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DEVELOPMENT OF ROWS AND SERIES LEARNING BASED *ON PROBLEM BASED LEARNING* TO IMPROVE CRITICAL THINKING OF HIGH SCHOOL STUDENTS

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ABSTRACT

This research aims to develop a Problem Based Learning (PBL)-based arithmetic row and series learning tool to improve the critical thinking skills of high school class X students. The research uses the Research and Development (R&D) method with the Borg & Gall model which is simplified into three stages, namely preliminary study, product development, and implementation. The products developed are in the form of teaching modules and PBL-based Student Worksheets (LKPD). The research subjects amounted to 19 students in class X of SMA Negeri 15 Adidarma. Data was obtained through expert validation sheets and critical thinking skills tests in the form of pretest and posttest. The validation results showed that the learning tool obtained a percentage of 76.94% with the valid category. The results of the implementation showed that the average pretest score of 48.11 increased to 79.74 in the posttest. The N-Gain test result of 0.62 was included in the medium category. Thus, Problem Based Learning learning tools are declared valid and effective in improving students' critical thinking skills in arithmetic row and series material.

INTRODUCTION

Education is a process of cultural transformation and noble values of personality that is carried out systematically and programmatically. This is in accordance with Law Number 20 of 2003 concerning the National Education System in Chapter I Article 1 Paragraph 1 which states that education is the learning of students to actively develop their potential to have religious spiritual strength, self-control, personality, intelligence in thinking, noble morals, and the skills needed by themselves in the environment, society, and state (Lestari, 2022). Education is also an effort to nurture and develop human personality, both spiritually and physically, through a planned teaching and practice process so that students acquire various useful skills in life(Salsabilah et al., 2021) .

In the context of education, mathematics is a subject that has an important role in training logical, systematic, and critical thinking skills. However, the abstract nature of mathematics often causes difficulties for students. The process of learning mathematics in school has not been completely a fun activity, even though in daily life many human activities are related to the concept of mathematics. (Sohilait, 2012)states that linking real-life experiences with mathematical ideas in learning is essential for learning to be meaningful and students to enjoy the learning process more.

The era of society 5.0 requires students to have 21st century skills, one of which is critical thinking skills. Critical thinking skills are the ability of individuals to analyze, evaluate, and determine steps to solve problems logically and systematically(Setiawan et al., 2023). This ability is important to develop because the development of technology and the increasingly rapid flow of information require individuals to be able to sort information appropriately and use technology wisely (Dwi et al., 2022). In mathematics learning, critical thinking skills can be trained through problem-solving activities that encourage students to think analytically, logically, and systematically. Therefore, a learning process is needed that is able to facilitate students to actively think and engage in solving real problems.

Recent international research studies show that the *Problem Based Learning* (PBL) is an effective learning approach in developing students' critical thinking, collaboration, and problem-solving skills. The results of bibliometric analysis of 742 articles in the Scopus database show that research on PBL continues to increase because it is considered to be able to develop students' critical and adaptive skills (Handoyo et al., 2024). In addition, various studies have also shown that the application of PBL has a positive effect on students' mathematical critical thinking skills and concept understanding.

Several previous studies have shown that *Problem Based Learning* (PBL) is an effective learning model in improving students' high-level thinking skills. Research conducted by Tambunan et al. (2022) shows that the development of PBL-based LKPD on row and arithmetic series material has a very high level of validity, practicality, and effectiveness so that it is suitable for use in learning. Another study by Rahmadani (2024) shows that PBL-based modules are in the category of being very valid, practical, and effective in improving students' critical thinking skills. In addition, Wardani et al. (2024) found that PBL-based LKPD on row and series materials can significantly improve students' problem-solving skills. The difference in this study lies in the focus and product developed. This study specifically emphasizes on improving critical thinking skills through the development of integrated learning tools in the form of teaching modules and PBL-based LKPD on arithmetic row and series materials. Meanwhile, the research of Tambunan (2022) and Wardani et al. (2024) focuses more on problem-solving skills, Rahmadani et al. (2024) are applied to economics subjects. In addition, this study uses a simplified Borg & Gall development model and a *pretest-posttest one-group design* to see the improvement of students' critical thinking skills.

