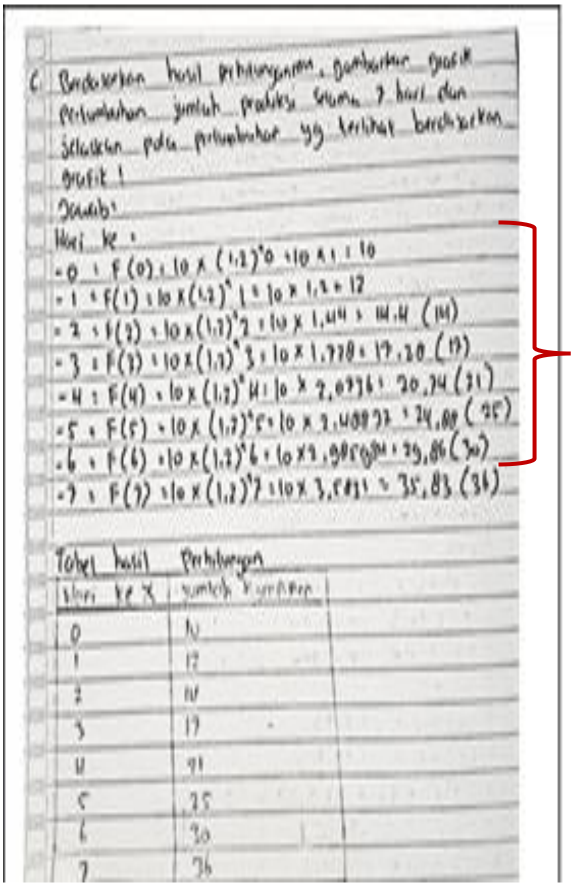
Based on Figure 3, in applying the conceptual aspect (employ), students do not experience difficulties in applying the exponential growth formula $f(x)=P0 \cdot a^x$, students can calculate the production value on the 5th day carefully, and ensure the accuracy of the results through rechecking. Students can also visualize data well through clear graphs, and explain changes in value quantitatively and qualitatively. This is shown during the interview.

Researcher : "Once you understand the problem, what steps do you take to solve it?"
Subject : "I start by plugging the known values into the formula. For example, on day 5, I replace x with 5 and calculate the result. After that, I also draw a graph based on the calculation results to visualize the production growth."

Based on Figured 4, in the aspect of interpreting and communicating (interpret), students are able to provide comprehensive explanations related to the calculation results, such as how the value of a affects the growth of production volume and the relevance of exponential patterns to the real situation presented in the problem.

Based on Figure 5, students not only conclude that production increases steadily, but are also able to connect the calculation results with graphs, showing in-depth analysis of growth patterns. This is demonstrated during the interview.

Researcher : "Do you have difficulty calculating or drawing graphs? How do you overcome it?"
Subject : "Not really, ma'am. If I have any difficulties, I usually double-check the results with a calculator and see if the results match. For graphs, I make sure that the scale and values I use match the data in question."



Interpret, namely reinterpreting mathematical results, solutions, or conclusions into the context of the problem.

c. Based on the calculations, draw a graph of the growth in production volume over 7 days and explain the growth seen based on the graph

Answer:

Day to

$0 = f(0) = 10 \times (1{,}2)^0 = 10 \times 1 = 10$

$1 = f(1) = 10 \times (1{,}2)^1 = 10 \times 1{,}2 = 12$

$2 = f(2) = 10 \times (1{,}2)^2 = 10 \times 1{,}44 = 14{,}4 (14)$

$3 = f(3) = 10 \times (1{,}2)^3 = 10 \times 1{,}728 = 17{,}28\ (17)$

$4 = f(4) = 10 \times (1{,}2)^4 = 10 \times 2{,}0736 = 20{,}736\ (21)$

$5 = f(5) = 10 \times (1{,}2)^5 = 10 \times 2{,}48832 = 24{,}8832\ (25)$

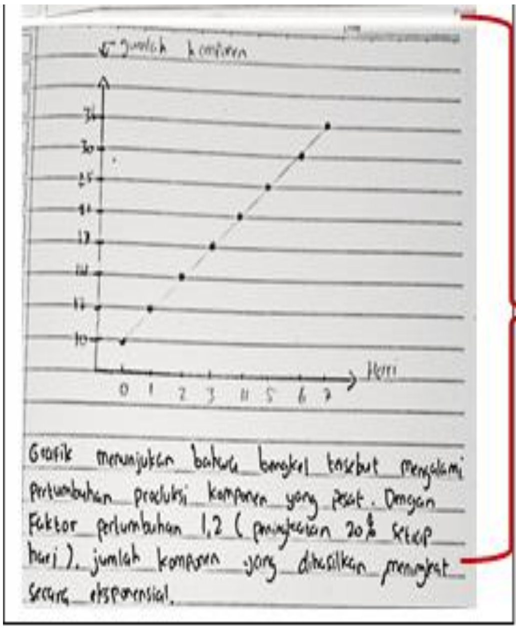
$6 = f(6) = 10 \times (1{,}2)^6 = 10 \times 2{,}985984 = 29{,}85984\ (30)$

$7 = f(7) = 10 \times (1{,}2)^7 = 10 \times 3{,}5831808 = 35{,}831808\ (36)$

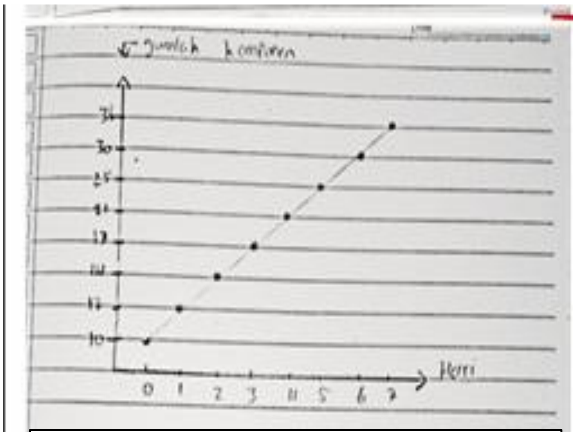
Calculation result table

Day to x	Number of component
0	10
1	12
2	14
3	17
4	21
5	25
6	30
7	36

Figure 4. Subject T1's Answer.



Interpret, namely reinterpretin g mathematica l conclusions into the context of the Probem.



The graph shows that the workshop is experiencing rapid growth in component production. With a growth factor of 1,2 (a 20% increase each day), the number of components produced is increasing exponentially.

Figure 5. Subject T1's Answer.

From the interviews and the results of the students' answers, it was identified that students with high Self-Regulated Learning did not have difficulty with mathematical literacy in answering exponential problems. However, the findings in this study, students with high Self-Regulated Learning had the main problem located at the graphic representation stage, especially in the aspects of scale accuracy and visual interpretation of mathematical models. Students were able to use effective learning strategies, including reflection on the steps taken and the ability to elaborate mathematical concepts independently. This shows that students not only master procedural skills, but also understand concepts and can apply them in various contexts meaningfully.

3.1.2 Students with moderate self-regulated learning (S1)

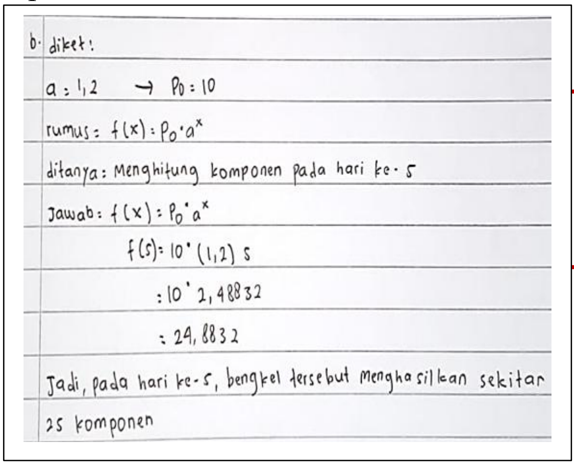
The following are the result of the students answers with moderate self regulated learning.

Formula, namely formulating real problems mathematically

(a) is the daily growth factor, where $(a > 1)$ indicates that the number of components produced increase everyday. If $(a = 1)$, then there is no growth, and if $(a < 1)$, then the number of components produced will decrease. Therefore, to indicate growth, we need (a) to be greater than 1.

Figure 6. Subject S1's Answer.

Based on Figure 6, this explanation is not deeply connected to the mathematical model $f(x)=P0\cdot a^x$ where in the question students are asked to explain how to form a mathematical model to describe the growth of component production in the workshop, but students do not explain it, so students do not fully utilize the information in the question to build a stronger mathematical representation



Employ, use concepts in problem solving

b. Known
$1{,}2 \rightarrow P_0 = 10$
Formula = $f(x) = P_0 . a^x$
Questions: count components on day 5
Answer:
$f(x) = P_0 . a^x$
$= 10.(2{,}48832)$
$= 24{,}8832$
So, on the 5th day, the workshop produced about 25 components.

Figure 7. Subject S1's Answer.

Based on Figure 7, in the aspect of applying the concept (employ), students can write down the concept and do not experience difficulties in using the given formula correctly, students can calculate the value of f(5)=24, and describe the exponential growth graph correctly. However, students seem to only focus on the calculation procedure without providing validation of the results or explaining how the numbers are relevant in the context of the problem where the problem requires students to show the calculation steps clearly. When applying the concept of exponents, students are able to use relevant mathematical formulas, although the steps are sometimes less systematic. This can be seen from the students' answers during the interview.

Researcher : "Once you understand the problem, how do you determine the steps to solve it?"

Subject : "I immediately used the formula f(x)=P0·ax that has been taught. But, sometimes I forget to check whether the numbers are correct or not, so I recalculate several times to make sure."

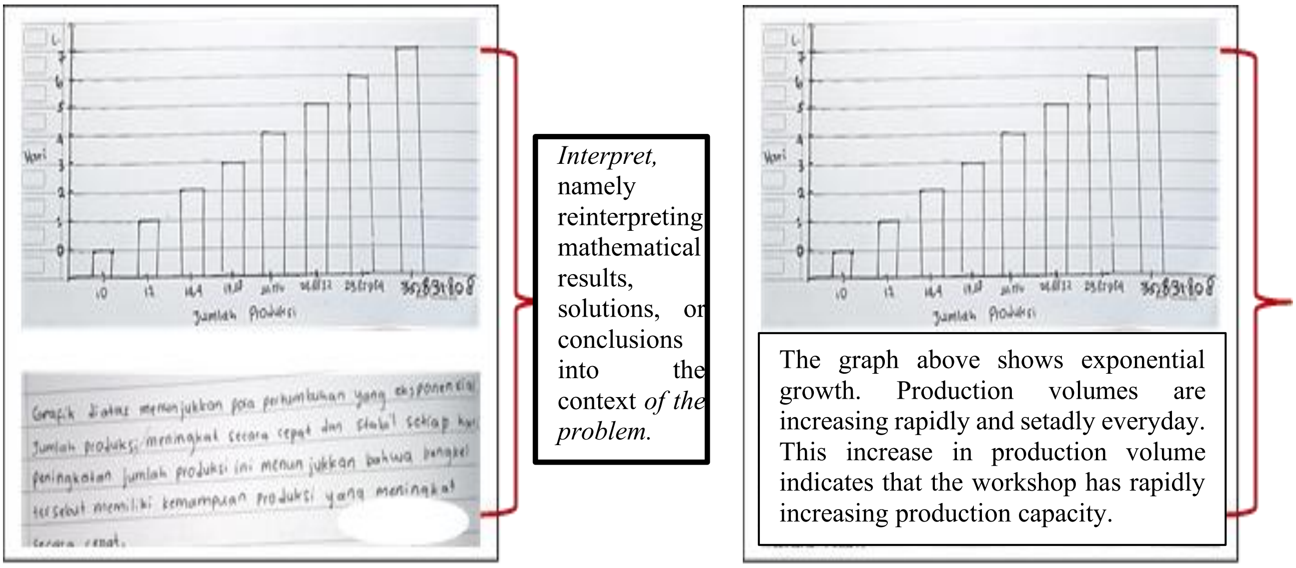


Figure 8. Subject S1's Answer.

Based on Figure 8, in the aspect of interpreting and communicating (interpret), students successfully concluded that the amount of production on the 5th day was around 25 components and described the graph with a bar chart as a stable exponential growth pattern. However, even though students have shown the correct calculations and presentation of data in the form of graphs, problems arise in the aspect of visual interpretation and reinterpretation of mathematical results into the context of the problem.

Students choose to use a bar chart to represent the amount of production over seven days, but the graph presented does not fully reflect the characteristics of exponential growth accurately. This is evident from the use of a horizontal axis that does not follow the convention of a time-to- production growth bar chart, the horizontal axis should be filled by day 1, day 2, and so on and the vertical axis filled with production value. In addition, the graph is depicted with a scale range that appears inappropriate and disproportionate to the student's calculation data, as a result the exponential growth visual becomes dull, or even looks like it is rising slowly and steadily when in fact it should be increasing faster.

Then the student's written interpretation states that the growth occurs "fast and steady every day," which is less in accordance with the true exponential nature, where growth occurs increasingly quickly and is not linear. This indicates that although the student understands that there is an increase in production, he has not been fully able to critically interpret the exponential pattern or relate the graph and calculations back to the context of the problem as a whole. Thus, the main problem lies in the student's limitations in communicating mathematical information into accurate visual representations and contextual narratives.

Students also showed particular difficulties when entering values into formulas, as expressed in their statements.

Subject : *"Sometimes I'm confused about what position x represents, so I try it out until the result is right."*

At the stage of interpreting and communicating results, students can explain part of the process but not in depth.

Researcher : *"What about the graph you made? What were your steps in drawing it?"*

Subject : *"I made a graph based on the calculation results only. However, I only plotted a few important points, such as day 1 and day 5. I didn't pay much attention to the overall shape of the graph."*

Researcher : "From the graph you created, what can you conclude about the exponential growth pattern?"
Subject : "The graph shows a steady increase in growth, but I don't really understand why it is like that. Maybe because the growth factor is more than 1."

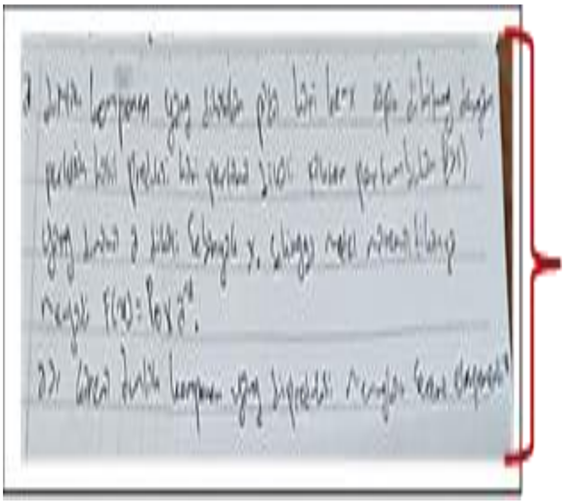
Students also showed that the process of evaluating their work was not yet fully optimal. When the researcher asked,

Researcher : "How do you evaluate the results of your work? Do you feel confident with your answers?"
Subject : "I usually see if the end result makes sense, but sometimes I forget to check the process in detail. If I have more time, I like to ask a friend to make sure."

Overall, the main problems experienced by students with moderate Self-Regulated Learning include difficulties in understanding the meaning of context, inaccuracy and imprecision in constructing graphs, and limitations in explaining mathematical relationships descriptively. Although students already have the awareness to solve problems independently, suboptimal self- regulation has an impact on their ability to integrate mathematical understanding, strategies, and communication as a whole. This reinforces that mathematical literacy does not only rely on procedural knowledge, but requires integrated reflective, representative, and communicative thinking skills.

