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Development of PBL-Based Math Comics for the Improvement of Students' Critical Thinking Skills

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ABSTRACT

The development of Problem-Based Learning (PBL)-based mathematics comics involves creating mathematics learning media that combine elements of pictures and stories to help students understand concepts and improve their critical thinking skills. The development of PBL-based math comics uses the Canva and Live Worksheets applications. This research aims to produce PBL-based math comic worksheets for students, created in Canva and Live Worksheets, to improve critical thinking skills in Phase D students. The research carried out is Research and Development (R&D), using the Analysis, Design, Development, Implementation, and Evaluation (ADDIE) model. The results of the research are PBL-based math comic worksheets to improve students' critical thinking skills, accessible on various internet-connected devices. This math comic worksheet focuses on the Pythagorean Theorem for Phase D students, presenting problems in a context-based format and using easy-to-understand language. The research was conducted at SMP IT Nurul 'Ilmi 2 Jambi City with one mathematics teacher, nine students in the small group trial, and 28 students in the large group trial. The results of the study show that the product developed underwent several revisions to become worthy of testing. The instrument used uses the Guttman scale, so that the final validation after revision reaches 100%. The validity of PBL-based math comic worksheets is 100% (very valid) according to material experts and 100% according to media design experts. The percentage of practicality of PBL-based math comic worksheets by educators is 100% (very practical), and by students is 98% (very practical), and the percentage of effectiveness of PBL-based math comic worksheets from the student response questionnaire is 98% (effective). The learning outcome test, in the form of a pre-test and post-test using N-Gain, was completed by 16 people in the medium category, 10 in the high category, and 2 in the low category.

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1. INTRODUCTION

Making a decision requires critical thinking skills that involve thorough analysis to produce the right decision. Critical thinking is reasonable, reflective thinking that focuses on deciding what to believe or do [1]. So, critical thinking skills are among the life skills students have. Individuals need the ability to think critically to address problems in their social and personal lives [2]. Being able to think critically will help students solve problems, both simple and complex, and adapt to change. The ability to think critically also allows a person to solve problems in a structured, effective, and make good decisions in various contexts [3]. 21st-century students must be able to think critically to analyze and synthesize information and adapt to changing times [4]. Education in Indonesia includes critical thinking as one of the eight dimensions of the graduate profile, initiated by the Minister of Primary and Secondary Education of the Republic of Indonesia in 2025, namely faith and devotion to God Almighty, citizenship, critical reasoning, creativity, collaboration, independence, health, and communication [5].

Critical thinking skills are among the essential life competencies students must possess. Critical thinking is a logical, reflective thought process that focuses on determining what should be believed or done [1]. This skill is crucial for individuals to face challenges in both their social and personal lives [2]. With critical thinking abilities, students can solve a wide range of problems, from simple to complex, and adapt to ongoing changes. Critical thinking also helps individuals solve problems in a structured and effective manner and make appropriate decisions in diverse situations [3]. In the 21st century, students are required to master this skill to analyse and synthesise incoming information and adapt to the rapid developments of the era [4]. In Indonesia's education context, critical thinking has been designated as one of the eight dimensions of the graduate profile formulated by the Minister of Primary and Secondary Education of the Republic of Indonesia in 2025, namely faith and devotion to God Almighty, citizenship, critical reasoning, creativity, collaboration, independence, health, and communication [5].

Mathematics learning is one approach to developing critical thinking skills. Mathematics and critical thinking are closely related: understanding mathematical concepts requires critical thinking, and, conversely, critical thinking is strengthened through learning mathematics [6]. There are six indicators of critical thinking known as FRISCO: Focus, Reason, Inference, Situation, Clarity, and Overview. These indicators are described as follows: 1) Focus, the ability of students to answer questions according to the context of the problem; 2) Reason, the ability to provide justification based on relevant facts or evidence at each step of drawing conclusions; 3) Inference, the ability to draw accurate conclusions based on the identification process during problem-solving; 4) Situation, the ability to gather relevant information and apply appropriate mathematical concepts to solve a task; 5) Clarity, the ability to clarify symbols or any elements that remain unclear; 6) Overview, the ability to review the entire work from beginning to end based on the previous FRISCO criteria [7].