One of the learning models that can be used to improve critical thinking skills is *Problem Based Learning*. Models *Problem Based Learning* can be used for the mathematics learning process, especially arithmetic row and series material, because it can help students relate learning materials to real-world problems as a context for students to learn about critical thinking and problem-solving skills, as well as to acquire essential knowledge and concepts from the subject matter and strive to find problem solving independently will provide a concrete experience(Setyawan, 2022). As for the syntax or steps in the model *Problem Based Learning* as follows: (1) Problem Orientation (2) Orienting students to learn. (3) Guiding independent and group investigations. (4) Developing and presenting the results of the work. (5) Analyzing and evaluating the problem solving process.

The selection of row and series materials is based on observation results that show that students still have difficulties in understanding contextual problems, distinguishing rows and sequences, determining patterns, and solving problems in mathematical form. In addition, the results of interviews with teachers show that the *Problem Based Learning* model has been applied, but the learning steps have not been systematically arranged so that students are still less active in learning. Therefore, it is necessary to develop a more structured PBL-based learning tool to help improve students' critical thinking skills.

Based on this description, it is necessary to develop learning tools in the form of teaching modules and Student Worksheets based on *Problem Based Learning* on arithmetic row and series materials. This study aims to describe the development process of these learning tools and analyze their improvement in the critical thinking skills of high school students in class X.

RESEARCH METHODS

In this development research, the researcher uses *the Borg & Gall* development model. The development model put forward by Borg and Gall suggests that the research be carried out in a limited scope on a smaller scale and limit the number of steps in the research process. The stages of the research have been simplified into three main phases suggested by Sukmadinata, namely:

Figure 1. Borg & Gall Development Model

At the preliminary study stage, the researcher conducted initial observations and interviews with the aim of finding out the needs of mathematics learning in arithmetic row and series materials in class X of SMA Negeri 15 Adidarma. The results of initial observations and interviews as material to develop modules and LKPD.

At the development stage, the researcher prepares an initial design in the form of learning tools such as LKPD and modules based on theoretical studies and preliminary study results. The product that has been designed then goes through a limited trial involving 6-15 subjects to determine the feasibility and functionality of the product in learning. The results of the trial and input from users are then used as a basis for product revisions. In addition, the validation process is also carried out by lecturers and teachers to assess aspects of the material, language, and learning design so that the developed product becomes better and feasible to use in the learning process.

At the implementation stage, it is the stage of implementing learning products that have been developed in learning activities. At this stage, the activity begins with a pretest to find out students' critical thinking skills before learning. Furthermore, the learning process is carried out using developed products, such as LKPD based on *Problem Based Learning* (PBL). After the learning is completed, posters are given to find out the changes in students' critical thinking skills by comparing the results of the pretest and postes.

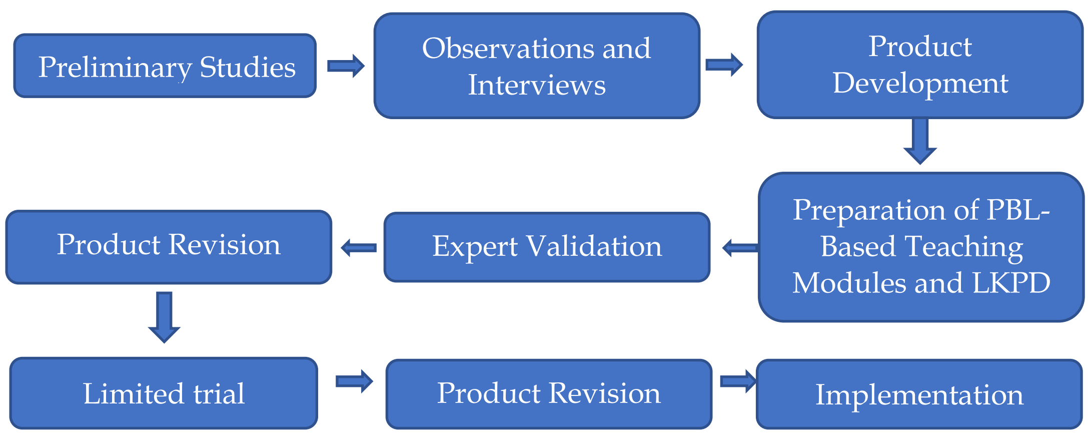


Figure 2. Research Flow Diagram

The research subjects at the implementation stage were 16 students in class X of SMA Negeri 15 Adidarma who were selected using the purposive sampling technique, which is the selection of samples based on certain considerations that are in accordance with the purpose of the research. The characteristics of the respondents in this study are class X students who have studied arithmetic row and series material.