3.1.3 Students with Low Self Regulated Learning (R1)

The following are the result of the students answers with low self regulated learning,



Formula, namely formulating real problems mathematically

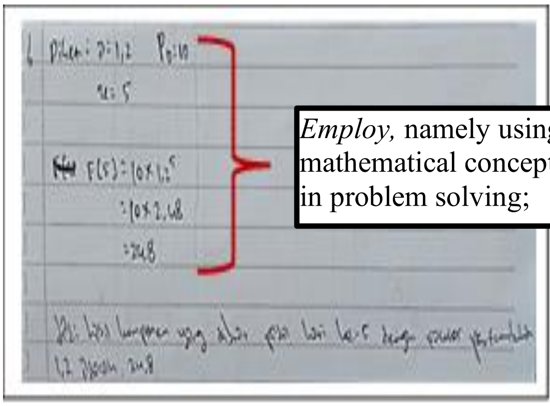
The number of components produced on day x can be calculated by multiplying the production results of the first day by the growth factor $a > 1$ where a is multiplied by x, so that the mathematical model becomes $F(x) = P_0 \times a^x$. $a > 1$ because the number of components produced increase exponentially.

Figure 9. Subject R1's Answer.

Based on Figure 9, the results of students' work that are included in the low Self-Regulated Learning category, there are a number of problems in mathematical literacy skills. In the formula aspect, students have indeed mentioned basic parameters such as the initial value of production ($P0$=10) and growth factors (a=1,2), and tried to determine the number of components on the 5th day. However, students were unable to formulate a mathematical model in a complete and contextual manner. Model(x) = 10·(1,2)^X used without any explanation regarding the reasons for its selection or its relevance to the context of the motorcycle component production problem. This shows that students have not been able to relate real situations to mathematical models in a meaningful way.

Based on interviews with students, it appears that they still need more time to understand the context of the problem and identify important information such as initial values and growth factors. This indicates that students need a more systematic strategy in understanding the problem. The following is a transcript of the interview between the researcher and subject R1.

Researcher : *"What was the first thing you did when you saw the question?"*
Subject : *"I read the questions first, but sometimes I'm confused about which information is important. So I try to find the initial numbers and growth factors, but it takes time to be sure."*



Employ, namely using mathematical concepts in problem solving;

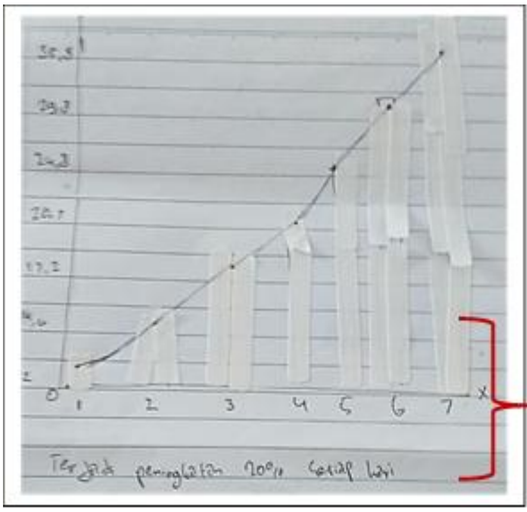
Known:
$a = 1{,}2 \quad P_0 = 10$
$x = 5$
$f(5) = 10 \times 1{,}2^5$
$= 10 \times 2{,}48$
$= 24{,}8$
So, the result of the component made on the 5th day with growth factor of 1,2 is 24,8.

Figure 10. Subject R1's Answer.

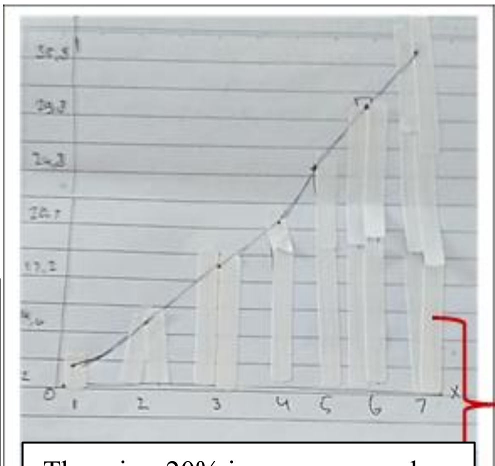
Based on Figure 10, in the aspect of applying the concept (employ), students use the given exponential formula and calculate the value of f(5) = 24. Students also appear to have a fairly good procedural understanding in calculating the value of the exponential function from day 1 to day 7. However, striking problems are seen in the application of the concept to the form of a graph. The graph drawn appears disproportionate and inaccurate, both in terms of scale and placement of data points. As a result, the graph that should show exponential growth actually appears almost linear. Furthermore, although students write that there is an increase of "20% every day", which corresponds to the growth factor value of 1.2, there is no further explanation regarding how this information reflects the overall exponential growth pattern. This indicates limitations in understanding the concept of growth ratio and connecting it visually and verbally.

In applying the exponential concept, students are able to use the appropriate formula but are not yet fully systematic in the solution steps.

Researcher : *"After understanding the problem, how do you determine the steps to solve it?"*
Subject : *"I immediately used the formula f(x) = P₀.aX that was taught, but sometimes I forget to check whether the numbers I use are correct. So I recalculate to make sure."*



Interpret, namely reinterpreting mathematical results, solutions, or conclusions into the context of the problem.



There is a 20% increase every day.

Figure 11. Subject R1's Answer.

Based on Figure 11, in the aspect of interpreting and communicating results (interpret), students do not provide meaningful explanations of the mathematical results obtained. The written explanation is limited to one short sentence that is not yet able to express the relationship between mathematical results and the real context in the problem. There is no attempt to explain the impact of growth on production activities in the workshop, or how the growth pattern can be used for planning purposes. In addition, there is no reflection on the suitability of the graph with the calculation or the possibility of inaccuracy in the visualization.

In addition, students experienced confusion in placing the value of x in the formula, which caused them to try several approaches before finding the appropriate answer.

In the aspect of interpreting and communicating results, students can explain most of the process but not in depth.

Researcher : *"What about the graph you made? What are the steps in drawing it?"*
Subject : *"I plot important points, like day 1 and day 5, but don't pay much attention to the overall shape of the graph."*

Researcher : *"From the graph you created, what can you conclude about the exponential growth pattern?"*
Subject : *"The graph keeps going up, but I don't really understand why it looks like that. Maybe because the growth factor is more than 1."*

Students also indicated that the process of evaluating their work was not yet fully optimal

Researcher : *"How do you evaluate your answers? Are you confident with the results you get?", the student answered, "I usually see if the final result makes sense, but rarely check the process in detail. If I have more time, I like to ask my friends to make sure"*

Overall, the problem of mathematical literacy of students with low SRL levels lies not only in the procedural aspect, but more in the inability to understand, represent, and communicate mathematical concepts contextually. Table 2 presents a comparison for student with high, medium and low Self regulated Learning,

Table 2. Comparison of Mathematical Literacy Across High, Medium, and Low SRL Levels

Aspect	High SRL (T1)	Moderate SRL (S1)	Low SRL (R1)
Problem Formulation	No difficulties; able to formulate mathematical models with clear reasoning.	Able to formulate problems but less optimal in explaining the mathematical model in depth.	Identifies basic parameters but fails to relate real situations to relevant mathematical models.
Concept Application	Systematic in calculating, visualizing data, and explaining changes quantitatively and qualitatively.	Uses the correct formula but lacks systematic steps and does not validate the results.	Uses basic formulas but struggles with solution steps, leading to often inaccurate results.
Result Interpretation	Explains results in-depth and relevant to the context but lacks accuracy in graphical representation.	Able to conclude results but inaccurately represents exponential patterns in graphs.	Limited explanation and fails to connect mathematical results to real-world contexts meaningfully.

Aspect	High SRL (T1)	Moderate SRL (S1)	Low SRL (R1)
Interview Conclusions	Demonstrates reflective and independent learning strategies; step evaluation is well executed.	Aware of weaknesses but learning strategies remain partial, and result evaluation is suboptimal.	Passive learning strategies, less reflective, and often reliant on others for result validation.
Main Issues	Inaccuracy in graph scaling and mathematical visual interpretation.	Difficulty in understanding problem context and selecting appropriate solution strategies.	Poor understanding of problem context, disproportionate graph representation, and limited reflection and communication.

3.2 Discussion

Based on the analysis of the research data and the comparison in the Table 2, it was found that students in the high self-regulated learning (SRL) category did not experience significant difficulties in understanding the context of the questions, formulating problems, determining solution strategies, and logically interpreting the results in ways relevant to real life. This indicates that students with strong self-regulation skills tend to manage their learning process independently, from planning and implementation to evaluating outcomes, which contributes to a better mathematical literacy process. This finding aligns with the theory put forward by Zimmerman (2002), which defines SRL as comprising metacognitive, motivational, and strategic behavioral processes that interact to support academic success. In the context of mathematics education, these abilities positively impact students' capacity to understand concepts and apply them in real-world situations.

Similarly, Aripin et al. (2024) found that students with high SRL were capable of accurately and carefully solving PISA-based contextual problems. These students demonstrated a clear understanding, unit conversion skills, and logical interpretations. They also applied effective problem-solving strategies, such as identifying irrelevant information and selecting optimal solutions in real-life scenarios like smartphone storage. In the same vein, Kholifasari et al. (2020) showed that students with high learning independence performed well in mathematizing and representing real-world problems, although some still faced challenges in reasoning and argumentation.

These results are corroborated by Tuti et al. (2025), who found that students with high SRL levels reached level 5 in mathematical literacy competency. These students were able to identify relevant information, apply appropriate mathematical procedures, and reflect critically on their solutions within various geometric contexts. Their high level of self-regulation enabled them to carry out multi-step reasoning and represent real-world problems mathematically with accuracy and coherence, further demonstrating the integral link between SRL and mathematical literacy.

On the other hand, students with moderate SRL exhibited several obstacles, particularly in understanding contextual problems and selecting appropriate solution strategies. Their thinking processes tended to be fragmented, and their ability to monitor and reflect on their solution steps was still limited. Santika and Khotimah (2023) observed that students frequently struggled at the problem formulation and interpretation stages when solving PISA-style problems. These difficulties were linked to limited understanding of contextual information and an inability to choose suitable strategies. This is consistent with Aripin et al. (2024), who noted that students with moderate SRL could understand problem structures and propose relevant strategies but often made careless computational errors or misinterpreted results. Likewise, Kholifasari et al. (2020) emphasized that students with moderate learning independence often struggle particularly in devising problem-solving strategies, especially in algebraic contexts.

The study by Tuti et al. (2025) also confirmed that students with moderate SRL were typically only able to achieve level 4 in mathematical literacy. While they demonstrated a basic grasp of the problem and could apply known procedures, their reflections and strategic flexibility were limited. These students often failed to complete problems that required synthesis, comparison, or abstract reasoning, suggesting that further support is needed to help them transition from routine to complex mathematical tasks.

Similar findings were reported by Mahajani et al. (2024) and Erli Rahmayanti et al. (2024), who concluded that students' mathematical literacy skills are significantly influenced by their level of learning independence. Students with low independence could generally identify problems and draw simple conclusions but had difficulty developing appropriate solution strategies. In contrast, highly independent learners showed mastery across all mathematical literacy indicators, including solving higher-order thinking skills (HOTS) problems in contextual settings. These findings suggest that mathematical literacy is not solely dependent on cognitive ability, but also heavily influenced by affective and metacognitive factors such as learning independence and self-regulation. In the context of 21st-century education, these competencies are crucial for helping students meaningfully understand and apply mathematical concepts to real-life situations (Mahajani et al., 2024; Rahmayanti et al., 2024).

Students in the low SRL category demonstrated difficulties at nearly every stage of the mathematical literacy process, from understanding the problem context and formulating the problem to interpreting the results. These students tended to be passive, lacked initiative in learning, and were less reflective about their mistakes. This finding aligns with research by Nurvicalesti (2021), who stated that students with low SRL levels exhibit limited mastery of mathematical literacy indicators. They often struggle to solve verbal problems and fail to grasp the purpose of the questions. Additionally, low-SRL students are generally unable to find or utilize relevant learning resources, which further impairs their ability to effectively solve context-based problems.

Kholifasari et al. (2020) further noted that students with low learning independence often encounter difficulties in mathematizing and tend to lack operational accuracy, conceptual understanding, and logical reasoning. Aripin et al. (2024) similarly found that although some low-SRL students could identify relevant information, they often failed to convert it into appropriate mathematical representations or complete logical steps in contextual problem-solving tasks.

Supporting these observations, the study by Tuti et al. (2025) revealed that students with low SRL were only able to reach level 3 in mathematical literacy. Their performance indicated a reliance on routine procedures and a struggle with abstract representation and complex reasoning. These students had difficulty transferring knowledge to new contexts and often left tasks incomplete, signaling a need for explicit scaffolding and motivation-focused interventions in mathematics instruction.

These findings reinforce the idea that the ability to organize, monitor, and evaluate the learning process is a key factor in enhancing students' mathematical literacy. Students with strong SRL skills are better equipped to independently understand problem contexts, identify important information, and apply suitable strategies in solving mathematical problems, including those involving exponential or geometric concepts that require deep understanding and real-life relevance. Students who display high levels of SRL are more perseverant and persistent in their learning than students with low levels of SRL (Gabriel et al., 2020).

Based on these insights, the researchers recommend implementing instructional strategies that emphasize the development of self-regulated learning. One effective method is the use of problem-based learning (PBL), as supported by the findings of Friska et al. (2024). In addition to the PBL approach, students' mathematical literacy can be further enhanced through the integration of interactive learning media and the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach. According to Aripin et al. (2024), incorporating technology-based learning tools, such as interactive visual applications and contextual simulations, can help students develop a more concrete understanding of mathematical concepts in real-life settings.

This interdisciplinary approach not only supports the growth of students' learning independence but also contributes directly to improving their mathematical literacy. With structured, real-world problem-based learning supported by strong SRL, students will be better equipped to understand, process, and communicate mathematical information across various contexts, thereby solving problems more effectively and meaningfully.

4. Conclusion

This study confirms that Self-Regulated Learning (SRL) plays a significant role in helping vocational high school students overcome various challenges in mathematical literacy, particularly in solving problems related to exponential material. Mathematical literacy encompasses the ability to formulate, apply, and interpret mathematical concepts in various real-world contexts. Students with high SRL abilities demonstrate better independence in organizing learning strategies, understanding concepts deeply, and evaluating as well as reflecting on their learning processes. These skills make them better prepared to address problems requiring advanced mathematical thinking. The results showed that students with high SRL were significantly more effective in solving exponential problems compared to those with low SRL.

However, this study has limitations, particularly the absence of direct interventions designed to systematically enhance students' SRL abilities. This presents an important opportunity for further research to explore effective strategies for supporting SRL development while simultaneously improving students' mathematical literacy. Examples include the use of interactive digital tools or reflective approaches that encourage students to understand the connections between mathematical concepts and their real-life applications. Furthermore, a more in-depth analysis is required to identify specific SRL indicators that contribute to improving students' abilities to formulate, apply, and interpret mathematical concepts.

Based on these findings, educators in vocational schools are encouraged to implement learning strategies that actively strengthen SRL while supporting the development of mathematical literacy. Context-based learning or the use of interactive media can help students connect mathematical concepts with real-world problems. Additionally, further research is needed to explore other factors influencing SRL development and their impact on mathematical literacy skills in a more comprehensive manner.

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Using Augmented Reality Based LKPD to Improve Mathematics Learning

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Abstract

This study develops a learning medium as a Student Worksheet (LKPD) based on Augmented Reality (AR) to support mathematics learning. The media is available only on Android devices and was developed using the ADDIE (*Analyze, Design, Development, Implementation, Evaluation*) model. Research instruments include interviews, evaluation tests, validation sheets, and student response surveys. Mathematical education lecturers conducted validation, while practicality testing consisted of individual, small-group, and field trials. Data were analyzed both quantitatively and subjectively. The validity results showed a score of 0.78 with the category "at the moment". The practical result indicated that the AR-based LKPD was in the "highly practical" category, with an average score of 4.24 and a completion rate of 83%. Moreover, AR-based LKPD enhanced student engagement, reduced learning fatigue, and improved mathematics learning outcomes. These findings imply that the AR-based LKPD can serve as an innovative alternative in mathematics learning and hold potential for broader implementation to improve the quality of teaching and learning processes.