Previous studies have shown a significant relationship between student worksheets and critical thinking skills. Research conducted by Elfina and colleagues found that worksheets can enhance students' critical thinking abilities [8]. A student worksheet is a

learning material designed in the form of pages containing reading material and tasks that can be completed during the learning process [9]. Therefore, teachers can innovate by developing worksheets to achieve learning objectives. One possible innovation is transforming worksheets into digital-based learning materials. The use of digital instructional materials makes the learning process more effective and interactive [10].

Another study found a significant correlation between the PBL model and students' critical thinking abilities. Findings from Arifin et al.'s research demonstrated that the PBL model is effective in enhancing students' critical thinking skills [11]. The PBL model is a learning approach that strengthens students' critical thinking by engaging them in systematic problem-solving activities [12]. The PBL model emphasises a learning design that starts with real problems and is relevant to everyday circumstances, enabling students to understand the material in depth through problem-solving. In addition, PBL is considered the right approach because it makes the problem-solving process a means to find mathematical concepts [13].

Based on the needs analysis carried out to identify the gap between ideal and real conditions in phase D mathematics learning at SMP IT Nurul 'Ilmi 2 Jambi City, Phase D students are junior high school students between 12 and 15 years old. The findings from observations and interviews with teachers and students indicate several issues, including students' limited critical thinking when working on mathematical problems, the use of learning methods that are not yet problem-oriented, and worksheets that are less engaging because they consist mainly of monotonous sets of questions. These factors contribute to the failure to achieve the intended learning objectives. Learning goals cannot be met if the learning process fails to capture students' interest [14]. In addition, when solving math problems, students are not accustomed to identifying the problem in detail, such as writing down what is known and what is asked, but are more likely to do calculations immediately.

To overcome these problems, innovation is needed by presenting learning media through PBL-based worksheets packaged attractively and not monotonously, so they are appealing to students and improve their critical thinking skills. The innovation is to make PBL-based worksheets less monotonous by incorporating the nuances of mathematical comics. Comic media is an effective learning medium that combines words and images, summarised in a storyline, displayed to convey scientific messages or information, and packaged in short dialogues [15]. Meanwhile, in the learning process, comics can increase understanding, participation, engagement, and improve students' critical thinking skills [16].

PBL-based math comic worksheets can be developed with the help of Canva and Liveworksheets applications to provide a more engaging learning experience and improve students' critical thinking skills. This PBL-based math comic worksheet is expected to help students better understand the Pythagorean Theorem and improve their critical thinking skills. This development research is also expected to benefit not only students but also Phase D mathematics teachers. Meanwhile, the difference lies in the use of comics, materials, and research subjects. The relevant research uses opportunity material for Phase E. In contrast, this study uses Pythagoras Theorem material for Phase D. There has been no research on the development of mathematical comics that raises the material of the Pythagorean Theorem, making this research innovative in terms of the material used in product design.

This study seeks to address the identified gaps by designing a product in the form of a PBL-based mathematics comic worksheet developed using Canva and Liveworksheets, aimed at enhancing students' critical thinking skills. The research is expected to make meaningful contributions to the field of education, particularly by creating learning media that foster critical thinking in mathematics. By examining the development process of PBL-based math comic worksheets intended to strengthen students' critical thinking abilities, this product is anticipated to serve as a reference for educators and future researchers in creating effective mathematics learning materials.

2. METHOD

The development of PBL-based mathematics comics to enhance students' critical thinking skills is conducted through a research and development (R&D) approach. This method is used to evaluate the validity, practicality, and effectiveness of the product being created [17]. The development process follows the Analysis, Design, Development, Implementation and Evaluation model, commonly known as the ADDIE model [18]. The ADDIE stages are outlined as follows:

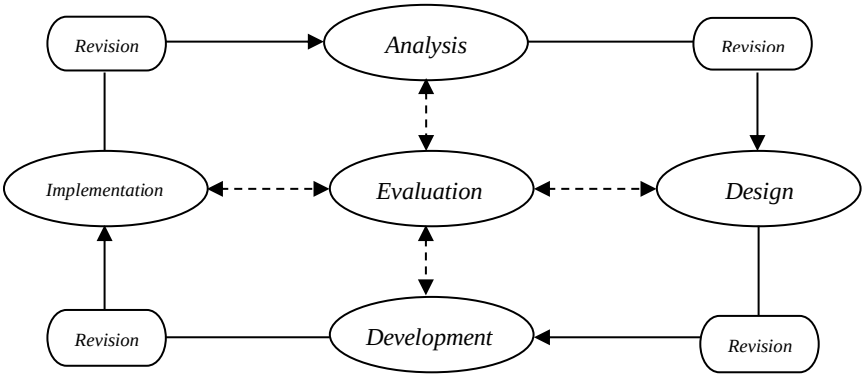


Figure 1. ADDIE development model

a. *Analysis*

Analysis is the initial phase of a development model, intended to identify existing gaps and determine the needs to be addressed. The needs analysis was conducted through observations, interviews, and questionnaires. The following activities were included in the needs assessment:

1) Identifying gaps by examining preliminary data related to the curriculum, learning system, students, and the current learning environment and conditions, carried out through observations and interviews.
2) Establish instructional objectives that address the gaps identified.
3) Analysis of student characteristics involves identifying abilities, experience, motivation, and other factors relevant to the development to be carried out. Data were collected by distributing test questions and questionnaires to students as research participants.
4) Identify available resources, including technology, content, human resources, the internet, and other supporting resources.

5) Identify potential delivery systems by reviewing learning systems with strong potential for use, and outline the development to be carried out. It is based on learning objectives, the condition of teachers, students, and other supporting resources.
6) Developing a research project management plan involves determining who is involved in this research. The goal is to carry out the development process in a more disciplined, more directed manner.

After this analysis, the development goals become clearer, and the data used as a reference for development are more focused.

b. *Design*

The *design stage* includes forming a team comprising developers, validators, material and design experts, practitioners, and respondents. After the team is formed, it prepares a draft research schedule from collecting reference sources to presenting research results. After that, make *flowcharts* and product *design* specifications into *a storyboard*.

c. *Development*

This stage is the production stage that transforms concepts from the design stage into concrete products. At this stage, the development process involves creating a product by creating storyboards in the Canva and Liveworksheet applications, as well as validation by material and *media design* experts. Experts will review the initial product and provide input, suggestions, or comments to identify what needs improvement until the product is declared valid.

d. *Implementation*

The implementation phase includes small- and large-group trials to evaluate the product's effectiveness and practicality. Proper preparations and approaches are put in place so that the implementation of learning products runs smoothly and provides maximum benefits to students and teachers.

e. Evaluation

Throughout the development process, formative evaluations are conducted to verify that the system is progressing as intended. In the final phase, a summative evaluation is conducted to assess the product's overall impact, with the primary aim of determining whether the development objectives have been met. This is done by comparing pre-test and post-test results and by reviewing students' feedback. Product quality is seen from practicality and effectiveness. Practicality is assessed by ease of application, usefulness, and compatibility between the curriculum and the learning process. Effectiveness shows how the developed product achieves learning goals, improves learning outcomes, and understanding. The product is considered effective when it demonstrates a beneficial influence on the learning process or its results.

Trial subjects

The test subjects in the development research are the parties involved in testing the products that have been developed, namely mathematics teachers and Phase D students of Class VIII SMP IT Nurul 'Ilmi 2 Jambi City, who are selected by the purposive sampling method or adjusted to the research needs. The author first submitted a research permit to the Principal as an opening of the flow of meetings between the researcher and the subject. The products in this study were tested on junior high school mathematics teachers using a practicality test response questionnaire.

Furthermore, small-group trials were conducted with Phase D students of varying abilities. This trial was conducted to evaluate the practicality of the developed mathematical comics. At this stage, the product's feasibility is examined to determine whether it can effectively support students' varying learning abilities.

Data Types and Data Sources

This study uses both qualitative and quantitative data. Qualitative data was collected during the product validation stage in the form of suggestions, critiques, feedback, and comments from expert teams, including material and design specialists. This feedback served as a guide for refining the PBL-based mathematics comic to enhance students' critical thinking skills. Such qualitative input forms the foundation for improving the product's relevance, clarity, and instructional effectiveness. Additional qualitative data were also gathered through small-group testing.