The research instruments used were in the form of Critical thinking skills test which is compiled based on several indicators, while Six indicators of critical thinking skills (Student & Rice, 2017) Among them:

1. Compare information from various sources before completing a task.
2. draw conclusions based on the analysis of numbers, facts, or relevant information.
3. inferring or interpreting information from reading or learning.
4. Analyze competing arguments, perspectives, or solutions to a problem.
5. Develop a persuasive argument based on supporting evidence or reasons.
6. Solving complex problems or answering questions that don't have one correct answer

Table 1. Instrument Grid

Yes	Critical Thinking Indicators	Question Indicator	Material	Question Form	Question Number	Maximum Score
1	Compare information from different sources before completing a task	Compare two problem-solving strategies based on the information provided	Arithmetic Rows and Rows	Description	1	4
2	Draw conclusions based on the analysis of numbers, facts, or relevant information	Draw conclusions based on the results of calculations and information on the questions	Arithmetic Rows and Rows	Description	2	4
3	Infer or interpret information from reading or learning	Interpreting information and giving opinions based on the given situation	Arithmetic Rows and Rows	Description	3	4
4	Analyze arguments, perspectives, or solutions to a problem	Analyze the advantages and disadvantages of several available solutions	Arithmetic Rows and Rows	Description	4	4
5	Develop a persuasive argument based on evidence or supporting reasons	Constructing a logical argument with supporting reasons or evidence	Arithmetic Rows and Rows	Description	5	4
6	Solve complex problems or	Solve contextual problems and	Arithmetic Rows and Rows	Description	6	4

Yes	Critical Thinking Indicators	Question Indicator	Material	Question Form	Question Number	Maximum Score
	open-ended questions	provide logical solutions				

Table 2. Critical Thinking Indicator Assessment Rubric

Yes	Indicator	Criteria	Score
1	Compare information from different sources before completing a task	Unable to compare information from various sources.	1
		The comparison of information is limited and inaccurate.	2
		Compare information from multiple sources quite precisely,	3
		Compare information from various sources in a complete, precise, and logical manner.	4
2	Draw conclusions based on the analysis of numbers, facts, or relevant information.	Unable to draw conclusions based on analysis of figures or facts.	1
		Conclusions are less supported by analysis of relevant figures or facts.	2
		Drawing conclusions based on a fairly accurate analysis, but there are still minor shortcomings.	3
		Draw precise conclusions based on a complete analysis of numbers, facts, and information	4
3	Infer or interpret information from reading or learning	Unable to interpret information from reading or learning	1
		The interpretation of information is not precise and unclear.	2
		Interpreting information fairly precisely, but incompletely.	3
		Interpret information appropriately and clearly using your own language.	4
4	Analyze competing arguments, perspectives, or solutions to a problem	Unable to analyze the arguments or solutions given.	1
		The analysis of arguments or solutions is still limited and less logical.	2
		Analyze arguments or solutions logically but not in depth.	3
		Analyze various arguments or solutions logically, critically, and deeply.	4
5	Develop a persuasive argument based on evidence or supporting reasons	Unable to develop persuasive arguments.	1
		Arguments are less supported by sufficient evidence or reason.	2
		Develop an argument with evidence, but it is not strong or incomplete.	3
		Develop a strong and persuasive argument with the support of clear evidence or reasoning.	4
6	Solving complex problems or answering questions that don't have one correct answer	Unable to solve a given complex problem.	1
		The solutions provided are not precise and less logical.	2
		Presenting solutions that are quite precise and logical, but less creative or incomplete.	3
		Presenting precise, creative, and logical solutions to complex problems.	4

The scoring technique in this study is carried out by giving a score to each student's answer based on the critical thinking skill assessment rubric. Each indicator is assessed using a score range of 1–4 according to the level of accuracy, completeness, and clarity of the student's answers. The scores obtained are then summed and converted into a scale of 0–100 using the following formula:

$$Nilai = \frac{Skor\ yang\ diperoleh}{Skor\ Maksimal}\ x\ 100$$

The instrument testing procedure is carried out through several stages. First, the instrument is validated by experts to assess the suitability of the material, construction, and language. Next, the validity test of the question item is carried out using Product Moment correlation, while the reliability test uses Alpha Cronbach to determine the consistency of the instrument. After that, a Shapiro-Wilk normality test is carried out to find out whether the pretest and posttest data are normally distributed with a significance level of 0.05.