Keywords: Augmented Reality; Mathematics Learning; Student Worksheets

1. Introduction

All sectors, including Education, are transforming as we enter the digital era. Education is one field that continues to develop along with technological advances. Augmented Reality (AR) is a technology. Artificial intelligence has transformed the way we learn. AR is increasingly important and engaging, and has numerous benefits for students, teachers, and the learning environment. According to Law Number 20 of 2003, Education is a learning process that enables students to actively develop their potential to gain strength, religious independence, intelligence, and noble character. According to Purwaningtyas et al. (2024), Education is activities that develop knowledge and skills through designed learning, both formal and non-formal Education.

Mathematics is an important lesson in school and essential for human activities. Understanding mathematical concepts needs to be taught from elementary school, because learning mathematics involves not only passively receiving information, but also actively involving students in a way (Safari & Rahmalia, 2024). Mathematics learning is also a teaching and learning activity that involves mathematics, making it valuable and relevant to everyday life (Setyo et al., 2020). In the context, ethnomatematics plays an important role as it connects mathematics with culture and community practices, thereby making learning more meaningful. This statement aligns with the opinion of (Rawani & Fitra, 2022) that learning mathematics requires an approach so that its implementation provides effectiveness. Ethnomathematics is a bridge between mathematics and culture. There are different ways of doing mathematics in community activities. Etnomathematics helps students understand that mathematics is not merely an abstract science, but also emerges from daily activities, traditions, and local culture that can be used as a context for learning. Thus, integrating ethnomatematics in mathematics education enriches students' understanding of concepts, fosters appreciation for local wisdom, and makes learning more contextual. Technological advances, especially the internet, greatly assist teachers in creating electronic teaching materials. Teacher skills are a key component in creating engaging teaching materials. The teacher is the most important contributor to the success of their students' learning process, remembering technology development at the right moment (Hariyati & Rahmadyanti, 2022) .

LKPD is a tool that helps learning, which helps students remember and understand what they have learned during the learning process (Ernawati & Nirfayanti, 2021) .According to Firmansyah (2021) ,Student Worksheet (LKPD) are tools to help support and facilitate teaching activities, allowing for effective student interaction. This allows educators to conduct learning more easily, and students will learn to learn independently and master how to complete written assignments. Technology makes learning easier. Because technology can make learning more engaging, it aims to facilitate learning. Therefore, advanced, reality-based learning materials are appropriate and suitable for fostering student interest in learning mathematics.

Prasetya (2024) said Augmented Reality is a technology that develops information rapidly and is used to facilitate the delivery of information virtually. According to Siregar et al. (2024) using AR in learning can increase students' motivation, involvement, and understanding of teaching materials. AR can also display 3D objects and animations as if they were in a real environment. Current teaching materials and learning processes have not changed and are not yet suited to student characteristics (Maskur & Rakhmawati, 2020) .Many educators have not yet adopted technology and still use conventional teaching materials. Therefore, the availability of teaching materials is a key factor in supporting the success of the learning process (Famulaqih & Lukman, 2024) .

AR-based worksheets are an excellent option for optimizing math learning. If images can move to explain the material being studied, as is commonly used in teaching materials, students will be more engaged in learning math. Research in education and AR development has produced positive findings. These results indicate that AR can be used as a learning tool. Most research about augmented reality in education shows that this technology can help education. This is supported by the study of Siregar et al. (2024) who found that the use of learning media augmented reality has a significant impact. A study by Pathorrahman et al. (2024) , found that using AR applications can enhance learning by making it more engaging and enriching students' learning experiences. Explanation. This also agrees with Nurvitasari and Sulisworo (2023) AR-based LKPD can be interesting and motivate students to study mathematics. However, the learning media still used a laptop in that study.

Based on the aforementioned explanation, this study focuses on developing a learning medium in the form of an Augmented Reality (AR)-based worksheet designed to be implemented through Android devices. The selection of Android as a platform is grounded in its wide availability and accessibility for students, making this medium more practical to use in the learning process. The integration of AR within the worksheet provides a more interactive and contextual learning experience, as students are not only engaged with static texts and images but can also directly interact with virtual objects displayed through the application. Accordingly, AR-based worksheets are expected to enhance students' learning interest, strengthen conceptual understanding, and support the achievement of more optimal learning outcomes, particularly in mathematics, which is often perceived as abstract and difficult to comprehend. SMP LTI Igm in Palembang, South Sumatra.

2. Method

The research location was SMP LTI Igm in Palembang, South Sumatra. The study was conducted by ninth-grade students, as many as 18 at SMP LTI Igm. This type of research uses research and development methods. *Research and development* methods are used to produce specific products and test the effectiveness of these products (Sudaryono, 2016).

The procedure used in this study is the ADDIE development model. The ADDIE model concept is applied to build basic performance in learning, namely, developing a learning product design (Hidayat & Nizar, 2021). The ADDIE model consists of several stages: analysis*, design, development, implementation, and evaluation* (Pribadi, 2014).

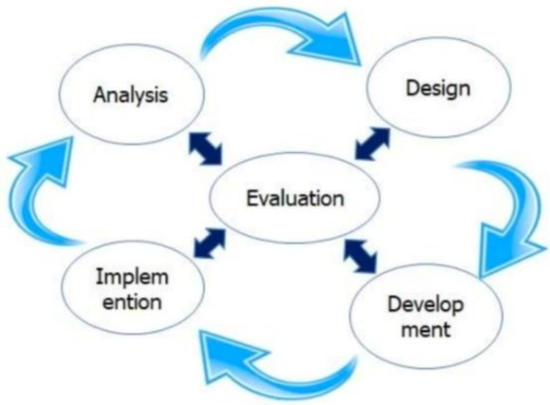


Figure 1. Explaining the ADDIE development model (Dwitiyanti et al., 2020).

In the analysis phase of this research, the researchers analyzed the materials, curriculum, and student needs. They then began developing research instruments and product designs during the design phase. The product was created, validated, and formatively modified in the development phase. Next, implementation and evaluation took place.

Validation sheets collect data on a medium's feasibility and the teaching materials' design. In this case, LKPD is using *augmented reality.* The following is a grid of validation sheets tested in this study. Table 1 shows the LKPD validation sheet, which is designed based on four aspects, namely content and presentation, language, appearance, and usefulness. The content and presentation aspects include indicators of suitability and completeness of the material. Aspects of the accuracy of the text with the material. Aspects of the display include attractiveness, design accuracy, color, font, and image suitability. Practical aspects include ease of use, support of teaching materials for student learning independence, ability to increase learning motivation, and ability to increase knowledge and broaden students' horizons.

Table 1. LKPD Validation Sheet Grid

Aspects	Indicators
Contents & Presentation	Conformity of the material with SK, KD, and indicators The material presented is in line with the learning objectives Material completeness Ease of understanding sample questions Collapse of material presentation Presentation support
Language	Appropriateness of writing and use of letters Straightforward (accuracy of sentence structure and effectiveness sentence) Communicative and motivating sentence structure for students Language suitability with the thinking level of students Ability to encourage participants' curiosity Educate Accuracy of text with material
Display	Early view appeal Display design precision Color and font selection Compatibility between stories, images, and materials.
Benefits	Easy to use Teaching material support for participants' learning independence Educate The ability of teaching materials to increase motivation Learn The ability of teaching materials to increase knowledge and broadening learners' horizons

Source: adopted and modified (Batubara, 2023)

In addition to finding out whether the augmented reality application media is valid, a validation sheet has been prepared. The following is the grid for the Augmented Reality application media validation sheet.

Table 2. Augmented Reality Application Media Validation Sheet Grid

Aspects	Indicators
System Quality	Functionality
	Efficiency
Display Design	Consistency
	Color Usage
	Use of Icons
Augmented Reality	3D Objects
	User Interaction with AR

Table 2 shows the AR media validation sheet compiled based on three aspects, namely system quality, display design, and *augmented reality*. The quality aspects of the system include indicators of functionality and efficiency. The design aspect of the display includes the consistency of color and icon use. Aspects of Augmented Reality include 3D objects and user interaction with AR.

Next, the evaluation test question will be validated to determine whether the questions are valid. The following is a grid for the evaluation test question sheet.

Table 3. Evaluation Test Question Validation Grid

Aspects	Indicators
Content (Content)	Suitability of evaluation techniques with learning objectives
	Instrument equipment
Construction Questions	Presence of instructions
	Clear questions and demand answers
	Variety of questions
	Clarity of images and writing
Augmented Reality	Accuracy of sentence writing
	Appropriateness of language use

Source: Suhardi (2022)

Table 3 shows the validation sheet of the evaluation test questions, which are arranged based on three aspects, namely content, question construction, and language. The content aspect (content) includes the suitability of assessment techniques and the completeness of the instrument. The construction aspect of the question includes the presence of instructions, clear question words, variation of the question, and the image's clarity. The linguistic aspect includes the accuracy of sentence writing and the appropriateness of language use.

The questionnaire given to students allows us to evaluate students' responses to the teaching materials that have been developed. The grid of questionnaire instruments can be seen in Table 4 below:

Table 4. Questionnaire Sheet Grids

Aspects	Indicators
Uses	The use of these teaching materials makes learning more attractive and more effective
	The use of these teaching materials can increase knowledge
Ease	Teaching materials present the material clearly and easily understood
Satisfaction	The teaching materials presented are interesting and fun
	Teaching materials are used according to expectations
Attraction	The design of teaching materials is interesting and adaptive (has high adaptability to the development of knowledge and technology)
	Contains illustrations, pictures, explanations that are in harmony with material

Source: Adopted and modified (Batubara, 2023)

Learning materials support the learning process, making learning more engaging and compelling, and enhancing students' knowledge. The content is presented clearly and efficiently, enabling learners to grasp concepts more effectively. Furthermore, the materials provide satisfaction by offering an enjoyable learning experience that aligns with users' expectations. With an attractive design adaptive to the development of science and technology, as well as illustrations and images consistent with the subject matter, the learning materials possess strong appeal and contribute to improving students' motivation and comprehension.

Interviews with students are conducted after the trial stage of teaching materials to support the data on the practicality and potential effects of the developed teaching materials, as well as a final evaluation for improving the teaching materials developed based on comments and suggestions provided by students.

The test instrument is used to determine the level of students' mastery of the learning materials that have been provided with the teaching materials that have been developed, as well as to find out the potential problem-solving effects of the products that have been developed. The test instruments provided were in the form of 5 written test questions.

Data analysis techniques for validation sheets are given to experts using data obtained in the form of qualitative and quantitative data. Qualitative data is in the form of suggestions and comments given by experts, while quantitative data is in the form of data from the Likert scale assessment. Quantitative data uses *the Likert* scale with an assessment score that can be seen in Table 5.

Table 5. likert Scale Assessment Score

Answer	Score
Strongly agree	5
Agree	4
Enough	3
Disagree	2
Strongly Disagree	1

Source: Sugiyono (2016)

Based on the table above, if the validator gives a very agreeable answer, the result of the score is 5. Agreeing will be given a score of 4, it is enough to be given a score of 3, disagreeing will be given a score of 2, and strongly disagreeing will be given a score of 1. After scoring using the Likert scale, the next step is to categorize the level of validity. Here is a table of validity categories.

Table 6. Validity Categories

Validity Value	Validity Categories
$0 \leq V < 0.4$	Low Validity
$0.4 \leq V < 0.8$	Medium Validity
$0.8 \leq V \leq 1$	High Validity

Source: Istiqomah et al. (2021)

Based Based on Table 6 above, the researcher set the teaching materials' validity target to have a medium validity category in this study. If the teaching materials developed have a low validity category, then the teaching materials will be revised again to reach the medium validity category.

The analysis in the practicality questionnaire is qualitative and quantitative. Qualitative data is in the form of suggestions and comments provided by experts; on the other hand, quantitative data is in the form of data from the results of the Likert scale assessment. It can be seen from a practicality criterion, which can be seen in Table 7.

Table 7. Practicality assessment criteria

Achievement Rate	Categories Practicality
$3.25 < \bar{X} \leq 4.00$	Very Practical
$2.50 < \bar{X} \leq 3.25$	Practical
$1.75 < \bar{X} \leq 2.50$	Impractical
$0 < \bar{X} \leq 1.75$	Very Impractical

Source: Kolo & Muh. (2021)

From Table 7 above shows that teaching materials with *augmented reality technology* are considered practical if they meet the minimum practical criteria and the average score is below 2.50. Furthermore, the analysis of the interview data was carried out by converting the interview results into the form of interview transcripts. Then, after the data is analyzed, it is presented as a discussion.

The students' ability test results will be assessed to determine the potential effects of the developed product. The product developed is considered to have potential if students can achieve a minimum completeness score of 70, and the total percentage of students who pass the required completeness is 70% (Ulfah et al., 2022). Here is a table of completeness categories.

Table 8. Completeness Categories

Interval	Category
$85 \leq H \leq 100$	Very High
$70 \leq H < 85$	High
$55 \leq H < 70$	Keep
$40 \leq H < 55$	Low
$0 \leq H < 40$	Very Low

Based on table 8, if the score falls within the range of 85-100, it is categorized as "Very High", if it is within 70-84, it is considered "High", if it is within 55-69, it belongs to the "Keep" category, if it is within 40-55, it is classified as "Low", and if it is within 0-39, it is categorized as "Very Low".

3. Results and Discussion

3.1 Results

3.1.1 Analysis stage

This analysis stage aims to identify information about mathematics learning, student needs, and any difficult-to-understand material. This analysis is necessary to develop media based on student needs. According to an interview with a math teacher, students still rely on math textbooks and LCD projectors to support their learning. However, these learning media reduce student interest due to the lack of engaging learning.

Initial survey results conducted by the researchers indicated that students expected enjoyable learning. Furthermore, when questioned about the material, students reported a lack of understanding of similarity-related issues. Similarity is a mathematical concept, specifically geometry, which studies the relationships between different shapes and sizes.

Based on the needs analysis and discussions with mathematics teachers, the development of teaching materials focused on creating media to enhance student interest and learning outcomes. Therefore, it was decided that Augmented Reality-Based Student Worksheets (LKPD) were the appropriate teaching materials.

3.1.2 Design Stage

The design stage is the planning stage. Researchers undertake two steps at this stage: developing research instruments and designing the product. Before the teaching materials are implemented with students, they are first evaluated by a validator to determine the validity of the Student Worksheets (LKPD). This instrument uses four aspects: content and presentation, language, appearance, and usability.

After the teaching materials were declared valid, the student worksheets (LKPD) were piloted with students to determine their practicality. They used a questionnaire of four aspects: usefulness, ease of use, satisfaction, and attractiveness. Interviews were also conducted to support the practicality data. To determine their potential impact, researchers administered an evaluation test to students.

The first step in product design is creating a paper-based initial design for the activities included in the LKPD. The second step is AR design, starting with determining the application to create 3D objects and the application to display the AR. The following are the materials needed to complete the application development.

a. Unity Engine 2021 for app creation
b. Vuforia for creating markers, databases, and licenses
c. SketchUp for 3D object creation

The final stage in the design process is designing the Sheet Work Participant Educate use application using Canva. In the first section, the researcher explains the learning objectives, instructions for using the Student Worksheet (LKPD), core competencies, basic competencies, and competency achievement indicators.

3.1.3 Development Stage

The development phase consists of several stages: product creation, validation, and formative revision.

a. Product Creation

The product creation phase involves several steps. First, the researcher creates AR media. The researcher creates a 3D object using the SketchUp application. The following image shows a 3D object in SketchUp.