Quantitative data, on the other hand, were obtained from validator evaluations and teacher and student assessments collected via practicality sheets and student response questionnaires. The outcomes of these instruments provide indicators of the product's practicality and students' acceptance as users. Moreover, quantitative data were derived by calculating the percentage increase in students' critical thinking abilities after the large-group trial, based on pre-test and post-test score comparisons. The integration of both qualitative and quantitative data enables a comprehensive assessment of the development process and its effect on student learning outcomes.

Data Collection Instruments

Instruments play an important role in systematically and validly assessing each stage of evaluation, validation, practicality, and product effectiveness. Valid criteria are used to obtain data that demonstrate the validity of the material and product design developed. Two research instruments were designed for validity purposes: the material expert validation sheet for content testing and the design expert validation sheet for product design testing. This instrument is intended to ensure that the product's content and visuals comply with the standards of competence in learning. Practical criteria are used to obtain data to declare that the developed product is practical in use. There are two instruments designed for practical assessment, namely the practicality sheet by the mathematics teacher and the response sheet by the student. The results of this instrument provide an idea of how easily the product can be implemented in mathematics learning.

Furthermore, the criteria for product effectiveness are seen from the product's ability to improve students' critical thinking skills. The validator team has validated all instruments used. The triangulation of the instruments used allows researchers to validate the success of the products developed in supporting the success of learning objectives, especially in improving students' critical thinking skills.

Data Analysis Techniques

The collected data is then analysed to assess the validity, practicality, and effectiveness of the developed mathematical comics. The data analysis techniques carried out are:

a. Analysis of Practicality Test Data

Practicality data instruments in the form of a mathematics comic practicality questionnaire were given to mathematics teachers and students in small groups. The percentage is obtained using the following formula:

$$P = \frac{f}{N} x\ 100\% \quad (1)$$

Information:

P = percentage of response

f = total score of data collection

N = maximum score

The percentage of practicality results obtained is classified in percentages as follows [19]:

Table 1. Product Practicality Criteria

Criterion	Level of Practicality
P > 80%	Very practical
60% < $P \leq$ 80%	Practical
40% < $P \leq$ 60%	Quite practical
20% < $P \leq$ 40%	Less practical
0% < $P \leq$ 20%	Impractical

Based on these criteria, PBL-based mathematics comics to improve students' critical thinking skills are said to be very practical to use in learning if they are at the level of practicality with the criteria of "very practical", "practical", or "quite practical" by teachers and students.

b. Analysis of Effectiveness Test Data

Differences between *Pre-test* and *post-test* are used to determine the improvement of students' critical thinking skills after participating in learning using developed mathematics comics. The difference between the two tests is expressed through N-gain, with the following formula:

$$(g) = \frac{(S_{post})-(S_{pre})}{(S_{max})-(S_{pre})} \quad (2)$$

Information:

(g) = N-gain

(S_{post}) = Average score of the final meeting

(S_{pre}) = Average score of the initial meeting

(S_{max}) = Maximum average score

Furthermore, the percentage categories in the N-Gain score are as shown in Table 2 below:

Table 2. Categories of Interpretation of N-Gain Score Effectiveness [20]

Percentage	Interpretation
40% ≤ g < 55%	Less effective
55% ≤ g < 75%	Quite effective
g ≥ 75%	Effective

Based on the interpretation of the effectiveness of the N-Gain score, the math comics developed are declared effective if they obtain the category of "quite effective" or "effective".

Meanwhile, the categories of N-Gain score distribution [21] are as follows:

Table 3. Category N-Gain Score

N-Gain Value	Category
g > 0.7	High
0.3 ≤ g ≤ 0.7	Medium
g < 0.3	Low

Based on the N-Gain score category, students should show an increase in critical thinking skills.

3. RESULTS AND DISCUSSION

This study provides results in the form of; (1) PBL-based math comics to improve students' critical thinking skills developed with the help of Canva and *Liveworksheets applications*, (2) assessments or responses by subject matter experts and design experts to the product that has been developed, which serves as validation of the accuracy of the content and instructional design, (3) teacher responses and feedback from students during the trial both in small groups and large group trials collected using questionnaires that have also been validated by instrument experts that function as validation of practicality, (4) *pre-test* scores and *post-test scores* related to the use of products in learning that function as validation of product effectiveness. The development of this product was conducted using the ADDIE model with the following stages:

3.1 Analysis Stage

The analysis stage began with an interview with a mathematics teacher at SMP IT Nurul 'Ilmi 2 Jambi City to explore the curriculum used in the education unit, the flow and objectives of learning (ATP), and the expected learning outcomes (CP). The results of the analysis show that the curriculum implemented in Phase D of SMP IT Nurul 'Ilmi 2 Jambi City is independent. The material chosen in the development of PBL-based mathematical comic products is the Pythagorean Theorem.