This study uses the One Group Pretest–Posttest design because it aims to determine the improvement of students' critical thinking skills before and after the implementation of Problem Based Learning-based learning tools. This design allows researchers to compare students' initial abilities and final abilities after being given treatment so that the influence of the use of learning tools can be known more clearly.

The following is an explanation of data analysis

1. **Qualitative Data Analysis**

   This analysis was obtained through initial observation and interviews at the preliminary study stage. Qualitative data analysis used the interactive analysis model Miles, Huberman, and Saldana which included three stages, namely data reduction, data presentation, and conclusion/verification.

2. **Quantitative data**

   This analysis was carried out on expert validation analyzed using percentages with a Likert scale of 1–4. Percentages are calculated with the formula

$$Presentase\ (\%) = \frac{skor\ yang\ diperoleh}{Skor\ ideal} \times 100\%$$

Table 3. Product Validity Criteria

Percentage	Criteria
81-100	Highly Valid
60-80	Valid
40-60	Quite Valid
20-40	Invalid
0-20	Invalid

SOURCE (Nisa & Yohanie, 2024)

Next, the validity test of the instrument was carried out using *Product Moment Correlations,* while the reliability test was carried out using *Alpha Cronbach* (Karira, 2023). After that, a Shapiro-Wilk normality test was carried out to find out whether the pretest and posttest data were normally distributed with a significance level of 0.05. To determine the improvement of students' critical thinking skills after learning, the N-Gain calculation was used with the formula:

$$N - Gain = \frac{Skor\ Postest - Skor\ Pretest}{Skor\ Maksimim - Skor\ Pretest}$$

Table 4. N-Gain Interpretation Criteria

Percentage	Criteria
g ≥ 0.70	Height Enhancement
0.30 ≤ g < 0.70	Moderate Improvement
g< 0.30	PModerate Improvement

(Rizqiyani et al., 2022)

RESULTS AND DISCUSSION

Results

This research produces a product in the form of a *problem-based learning module,* following a discussion of the development stages using the Borg & Gall model.

1. Preliminary Studies

Based on the results of the preliminary study, it can be seen that students' critical thinking skills in row and series material are still relatively low. Students tend to solve problems by following the examples given or directly using formulas without analyzing the problem. In addition, students also experience difficulties in understanding contextual problems, determining solution strategies, and distinguishing the concepts of arithmetic rows and series.

The results of the learning observation show that students are not used to studying the information in the problem thoroughly and still have difficulties in compiling solution steps in a sequential and logical manner. Students also experience difficulties in identifying row patterns, determining the n syllable, and calculating the number of n first syllables. This condition shows that students' analysis, reasoning, and evaluation skills in mathematics learning have not developed optimally.

To overcome these problems, a learning model is needed that can actively involve students in the problem-solving process. One of the models that can be used is *Problem Based*

Learning (PBL) because it places problems as the starting point of learning and encourages students to analyze, reason, and evaluate the solutions obtained. Therefore, this study aims to develop Problem *Based Learning (PBL)-based row and series learning tools* to improve the critical thinking skills of high school grade X students.

Table 5. Interview Results

No	Problems
1	Low understanding of the basic concepts of rows and rows
2	Difficulty understanding story and contextual problems
3	Difficulty determining row patterns
4	Difficulty distinguishing arithmetic rows and series
5	Difficulty determining the nth quarter and number of tribes
6	Difficulty converting contextual problems to mathematical models
7	The implementation of the PBL model is unstructured
8	Students' critical thinking skills are still low
9	Difficulty analyzing information in questions
10	Tendency to use formulas without understanding the problem

2. Development

The development stage in this study consists of several steps, namely initial design, design validation, design revision, product trial, and product revision. The initial design of the product in this study is in the form of teaching modules and Student Worksheets (LKPD) based on *Problem Based Learning* (PBL) on arithmetic row and series materials for high school grade X students. The preparation is based on the results of preliminary studies through interviews with teachers and learning observations. The teaching module functions as a guideline for teachers in carrying out learning, while LKPD is used to support student activities in problem solving. The learning tool is designed according to the stages *of Problem Based Learning*, namely problem presentation, student organization, investigation, presentation of results, and evaluation, so that it is expected to train students' critical thinking skills. The initial design of this learning tool is still an initial design which will then go through the validation and revision stage before being used in the learning trial stage.