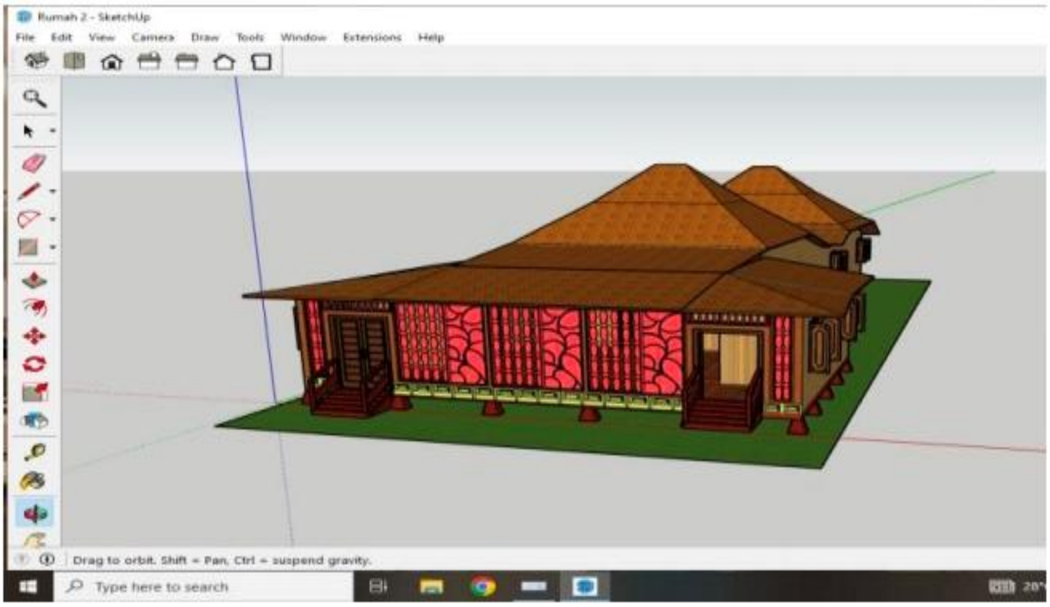
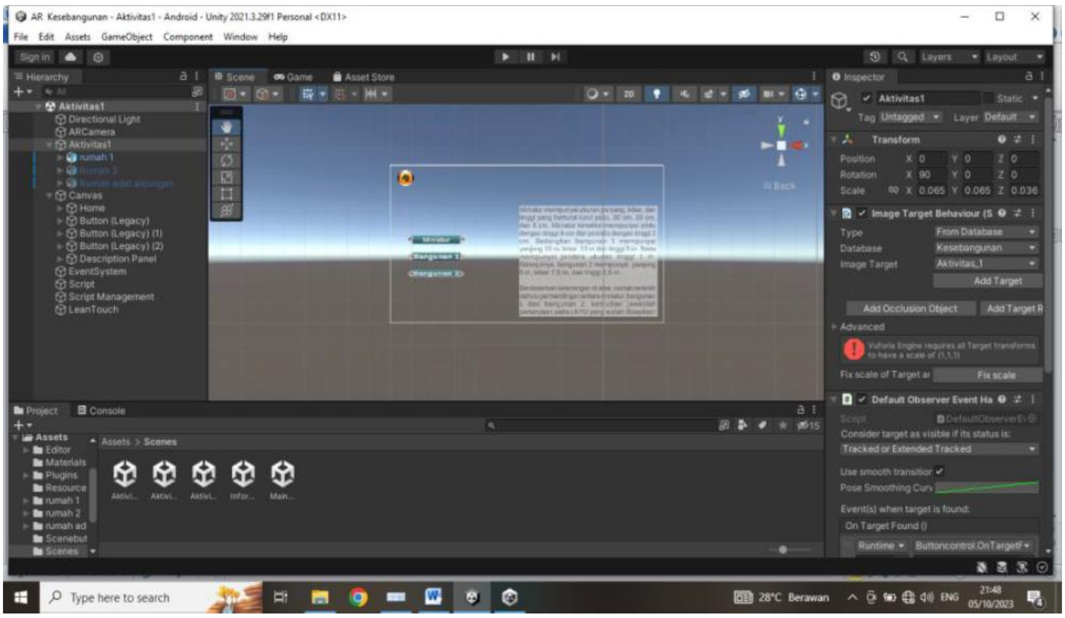


Figure 2. 3D Object View in Sketchup

Next, the 3D objects are imported into the Unity application. Before creating an application in Unity, researchers must obtain a Vuforia license, which will be integrated into Unity. To create an application in Unity, researchers must create a main menu scene and a game scene to display the 3D objects. Then, they program or code the application to get it up and running. Below are screenshots of the scenes and code in Unity.



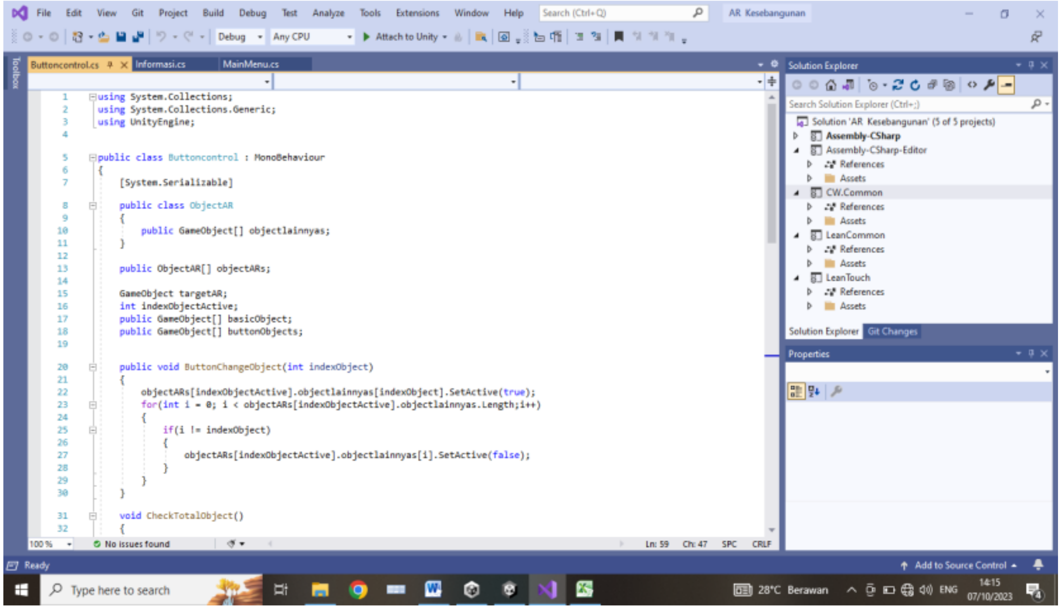


Figure 3. Screenshots of the scenes and code in Unity

b. Product Validation

After creating the teaching materials, the researchers validated them with three expert validators. The validators were selected based on their expertise in their respective fields. Two material experts from the Mathematics Education Study Program served as LKPD validators, and one media expert from the Information Systems Study Program served as the AR application validator. The table below displays the validation results from these experts.

Table 9. Analysis of Expert Validation Results

Validator	Score	Category
Subject Matter Expert 1	0.78	Medium Validity
Subject Matter Expert 2	0.76	Medium Validity
Media Expert	0.8	High Validity
Average score	0.78	Medium Validity

Based on Table 6, the validation results indicate that the evaluation by Subject Matter Expert 1 obtained a score of 0.78, while Subject Matter Expert 2 obtained a score of 0.76. Both sroes fall into the “Medium Validity” Category, suggesting that the material aspect is feasible, although further refinement is still possible. Furthermore, the evaluation by the Media Expert resulted in a score of 0.80, categorized as “High Validity”, indicating that the media aspect is considered highly feasible and supportive of successful learning. Overall, the average validation score was 0.78, classified in the “Moderate Validity” category, which implies that the developed product is suitable for use in the learning process while still allowing opportunities for quality improvement.

One-on-One Test

This face-to-face trial assessed the practicality of the developed LKPD product. The trial was conducted at this stage on six ninth-grade students with high, medium, and low abilities. These students were selected based on their final exam scores.

After the LKPD was piloted, a questionnaire was completed to assess the practicality of the teaching materials. During the individual pilot test, one student commented that using AR-based teaching materials made learning more engaging, but some information in Activity 3 was unclear, making it difficult to understand. The researcher will then make improvements based on the comments and suggestions received during the individual pilot test.

Figure 5. One-on-One Trial

Small Group Test

The small-group trial refined the previous stage, the one-on-one trial. The small-group trial was conducted with nine ninth-grade students based on applicability, appeal, and effectiveness. At this stage, the researcher explained that the developed worksheets were relevant to real-world contexts. The researcher interacted directly with the students and identified difficulties using the teaching materials, which would inform subsequent revisions.

Figure 6. Small Group Trial

During small-group testing, a student commented that their 3D object drawings tended to shift independently and not stay in place. Therefore, the student suggested that the 3D objects should stay in place and not move independently. The researchers will use these suggestions and comments to make improvements.

Field Test

At this stage, researchers will test the practicality and potential impact of using Sheet Work Participant Educate for the subject Research. The LKPD will be piloted on 18 ninth-grade students. However, this field trial will be conducted online due to the implementation of online learning for students in the Palembang area.

After the LKPD was tried out, several students thought that using AR-based LKPD makes Sheet Work Participant Educate more interesting because it can visualize 3D objects. Some students also stated that they could use the worksheet independently, but sometimes they also needed guidance to complete the tasks listed in the worksheet. The following table shows the results of the questionnaire data analysis regarding the AR-based worksheet's feasibility.

Table 10. Analysis of Practicality Questionnaire Results

Level	Score	Category
One on one	4.03	Very Practical
small group	4.36	Very Practical
Field test	4.34	Very Practical
Average score	4.24	Very Practical

The individual trial scored 4.03, while the small group trial scored 4.36. The field trial scored 4.34, resulting in an average practice questionnaire score of 4.24, categorized as very practical based on these three stages. In other words, this augmented reality worksheet is suitable for mathematics learning.

Next, we examined the evaluation test data from this study to determine whether the sheet Work in this AR-based study can influence student learning outcomes. Data on student learning completion is shown in the bar chart below.

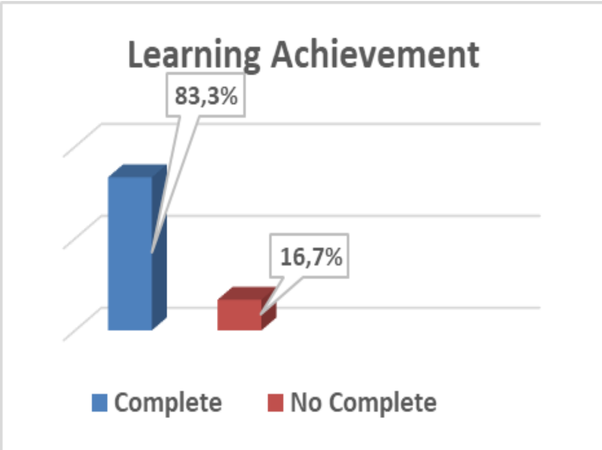


Figure 7. Learning Outcomes.

The The graph above shows that 83.3 % of students completed the evaluation test. However, 16.7% of students were declared ineligible to take the test. This was because 16.7% of students achieved the Minimum Passing Score (KKM). The developed product is considered to have potential effectiveness if students achieve a minimum passing score of seventy, and the total percentage of students who pass the required passing score is seventy percent. (Ulfah et al., 2022) . This matter show that augmented reality-based LKPD can improve student learning outcomes.

3.1.4 Implementation Stage

After the LKPD product has been tested in the previous stage and deemed practical and potentially impactful, the LKPD is suitable for implementation in a real-life learning environment. The teaching materials are then handed over to teachers for application in the learning process.

In this stage, students use their smartphones to work on AR-based worksheets, while in the previous stage, students only used the group representative's smartphone. Learning using Augmented Reality technology makes students more enthusiastic and involved because AR media can display 3D objects and make it easier to understand the material.

3.1.5 Evaluation Stage

This evaluation stage is carried out to review things related to AR-based LKPD development. Stage: This is done to analyze the strengths and weaknesses of the teaching materials that have been tested. Through the results of the trials, questionnaires, and interviews related to AR-based LKPD with grade 9 students, it can be concluded that AR-based student worksheets (LKPD) have practical value and the potential to impact student learning outcomes. This is because AR can display 3D objects in real time, making it easier for students to understand the concept of similarity and making the learning process more engaging and less boring.

Based on observations during the implementation of the AR-based worksheet, they found that it could not be implemented on devices other than Android. Students using iOS devices could not access the AR contained in the worksheet. This was a weakness of the AR-based worksheet they had developed.

3.2 Discussion

Augmented reality-based teaching materials are said to be engaging because they can directly display 3D objects. This is done using the context of the limas house, a traditional house and culture from South Sumatra. The cohesion between mathematics and culture is known as ethnomathematics. (Wulanda & Widiyasari, 2024). Thus, through AR-based LKPD sheets in the context of the Limas House, students can learn mathematics while learning about South Sumatra's culture and traditional houses. This aligns with research conducted by Sulfayanti et al. (2022) which states that by integrating the Limas House as a South Sumatran culture in learning, it is hoped that students will understand mathematical concepts and appreciate their ancestral culture and heritage. Gustina et al. (2025) also said combining AR and ethnomathematics deepens students' reasoning and encourages meaningful and culturally relevant learning experiences.

AR-based worksheets will help students understand the concept of similarity because they display a Limas House in 3D and directly. The use of teaching materials has a significant impact on the learning process. Students often struggle to grasp the concepts and problems presented because they lack a concrete context, leading them to simply imagine the context without directly seeing it. This aligns with the findings of Fauzi and Arisetyawan (2020). that the difficulties of learning mathematics are conveyed in an informative manner, meaning that students only get information from the teacher's explanation.

AR-based student worksheets (LKPD) support students' understanding of concepts and problems. This is because the application of AR technology in learning can display virtual objects projected into the real world. This statement aligns with Safari and Sabila's (2024) statement that learning using visual aids such as 3D objects allows students to connect abstract concepts with real-world situations. Omurtak and Zeybek (2022) also concluded that students enjoy using AR applications because AR applications make abstract concepts tangible and make learning more enjoyable.

This augmented reality-based teaching material can be accessed using a smartphone. 3D objects will appear on the smartphone screen after scanning the barcode on the worksheet. This allows students to access AR using their smartphones without working in groups. However, in this study, Nurvitasari and Sulisw632oro (2023) found that AR operations in learning still use laptops.

AR media is crucial in mathematics for presenting complex concepts. Students enjoy completing activities in worksheets and following instructions throughout the learning process. AR methods can enhance students' specific abilities while producing better learning outcomes than conventional methods (Velazquea & Mendez, 2021) . Some students, who see 3D objects appear through AR technology, immediately understand the instructions and complete the worksheets, but others remain confused. Maximizing the benefits of AR for students in learning mathematics requires a more wide-ranging approach in its implementation (Gusteti et al., 2023) .

Students' progress in learning to solve problems independently has been enhanced through the use of Sheet Work participant, an Augmented Reality-based participant. AR allows mathematics to be taught contextually and interactively, increasing student engagement and understanding (Estapa & Nadolny, 2022) . Furthermore, research results show that students prefer to participate in augmented reality-based worksheets during the learning process. AR makes learning more engaging and effective. Students are enthusiastic about learning because AR technology can display 3D objects in the real world.

The results of the student evaluation test showed an increase in the percentage of student learning achievement scores after using LKPD, which indicates the potential impact of LKPD based on Augmented Reality. This is also in line with the study by Darmansyah et al. (2024) which states that the use of AR media has a positive and significant influence on improvement results in student studies on eye science lessons for class VIII. Ikmawati et al. (2024) also studied the use of Augmented Reality in mathematics subjects, including nets of cubes and cuboids, which has been demonstrated. AR media supports learning outcomes, with students' average grades increasing from 70 to 85. Therefore, several studies have shown that using Augmented Reality media in the learning process can improve student interest and learning outcomes. This is because AR makes learning more engaging and easier to understand.