Student observations indicate that their critical thinking skills remain weak when solving math problems. In addition, this analysis found that teachers still use worksheets that contain only questions, which makes them less interested in students. Teachers want teaching materials that are more interesting and easier to understand, while also accommodating the resources available in schools, such as packaged books and technology facilities. Therefore, this research aims to develop mathematical comics that can increase students' interest in learning and critical thinking skills. The analysis of available resources includes content resources sourced from math package books; technology resources such as electricity, projectors, the internet, and Chromebooks; teaching facilities in classrooms; and human resources such as mathematics teachers and students.

3.2 Design Stage

This design stage addresses the needs identified in the analysis stage. Preparations are made in product development through the compilation of flowcharts and the creation of storyboards. *Flowcharts* are flowcharts that act as a guide in product development. With the planned structure, the development of PBL-based mathematical comics to improve students' critical thinking skills becomes more focused. After making the *flowchart*, a storyboard is created, a visual plan for the mathematical comic to be developed. Starting with the cover page, the introductory page outlines the flow of learning objectives and instructional instructions, as well as the order of the content pages, ensuring a systematic and engaging presentation. The developed math comic comprises 11 pages: a cover, a hint page, a content page, and a question page. On the content page, the comic storyline is arranged around five PBL syntax elements: orientation to problems, organising students to learn, guiding investigations, presenting the results of work, and analysis and evaluation.

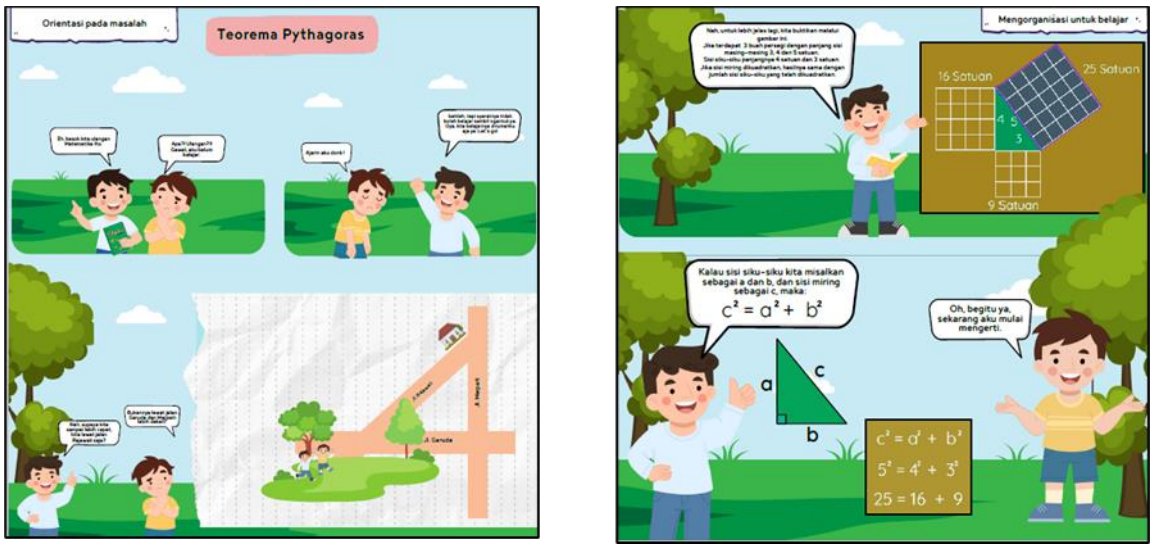
After *the storyboard* is completed, the application used during development is prepared. In this study, Canva is used to create a PBL-based math comic design, and after the design is completed, it is transferred to the LiveWorksheet application to turn the math comic into an interactive resource. The look of the math comic can be seen as follows:

(a) (b)

Figure 1. Comic view for a) home/*cover* page and b) hint page, CP and TP

On the cover page, there is a math comic title, namely "LKPD Mathematics Comics", and the focus of the material is "Pythagorean Theorem", as well as the class identity to show the target user of the product, namely "Class VIII", meaning that Phase D students can use this math comic. On the second page, there are "Instructions for use", "Learning Outcomes", and "Learning Objectives".