After the initial design of the teaching module and the Problem Based Learning *(PBL)-based Student Worksheet (LKPD*) has been prepared, the next step is to validate the design to determine the feasibility of the learning tool before it is used in the trial stage. Validation was carried out by three validators consisting of two lecturers from the Mathematics Education Study Program FKIP UBBG and one mathematics teacher from SMAN 15 Adidarma. The validation process aims to assess the suitability of the content, language, presentation, and integration of learning tools with *the Problem Based Learning syntax* and critical thinking skill indicators. Through this process, the validator provides various suggestions and inputs related to the clarity of the question instructions, the integration of contextual problems, the allocation of time in the LKPD, and the suitability of *the Problem Based Learning* stages in the learning tools. The results of the validator's assessment of the developed learning tools are presented in the following table.

Table 6. Learning Tool Validation Results

Yes	Validator	Empirical Score	Percentage	Average Percentage(%)	Level Validation
1	Validator I	243	305	79,67%	Fall
2	Validator II	211	305	69,18%	Valid
3	Validator III	250	305	81,97%	Highly Valid
	Average	234,6	915	76,94%	Valid

Based on Table 6 above, the highest percentage of validity was obtained of 81.97% with the very valid category, while the lowest percentage was 69.18% with the valid category. At the design revision stage, the researcher received several suggestions and inputs from validators for product improvement as follows:

Table 7. Design Revision

Yes	Initial Components	Validator's Advice	Revised Results
1	The question items are not equipped with clear instructions for work.	Add question hints	Instructions have been added to the question item so that students better understand what to do
2	LKPD has not included the allocation of time for learning activities	Add time allocation to the LKPD	In the LKPD, the allocation of time for each learning activity has been included so that the implementation of learning is more directed
3	Some of the questions are not clearly connected to the main issue and there are still ambiguous sentences	Clarify the relationship between the problem and the parent problem and correct ambiguous sentences	The question has been revised by emphasizing the relationship of each question item to the context of the main problem. Sentences that were previously ambiguous have been clarified so as not to cause mixed interpretations
4	The Problem Based Learning (PBL) syntax is not yet fully visible on the device, and the general information section of the teaching module (target learners) is not complete	Displays the complete PBL syntax and completes the general information section of the teaching module	The stages of PBL have been listed in full in the teaching module so that the learning flow is clearer. The general information section of the teaching module has also been completed, including the target students.

The product trial was carried out on a limited basis to determine the implementation of learning and the suitability of *Problem Based Learning* (PBL)-based learning tools that had been developed before product revisions. The trial involved 15 students of class X-1 SMAN 15 Adidarma and was carried out in two meetings. The first meeting discussed arithmetic row material through contextual problems to introduce the basic concept of rows, while the second meeting discussed arithmetic series material through group discussion activities in solving the problem of summing row tribes. The observation results showed that learning could be carried out well, although the presentation of row and series material separately made the relationship between the two concepts not optimally visible. In addition, at this stage, the validity and reliability of the test instruments tested on the same students were also tested, then the data of the students' work results were analyzed using the help of the SPSS program to determine the quality of the test instruments.

Validity testing is carried out by correlating the score obtained by students on each question item with the total test score. The *calculated r* value obtained from the results of the SPSS analysis is then compared with the *table r* value at a significance level of 5% (α = 0.05). A question item is declared valid if the *calculated r* value is greater than *the r of the table* and the significance value is less than 0.05.

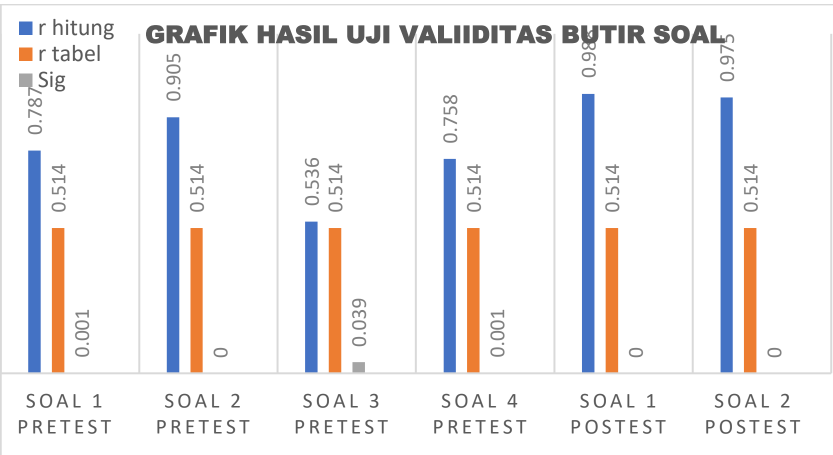
Table 8. Results of Calculation of the Validity Test of Pretest Question Items