4. Conclusion

This study successfully developed a Student Worksheet (LKPD) based on *Augmented Reality* (AR) using the enthnomathematic context of the limas house for teaching the concept of similarity. The findings indicate that the developed product meets the criteria of validity, demonstrates a very high level of practicality, and shows effectiveness through its potential effect on students' mastery of learning outcomes. These results highlight that integrating AR with ethnomathematics as an LKPD can provide students with a more contextual, interactive, and meaningful learning experience.

The novelty of this research lies in the combination of three aspects: the use of AR technology, the integration of the Limas House as a representation of local cultural ethnomathematics, and its implementation on the Android platform. This combination enriches mathematics learning resources and demonstrates that culturally grounded and technologically supported learning media can be innovative alternatives to improve students' interest and understanding of mathematics.

Nevertheless, this research has several limitations. The product is only accessible on Android-based devices, limiting its use across other platforms such as iOS. In addition, the AR features occasionally face technical instability, which may disrupt the learning process. The scope of the material is also restricted to the concept of similarity, and the study was conducted only at the Grade IX Junior High School level, making it less generalizable to other educational contexts.

Future research is recommended to expand the coverage to other mathematics topics, such as solid geometry or algebra, and to develop compatibility with multiple platforms, including iOS. Further trials should also be conducted at different educational levels, such as elementary and senior high schools, to test its effectiveness across various stages of student development. Improving the technical stability and responsiveness of the AR system is also essential to enhance accessibility and usability for teachers and students. This study provides a foundation for developing innovative learning materials that combine modern technology with local cultural wisdom in mathematics education.

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Development of Module Based on Higher Order Thinking Skills on Cylinder and Cone Matter

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Abstract

This study aims to develop a valid, practical, and effective Higher Order Thinking Skills-based learning module on Cylinders and Cones for SMP NU Sumenep seventh-grade students. This type of research is research and development with the ADDIE model (Analysis, Design, Development, Implementation, Evaluation). Data were collected using tests and questionnaires. Material and media experts validated the results. The results of the study show: 1) the validity aspect obtained an average of 87.5% with the criteria of "very good", 2) The practicality aspect seen from student assessments after using the learning module, obtained an average of 84.5% with the criteria of "good", 3) The effectiveness aspect seen from the results of students' mathematical problem-solving abilities, obtained an average of 76% with the criteria of "good". Based on the study results, we can conclude that the learning module related to cylinders and cones is suitable for use in learning because it has met three criteria: valid, practical, and effective. The HOTS-based learning module, especially about cylinders and cones, is expected to increase students' curiosity about the material, which can indirectly also improve students' understanding.

Keywords: Cylinder and Cone Material; Development of Learning Modules; High Order Thinking Skill; Research and Development

1. Introduction

Education plays an important role in improving the quality of human resources to compete in the era of the Industrial Revolution 4.0. In Indonesian education, the government often changes curricula to improve the quality of education. The curriculum is one of the determinants of educational success because it is a guideline for educators in implementing learning (Rahayu et al., 2023). Therefore, the curriculum needs to be developed dynamically according to the demands of the times (Ananda & Hudaidah, 2021).

Fulfilling the needs of the education system in the Industrial Revolution 4.0 era, the Ministry of Education and Culture has launched Merdeka Belajar. Merdeka Belajar is a step towards educational transformation that is presented as the policy and strategic direction of the Ministry of Kemendikbud RI, which is stated in the 2020-2024 strategic plan. Merdeka Belajar is expected to be a transformative educational step towards realizing superior Indonesian Human Resources (HR) with a Pancasila profile.

Implementing the Merdeka curriculum changes the learning system from teacher-centered to student-centered. Student-centered learning will train students to think critically in learning and problem-solving (Suatini, 2019). In addition, the Merdeka curriculum also emphasizes students' ability to observe their surroundings in the learning process, which requires students to be accustomed to solving problems and making the best solutions based on their knowledge (Tuerah & Tuerah, 2023). This concept is very suitable for the Higher Order Thinking Skill (HOTS) pattern because the Merdeka curriculum includes many things, including differentiated learning, focus on problem solving, flexibility in learning, HOTS-oriented assessment, and character development, so that the Merdeka Curriculum and HOTS complement each other and support educational goals. The Independent Curriculum, initiated by the Minister of Education, Nadim Makarim, allows educators to manage classes and allows students to explore and develop their critical thinking skills (Majidah et al., 2024). Students who are accustomed to exploring and practicing critical thinking skills will gradually become accustomed to high-level thinking.

According to Resnick (In Zebua, 2024), higher-order thinking skills involve basic mental activities such as describing, building representations, analyzing, making conclusions, and making relationships between two or more quantities. Integrating HOTS in learning is the key to preparing students who can think critically and creatively and solve problems (Zebua, 2024). The main goal of HOTS is to improve students' ability to think critically and creatively in processing the information obtained and applying it in problem solving using the knowledge they have and making decisions in complex situations so that they can face various challenges that occur in an increasingly sophisticated and modern era (Tasrif, 2022). We can say that HOTS refers to more complex thinking skills, which go beyond simply memorizing facts or understanding basic information. HOTS involves the ability to analyze, evaluate, create, or organize.

Supporting factors are needed to achieve high-level thinking skills, such as learning devices or media that support the implementation of HOTS-based learning, one of which is a learning module. The mathematics learning module strongly supports students' higher-order thinking by encouraging them to think critically and creatively, facilitating independent and reflective learning, and providing problem-based activities and real projects. A module is a unit of teaching material containing materials, methods, and evaluations systematically designed to achieve the expected competencies (Chuseri et al., 2021). The modules are arranged systematically and adjusted to the characteristics of students, which contain learning materials, student activity sheets, and practice questions. The existence of modules allows students to explore knowledge, learn independently, and minimize teacher assistance so that they can indirectly control and assess their abilities in learning (Andryani & Kurniawati, 2023). The module in this study is HOTS-based and related to the material on cylinders and cones.

One of the reasons why HOTS-based learning has not been implemented is that in the school, learning is still teacher-centered, and students only listen and work on questions. This causes students to be passive, and their high-level thinking skills are not honed. In addition, there are no tools or media to support HOTS-based learning, such as teaching modules. Some teachers still do not fully understand higher-order thinking and how to assess it, which indirectly hinders teachers in implementing HOTS-based learning (Rampean et al., 2022). During learning, teachers and students still refer to textbooks from publishers as the only source of learning (Shalikhah & Nugroho, 2023). To train and develop students' abilities in high-level thinking, there needs to be a teaching module that contains student activities in concept discovery to understand better the material being taught and practice questions to measure their ability to solve problems.

When faced with practice questions taken from textbooks, students still experience difficulties encountering geometry questions on geometric shapes, especially curved sides, which require analytical skills at the application level (C3), meaning that students are still not trained to work on HOTS-based questions. Level C3 or Applying is the ability to use knowledge, concepts, principles, or procedures learned to solve problems or carry out tasks in real or new situations. This means that students not only remember or understand information, but can also apply formulas, methods, or rules, use concepts in practical situations, and carry out procedural steps. It is common for students to find it challenging to solve problems with curved-sided geometric shapes because they have not been able to identify and analyze the problems given (Sitorus et al., 2023). In their research, Agustini & Fitriani (2021) stated that students have difficulty calculating the volume of curved-sided geometric shapes because they have only memorized the formula without knowing how it came from.

If students only memorize formulas, they may forget them later. In addition, when faced with the same concept but the form of the problem is modified, they will find it difficult (Agustini & Fitriani, 2021). This shows that students' understanding is still limited to memorization skills, and they cannot solve problems when faced with questions requiring high-level thinking skills. Thus, mathematics learning about curved-sided geometric shapes must be well-designed to understand the material successfully.

Several studies related to the development of learning modules have been conducted, including the development of realistic mathematics modules integrated with higher-order thinking skills (HOTS) on spatial geometry material (Chuseri et al., 2021), the development of learning modules with a scientific approach to improve students' problem-solving abilities (Sidik & Rumbia, 2021), and the development of problem-based learning modules that can improve students' mathematical literacy (Alayubi et al., 2024). However, this research differs from previous research because it emphasizes developing HOTS-based learning modules on cylinders and cones to train students' critical thinking skills.

The novelty of this research compared to previous research is: (1) Focusing on critical thinking, this module is made based on problem-based learning in which students are trained to think critically and the practice questions are specifically designed to include HOTS; (2) Integration of the PBL model about students' critical thinking focuses on the material of cylinders and cones; (3) The creation of questions is specifically designed to see the extent to which students' critical thinking refers to the indicators of critical thinking according to Facione, namely interpretation, analysis, evaluation, conclusions, explanations, and self-regulation.

Based on the problems above, researchers are interested in developing learning modules that can help teachers develop HOTS-based learning while helping students improve problem-solving skills and understand teaching materials better. Thus, the purpose of this study is to produce HOTS-based learning modules-based mathematics learning module product to improve the problem-solving skills of grade VII students on the material of cylinders and cones in stimulating critical thinking that is oriented towards problem solving and is expected to be a valid, practical and effective learning media in Junior High School NU Sumenep.

2. Method

The research location was NU Sumenep Middle School, Batuan District, Sumenep Regency. The research was conducted from April 15 to May 27, 2023, and involved 8 class VIII students, as many as 25 students at NU Sumenep Middle School, as research subjects. This study uses a research and development (R&D) method that aims to produce new products through the development process. The development model in this study uses the learning module development model according to the ADDIE model (Analysis, Design, Development, Implementation, and Evaluation) (Rayanto, 2020). The ADDIE model is suitable for developing various products, one of which is learning modules (Safitri & Aziz, 2022).

The development procedure in this study is adjusted to the module preparation procedure and the ADDIE model design development procedure. An explanation of the development procedure in this study can be seen in the Table1.

Table 1. ADDIE Model Development Procedure

ADDIE Stage	Activity
Analysis	The analysis stage aims to examine module problems, namely regarding needs analysis, curriculum and student characteristics analysis.
Design	The design stage aims to create a design for the learning module to be developed.
Development	The development stage is the stage of producing learning modules, which includes aspects of product creation and analyzing product trials.
Implementation	The implementation stage is the implementation of the mathematics learning module on curved-sided spatial geometry material to class VII students of SMP NU Sumenep.
Evaluation	The evaluation stage aims to evaluate the activities carried out by researchers. Analyze the practicality and effectiveness of the mathematics learning module that have been validated by a team of experts and has been field-tested.

Data collection methods used in this research were tests and questionnaires. The questionnaire method in this research is a validation questionnaire for mathematics learning modules and student responses. The test was in the form of questions on students' problem-solving abilities. The data collection instruments used in this study were classified into three types to meet the validity, practicality, and effectiveness criteria: a) validation sheet, used to measure the validity of the math learning module. Furthermore, the validation sheet was a questionnaire submitted to expert lecturers and mathematics subject teachers; b) student response questionnaire, used to measure practical aspects. This questionnaire aims to obtain data about students' opinions regarding the use of the module; c) problem-solving ability tests were carried out at the end of learning, using questions to measure the effectiveness aspect. The data analysis technique in this study was validity, practicality, and effectiveness analysis.

3. Results and Discussion

3.1 Results

This research uses the type of *Research and Development (R&D) with products developed in the form of HOTS-based learning modules (Higher Order Thinking Skills*) on the BCSS material, which researchers at SMP NU Sumenep have carried out. The development model used in this study is ADDIE, with the stages *of Analysis*, *Design*, *Development*, *Implementation*, and *Evaluation*. Based on the research and development carried out, the following research results were obtained:

3.1.1 Analysis stage

a. Needs Analysis

The needs analysis aims to identify the fundamental problems in mathematics learning at SMP NU Sumenep. After conducting a needs analysis, it is known that Merdeka Belajar creates a student-centered learning system so that students are expected to be able to think critically. Of course, in its implementation, teaching materials are needed to make students more active in the learning process and support them in the critical thinking process. However, in its implementation, this has not been implemented optimally in the learning process.

Based on what was found in the field, it is necessary to develop teaching materials in the form of learning modules that can facilitate students to be more active in mastering concepts and solving problems in the critical thinking process, following the independent curriculum that refers to the application of the HOTS concept. Based on this, the researcher developed an HOTS-based learning module for the material on curved side space for class VII at SMP NU Sumenep.

b. Curriculum Analysis

The curriculum analysis stage aims to determine the curriculum that applies in schools. In addition, it is known that the material in mathematics lessons can be used as learning modules. At the design stage, the curriculum defines the product design and components in the mathematics module.

c. Analysis of student characteristics

The analysis of student characteristics aims to determine the characteristics of students that are the basis for researchers to compile the modules to be developed. In general, students follow learning activities quite well. Learning using the lecture method makes students less active. Researchers see that students become active only when the teacher gives assignments or questions to be worked on in front of the class. Responding to these conditions, grade VII students of SMP NU Sumenep need teaching materials that can motivate and foster students' enthusiasm for learning independently or with teachers. Based on this analysis, HOTS-based learning modules can be applied to students and are expected to improve students' problem-solving abilities.

3.1.2 Design Stage

a. Preparation of Module Framework

The preparation of the module framework is based on the grade VII mathematics syllabus. The module is arranged into three main parts: the beginning, the contents, and the end. The first section contains the cover, foreword, table of contents, Learning Outcomes and Competencies, learning objectives, study instructions, and a concept map. The second section contains the learning module. The final section contains evaluation questions, a glossary, and a bibliography.

b. Collection and Selection of References

Collecting and selecting references to be used in module development. References are adjusted to the curriculum currently used in class VII of SMP NU Sumenep.

c. Design and Features of Learning Modules

The design and features of learning modules include the beginning, content, and end. The beginning contains 1) Cover, 2) Foreword, 3) Table of Contents, 4) Learning Outcomes and Competencies, 5) Learning Objectives, 6) Learning Instructions, and 7) Concept Map. The content section contains learning modules in the form of activities so that students can find concepts. The content section consists of learning activities, containing learning activities: analysis space, evaluation space, and creation space; examples, exercises, and evaluations, while the end section contains 1) Evaluation questions, 2) Glossary, and 3) Bibliography. The following is a screenshot of each section of the module.

d. Preparation of Learning Module Assessment Instruments

Preparation of learning module assessment instruments includes learning module assessments, student response questionnaires, and problem-solving ability test questions. The preparation of the learning module assessment sheet is made into three types: the suitability of the material content, the suitability of the presentation, and HOTS by the validator. The preparation of test questions is used to determine the effectiveness of the learning module in improving students' mathematical problem-solving abilities. The student response questionnaire was designed to determine students' responses after using the learning module. One type of question used in the student response questionnaire is positive statements.

3.1.3 Development Stage

The development stage aims to produce and assess the extent of the feasibility of the learning module that has been designed. The criteria for a good module that can be used in learning are modules that are systematic, communicative, facilitate independent learning, contextual, train HOTS, and are equipped with evaluation. To find out which learning modules are suitable for use, an assessment is carried out by the validator. After obtaining the feasibility assessment, the learning module is revised according to criticism and suggestions from the validator.

In the research on the development of this learning module, two validators were used, namely the Lecturer of STKIP PGRI Sumenep, Mrs. Kurratul Aini, M.Pd, and the Mathematics Teacher of SMP NU Sumenep, Mrs. Khalishaturrusyd, S.Pd.

a. Creating Learning Modules

b. Product trial analysis.

The trial process of the developed module involved an expert validation stage to assess its quality in terms of content, presentation, and integration of Higher Order Thinking Skills (HOTS). Table 2 presents the results of the module validation based on the average percentage scores for each research aspect, along with their respective categories.

Table 2. Module Validation Results

Research Aspects	Average Percentage	Category
Content Eligibility	88,9%	Very Good
Presentation Eligibility	85,625%	Very Good
HOTS	90%	Very Good
Average	**87,5%**	**Very Good**

Table 2 shows that the quality of the learning modules based on the validator's assessment shows a total average percentage of 87.5%; thus, the module shows Very Good. However, validators' responses, criticisms, and suggestions are also noted.