Question points	r count	r Table	Sig	Remarks
1	0,787	0,514	0,001	Valid
2	0,905	0,514	0,000	Valid
3	0,536	0,514	0,039	Valid
4	0,758	0,514	0,001	Valid

Table 9. Results of Calculation of Postest Question Item Validity Test

Question Item	r count	r Table	Sig	Remarks
1	0,988	0,514	0,000	Valid
2	0,975	0,514	0,000	Valid

Based on Tables 8 and 9, all pretest question items have a calculated r value of > r table (0.514) and a significance < 0.05, so that all question items are declared valid and suitable for use as research instruments.



The reliability test of the pretest instrument was carried out to determine the level of consistency of the instrument. The reliability test was analyzed using the ***Alpha Cronbach*** through the SPSS program. In the reliability test, Alpha Cronbach can be used > 0.60, then it can be concluded that the variable or measuring tool can be said to be reliable or consistent in measurement (Forester et al., 2024)

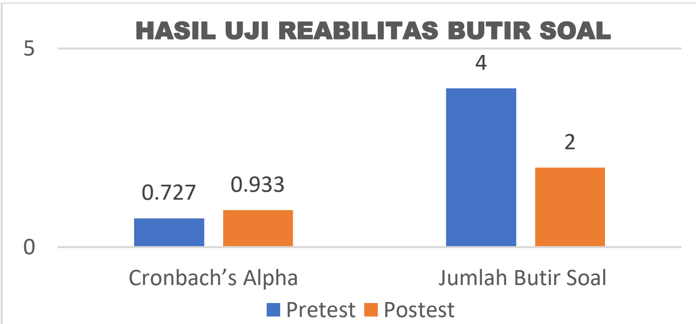
Table 10. Results of Reliability Test Calculation of Pretest Question Items

Cronbach's Alpha	Number of Question Items	Remarks
0,727	4	Reliable

Table 11. Results of Reliability Test Calculation of Postest Question Items

Cronbach's Alpha	Number of Question Items	Remarks
0,933	2	Highly Reliable

Based on tables 10 and 11 above, the Cronbach's Alpha value was 0.727 with the number of question items 4 and 0.933 with the number of question items as many as 2 items**.** The Cronbach's Alpha value was greater than 0.60**,** so it can be concluded that the postest instrument is suitable for use in the research.



The revision of the product was carried out based on the results of a limited trial by combining the material of rows and arithmetic series in one meeting through group discussions so that the relationship between the two concepts was clearer. The next meeting was used for a posttest to evaluate students' critical thinking skills. This revision made the learning flow more structured and supported the development of students' critical thinking skills.

Table 12. Product Revision

No	Initial Design	Revision 1	Revision 2
1	Arithmetic rows and series materials are presented separately at each meeting.	The validator suggested that the connection of concepts be more emphasized in learning.	After the trial, the row and series material is combined in one meeting so that students understand the relationship between the two concepts thoroughly.

No	Initial Design	Revision 1	Revision 2
3	The learning tools have not fully demonstrated an integrated flow.	The validator suggested refining the structure of the device to make it more systematic.	The learning tools are rearranged so that the flow is more structured and the material is more clearly linked.
4	Evaluation is carried out after a separate discussion of the material.	Validators suggest device improvements to be more focused on learning objectives.	The second meeting was focused on the implementation of the posttest to measure student understanding after the use of the revised device.

Ket: Revision 1 based on validator input
Revision 2 based on Trial

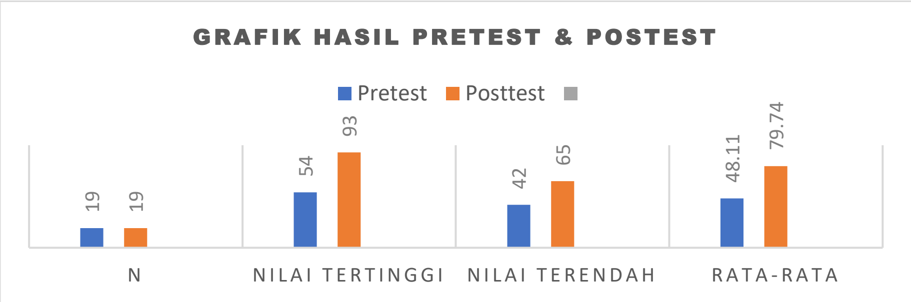
3. Implementation

The implementation stage was carried out by applying teaching modules and LKPD based on *Problem Based Learning* (PBL) that have been revised. The research used *a One Group Pretest–Posttest* design for grade X students. Pretest is given to determine the initial ability to think critically, while posttest is given after learning to see improvement.

Table 13. Pretest & Postest Results

Tests	N	Highest Score	Lowest Score	Average
Pretest	19	54	42	48,11
Posttest	19	93	65	79,74

Based on Table 13 above, it shows that the **average** pretest score is 48.11, while the average posttest is 79.74. This shows an increase in students' critical thinking skills after applying *Problem Based Learning* (PBL)-based learning.



The normality test was performed using Shapiro–Wilk through SPSS to determine if the data was normally distributed. The data was declared normal if the sig. value > 0.05 and abnormal if the sig. < 0.05**.** The results of the pretest and posttest normality tests are presented in the following table.

Table 14. Normality Test Results

	Tests of Normality					
	Kolmogorov-Smirnova			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Pretest	.214	19	.022	.909	19	.072
Posttest	.199	19	.046	.927	19	.155

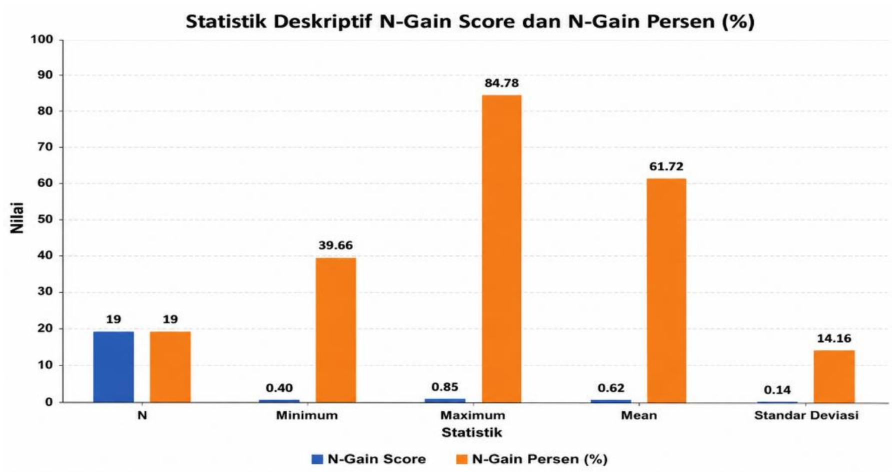
Based on table 14 above of the Shapiro–Wilk test, the significance value of the pretest was 0.072 and the posttest was 0.155 (>0.05), so that the data was distributed normally. Therefore, the analysis of ability improvement was carried out using the N-Gain test**.**

The improvement of students' critical thinking skills was analyzed using the N-Gain test by comparing pretest and posttest scores with the help of SPSS, then analyzed descriptively.

Table 15. Ngain test results

Variable	N	Minimum	Maximum	Red	Standard Deviation
N-Gain Score	19	0.40	0.85	0.62	0.14
N-Gain Percent (%)	19	39.66	84.78	61.72	14.16

Based on table 15 above, the results of the N-Gain **calculation were obtained,** an average score of 0.62 (61.72%) was obtained with the medium **category,** which shows that learning is able to improve students' critical thinking skills quite effectively**.**



Discussion

This research aims to develop arithmetic row and series learning tools based on Problem Based Learning (PBL) and to determine the improvement of students' critical thinking skills after the application of learning. The development of learning tools uses the Research and Development (R&D) method with the Borg and Gall model which is simplified into three stages, namely preliminary study, product development, and implementation.

At the preliminary study stage, information was obtained that students' critical thinking skills were still relatively low. Students tend to use formulas directly without analyzing the given problems. In addition, the learning process is still dominated by lecture methods so that students' involvement in learning is still limited. This condition causes students to be less active in expressing opinions, analyzing information, and solving problems systematically.