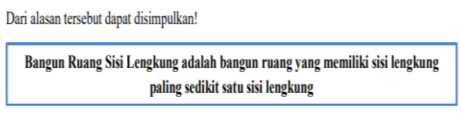
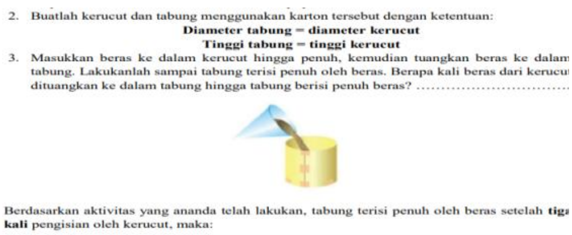
After the quantitative validation process, qualitative feedback was also obtained from the validators to provide more detailed insights into the aspects that needed improvement. This feedback was given in the form of responses, criticisms, and suggestions regarding the HOTS-based BCSS material learning module for mathematics lessons at SMP NU Sumenep. Table 3 presents the complete list of validator comments.

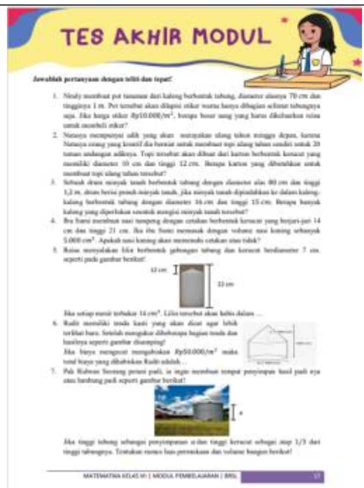
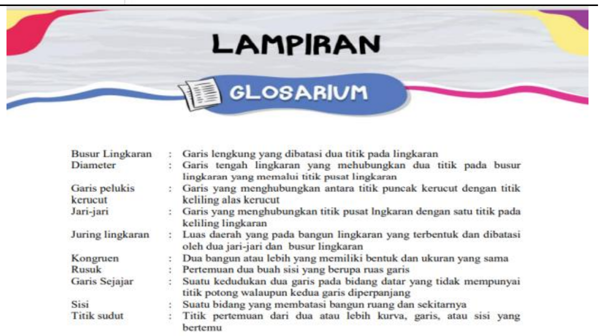
Table 3. Validators' Responses, Suggestions, and Criticisms

No	Responses, Criticisms, and Suggestions
1	Use a brighter font for the title of the module and avoid white color.
2	In the summary box for the definition of Curved Surface Shapes, replace the word "seminimalnya" with another word.
3	There are typos in the words "Diamterer" and "kerucur" in the text
4	In the point "Problem: Let's Read the Text", add an icon as a marker for independent student activities.
5	In the final text of the module, several questions need to be replaced with HOTS questions.
6	It would be better to include a glossary in the learning module to aid students in understanding the terms used in the module.
7	Also, provide the learning module as an e-module so it can easily carry anywhere and anytime.

Based on the feedback presented in Table 3, the researcher made several revisions to improve the quality and usability of the learning module. These revisions aimed to enhance visual clarity, linguistic accuracy, and the inclusion of features that promote independent learning and HOTS-oriented tasks. The detailed changes are presented in Table 4.

Table 4. Revised Results

<table>
<tr><th>Revised Results</th><th>Module Images</th></tr>
<tr><td>The title cover on the module has been changed to a lighter color font, and some icons on the cover have been fixed to make it look neater and more attractive</td><td>
</td></tr>
<tr><td>The word "at least" is replaced with "at least"</td><td>
</td></tr>
<tr><td>The words "Diamterer" and "Kercur" have been corrected to "Diameter" and "Kercut"</td><td>
</td></tr>
</table>

Revised Results	Module Images
In the point "Problem: Let us read the text," an icon image has been given as a marker of students' independent activities	
The final text of the question module has been replaced with HOTS questions in the form of description questions.	
A glossary has been included in the module to make it easier for students to use the word terms in the module.	
The modules have been made into e-modules to carry them anywhere and anytime easily. Students can use it by scanning the QR code listed in the module.	

3.1.4 Implementation Stage

The implementation or application stage aims to implement the learning module in the classroom after it has been declared feasible by the validator. Eight students participated in implementing this stage, and three meetings were held in class (6 x 45 minutes). In the first meeting, the researcher explained how the research would be conducted and its intended objectives. Next, the researcher went directly into the lesson. First, the researcher distributed the learning modules she had created to the students and began with the Curved-Sided Solid Geometry topic. In the second meeting, the material was reviewed at the beginning. In the second meeting, the researcher discussed the shape of a cone. Students were guided to find the definition of a cylinder, the elements contained in a cylinder, and the concepts of surface area and volume of a cylinder, as well as solve problems related to cylinders in everyday life. In the third meeting, students were asked to work on test questions and fill out a student response questionnaire prepared by the researcher. First, students filled out the student response questionnaire for approximately 10 minutes. After that, students worked on the test questions. They were given 90 minutes to complete the work. The researcher had prepared the answer sheets. After completion, students were asked to collect their answer sheets. From the first meeting until the last meeting, there were no significant obstacles; learning proceeded well and according to plan.

3.1.5 Evaluation Stage

The evaluation stage aims to evaluate the activities carried out by researchers. At this stage, the module assessment that is seen is the practicality and effectiveness of the learning module. The practicality aspect can be seen from the students' response questionnaires. Meanwhile, the effectiveness aspect is seen from the students' math problem-solving ability test results.

The data on the results of student responses after using the HOTS-based on BCSS material learning module at SMP NU Sumenep in mathematics lessons, which was then summed up to scores, the assessment results were used to see the practicality of the developed product, as presented in the Table 5.

Table 5. Data on the Assessment Results of the Student Response Questionnaire

Assessment Aspects	Indicator	No. Questionnaire	Average Score	%	Category
Module Features	*Self-instructional*	3 dan 5	3	75	Good
	Personal Abilities	7	3,625	90,6	Very Good
	Purpose	1 dan 6	3,3125	82,8	Very Good
	Associations of structure and sequence	10	3,25	81,25	Very Good
	Media	8	3,5	87,5	Very Good
	Active participation of students	4 dan 9	3,5	87,5	Very Good
	There is an evaluation	2 dan 15	3,6875	92,1	Very Good
Material	Benefits of modules in developing HOTS capabilities	11, 13 dan 16	3,5	87,5	Very Good
	Benefits of modules in assisting students on BCSS material	12, 14, 17 dan 18	3,53125	92,1	Very Good
Language	Clarity of the language the module uses	19	3,5	87,5	Very Good
	Clarity of writing or image illustrations	20	3	75	Good

After the module was revised based on validator feedback, a limited trial was conducted involving students to gather their perceptions of the module's quality and usability. The student response questionnaire covered three main aspects: module features, material, and language. The purpose of this stage was to evaluate the extent to which the developed module meets students' needs and expectations in supporting the learning process. The results of the student response questionnaire are presented in Table 6.

Table 6. Results of Student Response Questionnaire

Aspect	Score Average	Percentage (%)	Category
Module Features	3,4	85	Good
Material	3,5	87,5	Very Good
Language	3,25	81,125	Good
Average	**3,38**	**84,5**	**Good**

Based on the data in Table 6, the results of student responses to the modules that have been used show a good category with an average percentage of 84.5%. To obtain a more structured picture of each indicator's effectiveness level, the scores obtained from the analysis results are converted into percentages. This conversion is intended to facilitate the process of interpretation and categorization of data. Furthermore, the percentage is classified into specific categories that describe the level of effectiveness based on a predetermined range of values. The classification of the percentage of effectiveness scores can be seen in the following Table 7.

Table 7. Percentage of Effectiveness Score Category Percentage

Percentage (%)	Category
85,01-100,00	Very good
70,01-85,00	Good
50,01-70,00	Less Good
01,00-50,00	Not Good

Based on the recapitulation of the data from the student Problem Solving Ability test results, which is then summed up to the scores, the assessment results are used to see the effectiveness of the developed product assessed on every aspect of the cognitive level. After an assessment of each cognitive aspect, the results are obtained in Table 8.

Table 8. Test Question Results

Cognitive Level	Average Percentage (%)	Category
C4	78,75	Good
C5	75	Good
C6	72,5	Good
Average	**76**	**Good**

Based on the results of the Table 8, the effectiveness aspect was assessed with an average of 76% with good criteria.

3.2 Discussion

This study aimed to develop and evaluate a HOTS-based learning module for Building Curved Side Space (BCSS) material that is aligned with the Independent Curriculum, integrates engaging visual design, and systematically embeds higher-order thinking tasks. The findings from validation, field testing, and learning outcome analysis confirm that the module achieved its primary objectives: (1) meeting expert standards of validity, (2) being perceived as practical and engaging by students, and (3) effectively improving higher-order cognitive skills, the achievement of the main objective of this research is in line with the results of the (Ma'rifat and Suraharta, 2024) research which was also achieved in the validator test, practical based on the practicality test by teacher and students and effectively improve student learning outcomes.

Compared to previous studies on HOTS-based learning tools, the novelty of this research lies in its specific integration of the HOTS framework (C4–C6) into the BCSS topic for junior high school mathematics, supported by visual design elements that were iteratively refined through validator feedback. While earlier works, such as (Rukmana et al., 2024) have demonstrated the validity and effectiveness of HOTS-based modules in general mathematics topics, few have focused on three-dimensional geometry particularly curved surfaces were abstractness and spatial reasoning often hinder student comprehension. The current study addresses this gap by designing activities and problem sets that require not only calculation but also multi-step analysis, evaluation, and creation within a geometric context.

The high validation scores (>80%) across all expert assessments directly answer the initial research question regarding feasibility (what). Scientifically, this can be attributed (why) to the module's alignment with cognitive development theory, where visual aids, context-based tasks, and scaffolding strategies help bridge abstract spatial concepts with concrete student experiences. The positive student responses (84.5% overall) further confirm the module's practicality and its capacity to sustain learner engagement, which is consistent with (Salsabila, 2025), who emphasizes that active and challenging learning materials foster curiosity and motivation.

The effectiveness results, showing significant pretest–posttest gains (from 45 to 78, $p < 0.01$), are consistent with earlier research by (Ma'rifat and Suraharta, 2024), which also reported high learning gains from HOTS-based modules. However, the present study adds a new dimension by detailing performance improvements at each cognitive level: C4 (analysis), C5 (evaluation), and C6 (creation). Notably, the relatively lower gains in C6 highlight a common challenge in HOTS instruction—students' difficulty in generating original solutions—which has been less explicitly addressed in prior studies. This suggests that while the HOTS framework is effective overall, targeted scaffolding for creative problem-solving remains an area for further refinement.

In terms of differences from earlier findings, the module's design incorporated iterative media and content improvements based on validator suggestions—such as adding independent activity icons, revising terminology, and providing an e-module format—which were not prominent features in previous works. These design elements may explain the high student motivation results (85% reported increased challenge and interest) and could serve as a model for future HOTS-based resource development, especially for abstract geometry topics, this is in line with research results (Harianja and Anwar, 2021) which state that there is an increase in student learning outcomes after using HOTS-learning modules. This study not only confirms the validity and effectiveness of HOTS-based learning modules in mathematics but also contributes a novel, context-specific approach to BCSS instruction that integrates visual design and iterative feedback. This positions the current work as both an extension and a refinement of earlier research, offering practical implications for enhancing spatial reasoning and problem-solving skills in middle school mathematics.

4. Conclusion

This study is based on a problem-based learning model, and students' higher-order thinking skills are developed based on the ADDIE model, which includes Analysis, Design, Development, Implementation, and Evaluation. There are three determining aspects of a teaching module suitable for use in learning: validity, practicality, and effectiveness. Based on the research results described, all three aspects have been fulfilled: very good for validity, practicality, and effectiveness. In addition, after the implementation of the learning module in class VII SMP NU Sumenep, there was an increase in the average score from pretest to posttest on each indicator of students' critical thinking. This implies that the teaching module based on higher-order thinking skills on the material of cylinders and cones is suitable for use in learning.

The results of this study show that the development of HOTS-based learning modules on the BCSS material can meet the aspects of validity, practicality, and effectiveness. Therefore, this module is highly recommended for use in learning activities at school, both for independent and group activities. Furthermore, it is suggested that intensive training and mentoring be provided to teachers who will implement this module so that they better understand the HOTS approach and can innovate teaching according to the needs of students. In addition, it is also necessary to develop other supporting media, such as animated videos, simulations, or computer-based applications, that can help students understand concepts visually and interactively.

For further research, it is recommended that larger-scale testing be conducted involving different schools in different regions to ensure sustainability and generalization of results. In addition, developing modules with other materials that suit the needs and characteristics of students at various levels of education is also important. In addition, there is a need for a long-term evaluation of the continuous improvement of students' higher-order thinking skills and a more comprehensive assessment involving affective and psychomotor aspects. Through this effort, it is hoped that mathematics learning in Indonesia can be more advanced and able to compete internationally.

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GeoGebra as a Visualization Tool: Implications for Mathematics Anxiety in Analytical Geometry Lectures

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Abstract

This study investigates the impact of using GeoGebra as a geometric visualization tool on reducing mathematics anxiety among students in a Mathematics Education program. GeoGebra, an interactive software, enables dynamic visualization of geometric concepts, potentially fostering deeper conceptual understanding and alleviating anxiety in learning mathematics. A one-group pretest-posttest design was employed, consisting of three phases: preparation, implementation, and data analysis. Data were collected through a mathematics anxiety questionnaire administered before and after the intervention using Google Forms. The participants were 45 Mathematics Education students enrolled in an Analytical Geometry course. Data analysis involved tests of normality, homogeneity, and a paired sample t-test. The results indicate that: (1) GeoGebra effectively reduces students' anxiety in learning geometry; (2) its interactive visualizations enhance conceptual understanding and mitigate anxiety levels; (3) there is a statistically significant difference in anxiety levels before and after the use of GeoGebra; and (4) students reported a more enjoyable and less stressful learning environment, which increased their engagement with the course content. These findings suggest that integrating GeoGebra into geometry instruction can be a valuable pedagogical strategy for reducing mathematics anxiety and promoting meaningful learning experiences.

Keywords: Analytical Geometry; Interactive Learning; Geometric Visualization; GeoGebra; Mathematics Anxiety;

1. Introduction

Mathematics, particularly geometry, often triggers math anxiety among students because it demands strong spatial visualization skills (Thom et al., 2024; Lavicza et al., 2023). Yet, geometry plays a crucial role in developing spatial reasoning, which is key to success in STEM fields. Skills such as visualization and mental rotation are essential, for example, in engineering and architecture. Integrating technology into geometry learning has been proven to strengthen these abilities while reducing math anxiety (Cotabish et al., 2024). Strong spatial understanding not only helps students recognize and manipulate two- and three-dimensional objects but also fosters reflection, autonomy, and collaboration skills that support holistic learning (Amdar et al., 2024; Lübeck, 2023).

Geometry is often considered a difficult topic in mathematics by many students. This difficulty is frequently attributed to the abstract nature of geometric concepts, which require strong visual understanding. Students commonly struggle with fundamental topics, such as the properties of shapes and circle theorems, resulting in poor performance on geometry assessments. Moreover, a lack of visualization skills further complicates their ability to grasp geometric principles, as many learners are unable to effectively manipulate or visualize geometric objects (Mudhefi et al., 2024).