At the development stage, the researcher compiled teaching modules and LKPD based on Problem Based Learning which were designed in accordance with the PBL syntax, namely problem orientation, student organization, investigation, presentation of results, and evaluation. The learning tools that had been prepared were then validated by experts and obtained a feasibility percentage of 76.94% with a valid category so that they were suitable for use in learning. After revision based on the validator's suggestions, the learning tools were tested on a limited basis to see the clarity of instructions, understanding of the material, and suitability of the flow of activities before being implemented at the implementation stage.

The implementation stage was carried out using the One Group Pretest–Posttest design to determine the improvement of students' critical thinking skills before and after the implementation of Problem-Based Learning-based learning. The results showed that the average pretest score of 48.11 increased to 79.74 in the posttest. In addition, the results of the N-Gain analysis of 0.62 or 61.72% were in the medium category. The results showed that the Problem-Based Learning-based learning tools were quite effective in improving students' critical thinking skills.

Problem Based Learning (PBL) is effective in improving critical thinking skills because this learning model actively involves students in the process of solving real problems. Through PBL learning, students not only receive information from teachers, but are also trained to understand problems, analyze information, determine solution strategies, discuss, and draw logical conclusions. This process helps students develop analytical, systematic, and evaluative thinking skills in solving mathematical problems. In addition, group discussion and investigation activities in PBL encourage students to be more active in expressing opinions, defending arguments, and evaluating answers so that students' critical thinking skills can develop better.

The development of students' critical thinking skills is also seen during the learning process. At the beginning of learning, some students still have difficulty understanding contextual problems and tend to immediately use formulas without analyzing the information contained in the problem. However, after the implementation of Problem Based Learning-based learning, students begin to get used to discussing, expressing opinions, and evaluating the solution steps used. Investigation activities and group discussions help students become more active in building understanding and more confident in conveying ideas.

The results of this study are in line with Tambunan's (2022) research which shows that LKPD based on Problem Based Learning on arithmetic row and series material has a high level of validity and is effective in learning. The similarity between the research and this study lies in the use of the Problem Based Learning model on arithmetic row and series material. The difference is that Tambunan et al.'s research only focuses on the development of LKPD, while this study develops more complete learning tools in the form of teaching modules and LKPD and analyzes the improvement of students' critical thinking skills.

In addition, the results of this study are also in line with research (Rohman et al., 2022) which develops web-based mathematics learning media with a STEM approach to improve students' critical thinking skills. The results of the study show that the learning media developed is effectively used in learning with an effect size value of 0.504 which is in the medium category. The similarity between Rohman et al.'s research and this study lies in the purpose of the research, which is to improve students' critical thinking skills through the development of learning tools. The difference lies in the approach used, where Rohman et al.'s research uses a STEM approach, while this study uses the Problem Based Learning model. These differences show that various innovative learning approaches can be used to improve students' critical thinking skills.

Theoretically, the improvement of students' critical thinking skills in this study can be explained through the characteristics of the Problem Based Learning model that places students as the center of learning. In PBL learning, students are faced with problems that require them to identify problems, analyze relevant information, evaluate various alternative solutions, and draw logical conclusions. Therefore, Problem Based Learning learning is able to encourage students to develop high-level thinking skills in mathematics learning.

This research still has some limitations, namely only involving one class with a total of 19 subjects and using a One Group Pretest–Posttest design without a comparative class. In addition, the research is only carried out on arithmetic row and series materials with limited implementation time. The data analysis also still uses N-Gain so that it does not use paired sample t-test and effect size to strengthen the research results. Therefore, the next research is expected to use a larger sample and more complete statistical analysis.

CONCLUSIONS AND SUGGESTIONS

Conclusion

Based on the results of the study, it can be concluded that the development of row and arithmetic series learning tools based on Problem Based Learning (PBL) uses the Borg & Gall model which is simplified into three stages, namely preliminary study, product development, and implementation. The validation results show that the learning tool obtained a percentage of 76.94% with a valid category, making it suitable for use in learning.

The results of the study also show that development of PBL-based learning able to improve the critical thinking skills of students in class X of SMAN 15 Adidarma. This can be seen from the increase in average scores Pretest 48.11 to 79.74 in Posttest, and results N-Gain of 61.72% that are in the category moderate.

Suggestions

This research can be a reference for future researchers to develop Problem Based Learning (PBL)-based learning in different materials or educational levels, as well as develop assessment instruments with more diverse critical thinking indicators or add other aspects such as creativity and problem-solving.

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