Difficulty in understanding geometry is also influenced by another important factor: anxiety. Mathematics anxiety is a common phenomenon among students across various levels of education. It significantly affects students' ability to learn geometry, as studies have shown that students experience varying levels of anxiety depending on their geometric reasoning skills, which in turn can hinder their problem-solving performance (Wahyuni et al., 2024; Samosir & Dasari, 2022). At the visualization level, students show moderate anxiety, which can escalate to panic, while at the analysis level, students show moderate anxiety (Handayani & Permatasari, 2022). Anxiety arises during certain stages of problem solving, such as confusion in applying the Pythagorean theorem and uncertainty in providing the correct answer (Sunardi et al., 2019). This anxiety can negatively impact students' motivation to learn, their concentration, and their academic outcomes-particularly in geometry, which requires a deep understanding of visual-spatial objects and the ability to connect abstract concepts with visual representations (Isa & Johari, 2023; Maghfiroh et al., 2023).

The effective use of visual representations, such as digital tools, can enhance comprehension and reduce anxiety, leading to improved performance in geometry tasks (Zakelj & Klančar, 2022). As technology advances, innovations in education have focused on the use of interactive software that can help students understand abstract concepts more easily (Salami & Spangenberg, 2024). One of the most popular and effective software in learning mathematics, especially geometry, is GeoGebra. Technologies such as GeoGebra create dynamic and interactive visualizations of geometric concepts, and have been recognized as tools that can help students better understand abstract concepts (Schmid et al., 2023; Ardina & Boholano, 2024). The integration of Geogebra software into educational practices has shown significant benefits across multiple dimensions of learning and enables dynamic visualization of geometric concepts, making abstract ideas more tangible to students (Santiago, 2024). This software combines geometry, algebra, and calculus, facilitating a comprehensive understanding of mathematical relationships (Banu, 2024).

GeoGebra has the potential to reduce mathematics anxiety as it aligns with modern learning theories. Constructivist theory emphasizes the active role of students in constructing their own knowledge (Thi Thu & Thi Thu, 2023; Mijanović, 2023). Accordingly, GeoGebra enables students to actively develop their understanding of geometry through object manipulation and concept exploration, thereby enhancing learning control and reducing fear (Silveira, 2018). Furthermore, Bandura's self-efficacy theory indicates that successful experiences and positive feedback can increase self-efficacy (Pinheiro, 2009; Davison, 2015). Studies have shown a negative relationship between self-efficacy and mathematics anxiety (Hendral & Hidayati, 2023). GeoGebra provides instant visual feedback that can enhance students' self-efficacy, leading to a decrease in negative emotional responses, including anxiety in learning mathematics (Azizah et al., 2023).

Studies show that using GeoGebra in geometry topics has a positive impact on student engagement and test performance, fostering a more interactive learning environment, and making learning more accessible and engaging (Farhan & Yahfizham, 2023). Teachers are encouraged to incorporate technology to facilitate better understanding and interaction with geometric principles, as well as effective teaching strategies including problem-based learning and the use of manipulative aids, which have been identified as beneficial in geometry instruction (Amdar et al., 2024). GeoGebra aligns with the needs of 21st-century education by utilizing technology to stimulate interest and enhance understanding of mathematical concepts (Salsanabila et al., 2024). By using GeoGebra, students can see visual representations of geometric shapes and their calculation processes, which are expected to reduce students' anxiety in facing mathematical problems, especially geometry. However, although GeoGebra's potential in reducing anxiety has been recognized theoretically, there is still limited empirical research that specifically explores the direct impact of GeoGebra use on students' anxiety in learning mathematics.

The use of GeoGebra applications in mathematics learning provides benefits not only for students but also offers practical advantages for teachers and prospective teachers, such as helping to visualize abstract concepts interactively, accelerating lesson preparation, and providing instant feedback that facilitates the correction of students' understanding (Hohenwarter & Lavicza, 2009). In addition, GeoGebra encourages exploration-based learning so that students are more active in constructing knowledge, while teachers take on the role of facilitators (Setiawi et al., 2021). With the support of this technology, teachers can enhance their confidence in teaching, adjust the level of learning difficulty according to students' needs, and at the same time create a fun learning environment to reduce mathematics anxiety (Raisatunnisa et al., 2025).

There is a research gap in the study of GeoGebra usage, namely the lack of studies that specifically examine the direct impact of GeoGebra on students' anxiety in learning geometry, although many studies have discussed its role in improving mathematical understanding. Most studies still focus on improving learning outcomes and conceptual understanding, without further examining whether the technology can also reduce the inhibiting emotional factor, namely anxiety towards mathematics. The urgency of this research is grounded in the existing literature on anxiety. Although specific statistical data on the prevalence of mathematics anxiety in Indonesia is still limited, studies indicate that mathematics anxiety affects 67.6–86.2% of Indonesian students' academic performance (Sari & Mujazi, 2024; Maf'ulah & Fadhilah, 2024). Global data show varying prevalence across countries, with the majority of students reporting anxiety in learning mathematics. A large-scale study in Qatar involving 10,093 students in grades 7–12 revealed that 20% of students experienced high mathematics anxiety (Megreya et al., 2024). In the United States, 47% of pre-service teachers reported moderate to high mathematics anxiety, and 53% of prospective school counselors experienced moderate to high mathematics anxiety (Gill, 2018). Thus, mathematics anxiety is a global issue that impacts students' academic achievement in various countries (Shakmaeva, 2022). In Indonesia, research has shown that mathematics anxiety has a significant negative effect on students' mathematics learning achievement (Maghfiroh et al., 2024).

This research is important because mathematics anxiety, especially in the context of geometry, can hinder students' ability to understand important concepts. By using GeoGebra, it is hoped that students can reduce the anxiety they feel when learning mathematics, especially geometry, thereby increasing the overall effectiveness of learning. The research problems in this study are as follows: (1) Can the use of GeoGebra reduce students' anxiety in learning geometry? (2) How does the visualization provided by GeoGebra affect students' understanding of geometric concepts and their mathematics anxiety? (3) Is there a significant difference in students' anxiety levels before and after using GeoGebra in mathematics learning? (4) How are students' experiences in using GeoGebra related to their feelings of anxiety toward mathematics?

This study took respondents from prospective mathematics teacher students, who are currently in their 3rd semester and taking the analytical geometry of plane course program. This study is highly relevant for prospective mathematics teachers, as it highlights the potential of visualization tools to enhance student engagement and understanding in analytical geometry. By integrating GeoGebra into their teaching practices, future educators can overcome common challenges in conveying abstract mathematical concepts, thereby reducing student anxiety and improving learning outcomes.

GeoGebra has been shown to significantly increase student interest in learning analytical geometry, as evidenced by studies showing that students report positive attitudes towards its use (Listiani et al., 2024). The software facilitates a deeper understanding of geometric principles, which is essential for future educators who must convey these concepts to their (Narh-Kert & Sabtiwu, 2022). Thus, the objectives of this study are not merely to fill the literature gap regarding the effects of GeoGebra use on students' anxiety in mathematics learning, but also to: (1) Identify the extent to which the use of GeoGebra can reduce students' anxiety in learning geometry. (2) Analyze the influence of the visualizations provided by GeoGebra on students' understanding of geometric concepts and their levels of anxiety. (3) Compare the differences in students' anxiety levels before and after using GeoGebra in mathematics learning. (4) Describe students' experiences in using GeoGebra and their relation to feelings of anxiety toward mathematics.

2. Method

This study is a type of quasi-experimental quantitative research, with a one group pretest-posttest design. The design does not use a control or comparison group and measures the differences before and after treatment in the same group. The one-group pretest-posttest design is considered effective for determining the impact of treatment directly on the same subject, although it has limitations in terms of control over other variables that affect the results (Stratton, 2019; Kongkaew et al., 2020).

Experimental research generally uses a control group to compare treatments; however, a research design without a control group is still considered appropriate in this context, with the consideration of focusing on participants' internal changes (Pretest–Posttest Design). The main objective of this study is to examine whether the use of GeoGebra as a visualization tool has implications for changes in students' mathematics anxiety levels. Thus, what is more important is analyzing the changes within participants before and after the treatment (within-group changes), rather than comparing between groups. The one-group pretest–posttest model is sufficiently strong to address this research question.

The data collection technique was by survey using Google Forms fully online. The survey was conducted from October to November 2024. The respondents of this study were all third-semester students of the Mathematics Education study program who were taking the Analytical Geometry course with the topic of the coordinate system (determining coordinate points and drawing straight lines between points on a plane), with a total of 45 students. The respondents were students with a low level of ability in determining coordinate points on the Cartesian plane. This was identified when the researcher asked the students to manually determine coordinate points on a diagram drawn on the whiteboard. The GeoGebra platform was downloaded and installed on a laptop, then displayed through PowerPoint, followed by an explanation of how to use it to understand the concepts being studied.

The variables of mathematics anxiety before and after using Geogebra were measured using a Likert scale questionnaire with 10 items each. Descriptions of indicators and questionnaire statement items before and after using GeoGebra are presented in Table 1 and Table 2.

Table 1. Students' Mathematics Anxiety Questionnaire Before Using GeoGebra

Instructions: Please mark the answer that best describes how you feel about mathematics before using GeoGebra. The scale used is a Likert scale with the following ranges: 1 = Strongly Disagree, 2 = Disagree, 3 = Neutral, 4 = Agree, 5 = Strongly Agree.

No	Statement
1	I feel nervous when I start math class.
2	I feel like I can't understand math problems.
3	I often feel anxious when I have to take math tests.
4	I avoid math class because I feel stressed.
5	I feel uncomfortable every time I have to do math problems.
6	I feel panicked when I can't solve math problems quickly.
7	I often feel stressed during math class.
8	Every time I think about math, I feel stressed.
9	I am not confident in my ability to solve math problems.
10	I feel scared when I have to solve complicated math problems.

Table 2. Students' Mathematics Anxiety Questionnaire After Using GeoGebra

No	Statement
1	Using GeoGebra makes me more confident in solving math problems.
2	I feel more comfortable facing math lessons after using GeoGebra.
3	GeoGebra helps me to understand math concepts better.
4	I feel calmer when solving math problems using GeoGebra.
5	I feel GeoGebra helps me reduce my fear of difficult math problems.
6	I feel more relaxed during math lessons after using GeoGebra.
7	GeoGebra makes math easier to understand and more fun.
8	I am more confident in facing math exams after using GeoGebra.
9	Using GeoGebra helps me focus more on math lessons.
10	After using GeoGebra, I feel math becomes easier and more interesting.

The questionnaires in Tables 1 and 2 were adapted from the mathematics anxiety scale used by Ramirez et al., (2018) and Dowker et al., (2016) with slight modifications according to the research objectives. The validity test of the instrument used the item-total correlation test, declared valid if the Item Sig. correlation value <0.05, while the reliability measure was determined based on the Cronbach's Alpha coefficient value and declared reliable if the Alpha value ≥ 0.6. The validity and reliability coefficients of each statement in the questionnaire are presented in Table 3.

Table 3. Validity and reliability coefficients of the anxiety questionnaire before and after using GeoGebra

Before			After		
Item	**Sig.***	**Alpha****	**Item**	**Sig.***	**Alpha****
1	0,000	0,814	1	0,000	0,902
2	0,000		2	0,000	
3	0,000		3	0,000	
4	0,000		4	0,000	
5	0,000		5	0,000	
6	0,006		6	0,000	
7	0,000		7	0,000	
8	0,000		8	0,000	
9	0,006		9	0,000	
10	0,000		10	0,000	

*) Corrected Item – Total Correlation
**) Cronbach's alpha coefficient

Table 3 shows that all items both before and after the intervention have Sig. values below 0.05, indicating that all questionnaire items are declared valid (Chakrabartty, 2020). Furthermore, the reliability test aims to determine the consistency of the instrument in measurement. The Cronbach's Alpha value is used as an indicator of reliability. According to Raykov et al., (2022), an Alpha value ≥ 0.70 is considered to indicate good reliability. In Table 3, the Cronbach's Alpha value is 0.814 before the intervention and 0.902 after the intervention, indicating that the instrument has a high level of reliability.

The procedure for completing the research questionnaire was as follows : before the distribution began, the researcher provided a brief explanation of the purpose of the questionnaire and the instructions for filling it out, emphasizing that all responses would remain anonymous and confidential. Students were asked to answer honestly based on their personal experiences, not on assumptions they believed to be correct, and not by following their peers' answers. The questionnaire was administered via Google Form, which could be easily accessed using either a laptop or a smartphone. Respondents were instructed to complete the questionnaire in the classroom after the lecture ended so that they were in the same situation and condition.

The research procedure consists of three main stages: preparation stage, implementation stage and data processing stage. The process in each stage is presented in Figure 1.

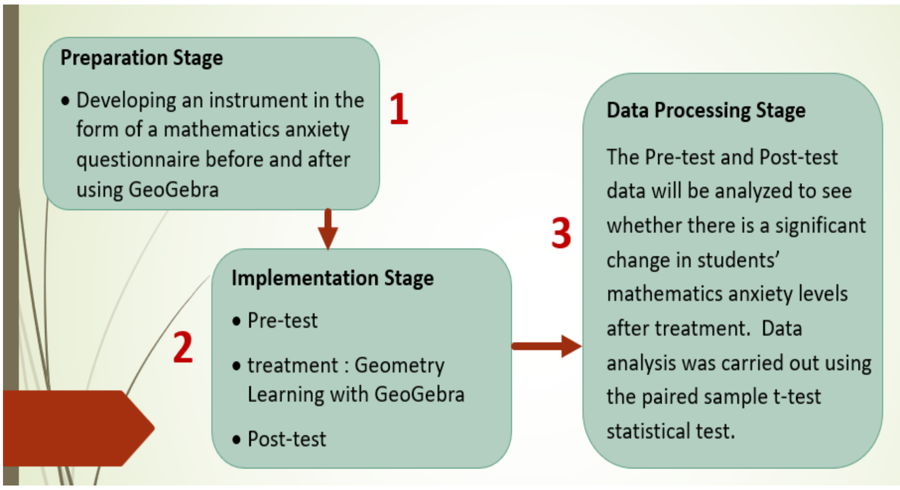

Figure 1. Research Procedures.

3. Results and Discussion

3.1 Results

The purpose of this study was to determine whether the use of GeoGebra as a visualization tool in geometry learning has an impact on students' mathematical anxiety. The description of the survey results in the form of tabulation of mathematical anxiety data before using GeoGebra is presented in Table 4.

The data tabulation in Table 4 interprets the respondents' perception data on mathematics anxiety before using GeoGebra as a learning aid. There are 10 statements describing various aspects of mathematics anxiety, with five response categories: Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree. Before using GeoGebra, students' mathematics anxiety levels were generally low to moderate. This is reflected in the dominance of "Disagree" and "Neutral" responses in most statements. There were 14.01% of respondents who agreed with the anxiety indicators and 2.45% who strongly agreed with the anxiety indicators, so there were still 16.46% of mathematics education students who were anxious when facing mathematics. There were indications of higher anxiety in certain situations, such as time pressure and mathematics exams. Furthermore, the tabulation of mathematics anxiety data after using GeoGebra is presented in Table 5.

Table 4. Data Tabulation Mathematics Anxiety Before Using GeoGebra

No	Statement	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)
1	I feel nervous when I start math class.	11.1	37.8	44.4	4.4	2.3
2	I feel like I can't understand math problems.	8.9	37.8	44.4	6.7	2.2
3	I often feel anxious when I have to take math tests.	4.4	33.3	33.3	26.7	2.3
4	I avoid math class because I feel stressed.	24.4	57.8	15.6	2.2	0
5	I feel uncomfortable every time I have to do math problems.	8.9	48.9	40	0	2.2
6	I feel panicked when I can't solve math problems quickly.	0	17.8	24.4	46.7	11.1
7	I often feel stressed during math class.	11.1	57.8	28.9	2.2	0
8	Every time I think about math, I feel stressed.	13.3	57.8	22.2	6.7	0
9	I am not confident in my ability to solve math problems.	4.4	28.9	48.9	17.8	0
10	I feel scared when I have to solve complicated math problems.	6.7	31.1	31.1	26.7	4.4
	Average	9,36	40,9	33,32	14,01	2,45

Table 5. Data Tabulation Mathematics Anxiety After Using GeoGebra

No	Statement	Strongly Disagree (%)	Disagree (%)	Neutral (%)	Agree (%)	Strongly Agree (%)
1	Using GeoGebra makes me more confident in solving math problems.	0	2.2	17.8	68.9	11.1
2	I feel more comfortable facing math lessons after using GeoGebra.	0	0	24.4	62.3	13.3
3	GeoGebra helps me to understand math concepts better.	0	0	8.9	68.9	22.2
4	I feel calmer when solving math problems using GeoGebra.	0	2.2	26.7	57.8	13.3
5	I feel GeoGebra helps me reduce my fear of difficult math problems.	0	6.7	22.2	51.1	20
6	I feel more relaxed during math lessons after using GeoGebra.	0	2.2	26.7	62.2	8.9
7	GeoGebra makes math easier to understand and more fun.	0	2.3	24.4	51.1	22.2
8	I am more confident in facing math exams after using GeoGebra.	0	2.2	26.7	57.8	13.3
9	Using GeoGebra helps me focus more on math lessons.	0	4.4	17.8	66.7	11.1
10	After using GeoGebra, I feel math becomes easier and more interesting.	0	0	22.3	64.4	13.3
	Average	0	2.22	21,77	61,12	14,87

The data in Table 5, shows that the majority of students gave a positive response to the use of GeoGebra in learning mathematics. An average of 61.12% of students agreed and 14.87% strongly agreed that GeoGebra helped them feel more confident, comfortable, and understand mathematical concepts better. The most agreed statement was that GeoGebra helped them understand mathematical concepts (91.1% combined agree and strongly agree). In addition, students also felt calmer, more focused, and more prepared for exams after using GeoGebra. The level of disagreement was very low (average 2.22%), and no students strongly disagreed. This shows that GeoGebra is generally well accepted and contributes positively to reducing anxiety in learning mathematics.

To clarify the results of the Pretest and Posttest, Table 6 Change of mathematics anxiety before and after using GeoGebra and Figure 2 presents a comparison of the average levels of mathematics anxiety before and after using GeoGebra.

Table 6. Change (%) of Mathematics Anxiety Before and After using GeoGebra

Treatment	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Before Geogebra	9,36	40,9	33,32	14,01	2,45
After Geogebra	0	2,22	21,77	61,12	14,87
Change (%)	-9,36	-38,68	-11,55	47,11	12,42

The most significant decrease occurred in the **Disagree** category across almost all items. Item 4 decreased from 57.8% to 2.2% (-55.6%), while Item 1 also showed a substantial drop from 37.8% to 2.2% (-35.6%). This indicates that students' doubts about their ability to deal with mathematics were drastically reduced after using GeoGebra. The **Strongly Disagree** category also experienced a sharp decline. For Item 4, the percentage dropped from 24.4% to 0% (-24.4%). This means that almost no students strongly disagreed with the positive statements about their experience after GeoGebra-assisted learning.

For the **Neutral** category, the trend tended to decrease in most items. Item 3 dropped from 33.3% to 8.9% (-24.4%), and Item 1 decreased from 44.4% to 17.8% (-26.6%). This decline shows that students who were previously hesitant or had no clear opinion began to shift toward a more positive (agree) stance.

The most significant increase was observed in the **Agree** category. Item 1 rose from 4.4% to 68.9% (+64.5%), Item 4 increased from 2.2% to 57.8% (+55.6%), and Item 5 rose from 0% to 51.1% (+51.1%). This means that after learning with GeoGebra, the majority of students agreed that their mathematics anxiety had decreased. The **Strongly Agree** category also showed an increase, although not as substantial as the Agree category. Item 3 increased from 2.3% to 22.2% (+19.9%), and Item 5 rose from 2.2% to 20% (+17.8%). This indicates that there was a group of students who developed a very strong confidence in their positive feelings after using GeoGebra.

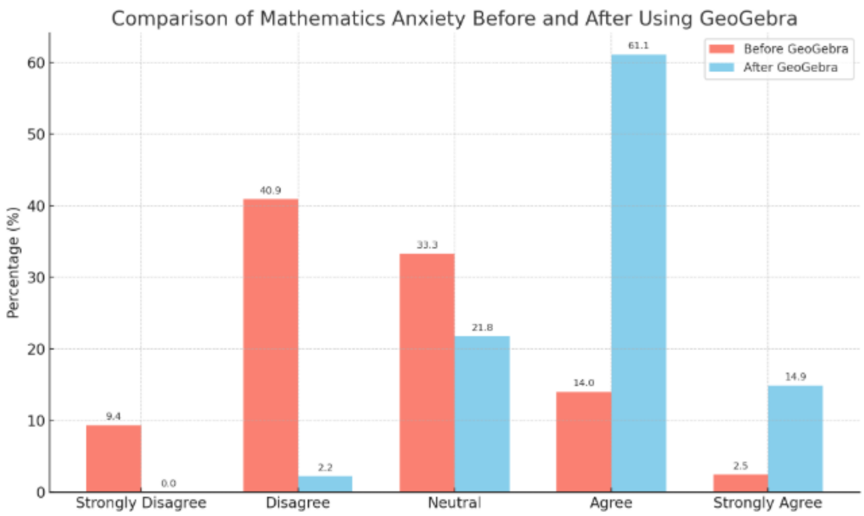

Figure 2. Comparison of Mathematics Anxiety Before and After Using Geogebra

Before using GeoGebra, the majority of students were in the Disagree (40.9%) and Neutral (33.3%) categories, indicating that they tended to disagree or remain neutral regarding statements of anxiety. After using GeoGebra, there was a significant increase in the Agree (61.1%) and Strongly

Agree (14.9%) categories, meaning that students felt more comfortable, confident, and supported with GeoGebra. Meanwhile, the Strongly Disagree and Disagree categories decreased drastically, indicating a reduction in doubt and negative anxiety.

To answer the research question 1 to 4, a Paired Sample t-Test analysis was then carried out. Before conducting the analysis, normality and homogeneity tests were carried out. (The results see Tables 6 and 7).

Table 6. Shows the Asymp. Sig (2-tailed) parameters, p value = 0.263. If $p > 0.05$, then the data is considered normally distributed. $p = 0.263 > 0.05$, so the research data is normally distributed. Next, a homogeneity test was carried out, the results of the homogeneity test are presented in Table 7.

Table 6. Result Normality Test

One-Sample Kolmogorov-Smirnov Test		
N		Results 90
Normal Parameters[a,b]	Mean	71,59
	Std. Deviation	12,786
Most Extreme Differences	Absolute	,106
	Positive	,078
	Negative	-,106
Kolmogorov-Smirnov Z		1,007
Asymp. Sig. (2-tailed)		,263

Table 7. Result Test of Homogeneity of Variances

Levene Statistic	df1	df2	Sig.
3,620	1	88	,060

The purpose of the homogeneity test is to determine whether the variance between groups is homogeneous (the same). Because Sig. = 0.060 > 0.05, the variance between groups is declared homogeneous. This means that the assumption of homogeneity is met, so that the ANOVA analysis can be continued in Table 8.

Table 8. ANOVA Test Results (One-Way ANOVA)

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3373,344	1	3373,344	27,095	,000
Within Groups	10956,044	88	124,501		
Total	14329,389	89			

One-Way ANOVA test in Table 8, is used to determine whether there is a significant difference between two or more groups of means in the dependent variable. The F value = 27.095 shows the ratio of variation between groups to variation within groups. Significance value (Sig.) = 0.000, Sig. = 0.000 <0.05, indicating a statistically significant difference between groups before and after using GeoGebra on math anxiety. Because the data is normally distributed and homogeneous, and shows differences through ANOVA analysis. Furthermore, parametric statistical analysis is carried out, namely the Paired Sample t-Test to test the research hypothesis. The results of the Paired Sample t-Test analysis can be seen in Table 9.

Table 9. Result Paired Sample T-Test

1. Paired Samples Statistics

Uji	Mean	N	Std. Deviation	Std. Error Mean
Pre-test	65,44	45	12,623	1,882
Post-test	77,73	45	9,701	1,446

2. Paired Samples Correlations

		N	Korelasi	Sig.
Pair 1	Pre-Test & Post-test	45	-0,014	0,928

3. Paired Samples Correlations

		Mean Difference	Std. Deviation	Std. Error	t-value	df	Sig. (2-tailed)
Pair 1	Pre-test & Post-test	-12,289	16,026	2,389	-5,144	44	**0,000**

95% Confidence Interval of the Difference	
Lower	Upper
-17, 104	-7,474

Table 9 number 1 shows the sample size tested was 45 respondents. The average post-test score was higher (77.73) compared to the pre-test (65.44). Table 9 number 2, shows the correlation value between pre-test and post-test scores is very low and not significant ($p = 0.928 > 0.05$).

Table 9 number 3, shows the Mean Difference = -12.289, which means the post-test score increased by an average of 12.289 points compared to the pre-test. The t-value = -5.144, with a p-value = 0.000, shows that this difference is highly statistically significant (since $p < 0.05$). The 95% confidence interval for the difference in scores is between -17.104 and -7.474, does not include zero, confirming that this difference is significant.

To determine the strength of the effect, an effect size calculation was conducted using Cohen's d, based on the t-value.

$$d = \frac{t - value}{\sqrt{N}} = \frac{-5{,}144}{\sqrt{45}} = \frac{-5{,}144}{6{,}708} = -0{,}77$$

(The negative sign is not considered, as it does not indicate the strength of the effect).

Based on the calculation, the value obtained was d = 0.77. According to Cohen's interpretation (d = 0.2 = small, d = 0.5 = medium, and d = 0.8 = large), the effect size of d = 0.77 falls within the medium-to-large category. This indicates that the use of GeoGebra not only has a statistically significant impact but also demonstrates a substantial effect strength in improving students' learning outcomes (Cohen, 1988).

3.2 Discussion

The findings of this study demonstrate that the integration of GeoGebra exerts a significant positive influence on students' self-efficacy in the context of geometry learning. Students who initially expressed doubts about their own abilities reported increased confidence in exploring mathematical concepts after utilizing GeoGebra. According to Gale et al., (2021), successful experiences serve as a primary source of self-efficacy enhancement. Through the use of GeoGebra, students experienced a sense of achievement in comprehending and solving tasks, which in turn positively contributed to their self-efficacy. Moreover, the interactive visualizations provided by GeoGebra not only facilitated a deeper understanding of the subject matter but also fostered a sense of control over the learning process, thereby further strengthening students' self-efficacy. These results are consistent with the findings of Zetriuslita et al., (2020), who emphasized that the integration of GeoGebra can reinforce learners' confidence in addressing mathematical challenges.

Furthermore, students' statements that GeoGebra helped them better understand mathematical concepts (91.1% agreed and strongly agreed) provide evidence of a significant improvement in conceptual understanding after the use of GeoGebra. The spatial visualization and dynamic simulation features made it easier for students to grasp the interconnections between concepts, particularly in the topic of analytic geometry. This improvement was reflected in the substantial differences between pretest and posttest scores, accompanied by a strong effect size, indicating that the impact of GeoGebra is not merely coincidental but truly substantive. In line with the findings of Ziatdinov & Valles (2022), GeoGebra enables the simultaneous integration of graphical, algebraic, and numerical representations, thereby facilitating students in developing deeper and more meaningful conceptual understanding. Thus, GeoGebra supports the transition from procedural learning to more meaningful conceptual learning. A solid conceptual understanding, in turn, helps reduce uncertainty and stress in learning mathematics.

The main novelty of this study lies in the empirical evidence that the use of GeoGebra not only enhances understanding but also quantitatively reduces mathematics anxiety among students. The majority of students reported feeling more comfortable (75.6% agreed and strongly agreed), calm (71.1%), and relaxed (71.1%) when learning mathematics with GeoGebra. The results of the analysis indicate a significant decrease in anxiety scores after the use of GeoGebra, with a medium to large effect size, confirming that this intervention has a tangible impact on students' affective dimensions. This reduction in anxiety can be explained through Cognitive Load Theory (Chadwick, 2024), whereby GeoGebra helps lower cognitive load by providing instant visualizations, thus preventing students from being overwhelmed by complex symbolic calculations. These findings are consistent with Zakelj & Klančar (2022), who demonstrated that interactive and dynamic educational technologies can reduce stress and anxiety in mathematics education. Furthermore, the high interactivity of GeoGebra makes learning more engaging and alleviates students' psychological pressure. In addition, these results align with the findings of Putri et al., (2020) and Min et al., (2024), who argued that visual learning media can help reduce mathematics anxiety by making abstract concepts more accessible and comprehensible, thereby lowering anxiety levels.

Another indicator shows that GeoGebra helps students remain more focused during learning. This finding is consistent with the studies of Ardina & Boholano (2024) and Farhan & Yahfizham (2023), which reported that interactive tools not only reduce anxiety but also enhance engagement and motivation in mathematics classes. Ingram et al., (2020) found that active participation in the learning process improves attention and information processing. In this context, GeoGebra creates a learning environment that fosters independent exploration and concentration, thereby indirectly shifting students' attention from anxiety toward meaningful learning activities. Students' statements that mathematics became easier and more enjoyable after using GeoGebra indicate a transformation in perception. According to Melo & Leal (2024), affective perceptions of mathematics strongly influence the level of anxiety. When students perceive mathematics as engaging and non-threatening, the likelihood of experiencing anxiety is reduced.

The primary objective of this study is to examine the implications of using GeoGebra. These findings are highly significant for prospective mathematics teachers, as they are not only expected to master the subject matter but also to develop pedagogical strategies capable of reducing students' affective barriers. With evidence that GeoGebra enhances self-efficacy, improves conceptual understanding, and simultaneously reduces anxiety, this study emphasizes that the integration of technology in mathematics learning can serve as a holistic approach. In this sense, GeoGebra is not merely a visualization tool but also a pedagogical instrument that optimizes both cognitive and affective dimensions, making it worthy of consideration in the teacher education curriculum.

The significant improvement in pre-test and post-test scores after using GeoGebra also highlights potential implications for teacher training and curriculum development, especially in addressing mathematics anxiety and improving learning outcomes. Integration of educational technology such as GeoGebra can transform traditional teaching methods, fostering a more engaging and effective learning environment. This supports the results of previous research by Em & Roman, (2020) which stated that teachers should receive training to effectively integrate GeoGebra into their lessons, focusing on its features that promote interactive learning. And in line with research by Martinez (2017) which stated that the curriculum should incorporate technology-based tools, aligned with standards that emphasize the use of manipulatives to enhance understanding of complex mathematical concepts. The curriculum should include GeoGebra as a standard tool for teaching various mathematics topics, as it has been shown to improve student performance and confidence (Pentang et al., 2022).

4. Conclusion

This study affirms that the use of GeoGebra in geometry learning provides not only cognitive benefits in terms of enhanced conceptual understanding but also affective benefits through the reduction of mathematics anxiety. This represents the main novelty of the research, positioning GeoGebra not merely as a visualization tool but also as an affective intervention that is empirically proven. These findings make an important contribution to the development of theory, methodology, and practice in mathematics education by emphasizing that technology integration should be viewed holistically—addressing both cognitive and affective aspects—so that mathematics learning becomes more inclusive, humanistic, and enjoyable.

The strategic implication of this study lies in the need for learning design in higher education, particularly in mathematics teacher education programs, to systematically integrate technologies such as GeoGebra into the curriculum. In doing so, prospective teachers will become accustomed to using visualization software as a pedagogical strategy that not only supports conceptual mastery but also fosters self-efficacy, reduces emotional barriers, and enhances students' mathematical well-being. Moreover, universities should instill the awareness that success in mathematics learning is measured not only by cognitive achievement but also by reduced anxiety and increased student confidence.

Nevertheless, this study has several limitations, including the absence of a control group, the short duration of the intervention, and external factors that could not be fully controlled, making the findings not yet generalizable to all contexts. Therefore, further research with stronger experimental designs, longer interventions, and better control of external variables is needed to ensure the sustainability and broader applicability of these findings in diverse learning contexts.

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