The third page and subsequent pages are content pages featuring mathematical comics. Packaged in activities that are close to students' daily lives, which aims to make this PBL-based math comic easy to understand, interesting, and fun for students. Here are some pages of math comic content that have been developed, namely:



(c) (d)

Figure 2. Content pages for c) orientation on the problem and d) organising to learn

The content page is designed to be more engaging, encouraging students to use math comics for learning. On the content page, there is a math comic storyline featuring the two main characters. The atmosphere was created by showing that the two people were good friends and by talking about the Pythagorean Theorem. The material to be studied is included in the character's conversation. In addition, the content page also shows the stages of PBL as part of efforts to improve students' critical thinking skills, namely orientation to problems, organising to learn, guiding investigations, presenting works, and evaluation. The evaluation of this design stage focuses on feasibility and effectiveness testing of flowcharts and storyboards before proceeding to the development stage, ensuring the design truly supports the achievement of learning objectives.

3.3 Development Stage

At the development stage, the researcher has prepared an instrument for a team of material and design experts to validate PBL-based mathematical comic products. The purpose of validation is to gather input, suggestions, or comments to inform product revisions. Thus, the quality of this PBL-based mathematics comic is expected to align with the development objectives. The validation process carried out includes:

a. Validation of Research Instruments

The instruments used by experts to assess products include questionnaires and mathematical questions. The expert team will validate the research questionnaire instruments, including material validation questionnaires, design validation, teacher practicality questionnaires, student practicality questionnaires, mathematics test questions, and student response questionnaires. The validation results for the material expert instruments initially reached only 61%; after revisions based on the validators' suggestions and comments, the results reached 100% and were categorised as "very valid". While the instrument validation rate among design experts was initially 63%, it was revised based on validators' suggestions and comments until it reached 100% for the "very valid" category. For the validation of the teacher's practicality questionnaire, 96% were categorized as "very valid," and for the student practicality questionnaire, 98% were categorized as "very valid." These results show that the questionnaire that has been prepared can and should be used for the validity, practicality, and effectiveness of the product.

b. Validation of Media Quality Test

Media quality tests are validated by material and design experts. Material experts validate the initial product at 62%, then revise it based on the validator's suggestions and comments until the final product is achieved. Meanwhile, the validation rate by design experts on the initial product was 72%, and validators provided input and suggestions for revision until the revised product. The validation results were 100% in the "very valid" category. After revision, the developed product is feasible and can be tested in research.

3.4 Implementation Stage

Once the product is deemed ready for testing, it is implemented in several phases: a practicality assessment through a small-group trial, followed by an effectiveness test. An additional effectiveness evaluation is then conducted in a large-group trial, during which students' critical thinking skills are measured using pre-test and post-test assessments.

a. Small Group Trials

The small-group trial is intended to evaluate the practicality of the PBL-based math comics designed to enhance students' critical thinking skills. In this phase, the product was tested with nine students, comprising three high-ability, three medium-ability, and three low-ability learners. After using the PBL-based math comics, the students provided feedback, suggestions, and input through a practical questionnaire. The questionnaire results showed a 96% score and a "very valid" rating, indicating that the PBL-based math comics are suitable for use without revisions.

b. Large Group Trials

The large group trial was applied to Phase D students at SMP IT Nurul 'Ilmi 2 Jambi City for 28 students. Learning activities using PBL-based mathematical comics to improve students' critical thinking skills were held in three meetings. In meeting 1, students were given a pre-test to assess their ability to think critically when solving contextual problems related to the Pythagorean Theorem. After students have completed the Pre-test questions and learned to use math comics, have students *share* 1 that has been developed. In the learning process, students are divided into several groups, and students and their group members discuss concepts using developed mathematical comics. Students also had the opportunity to explore contextual problems in math comics and present the results of their discussion to the class. At the second meeting, the learning process continued by using the math comics share 2 that had been developed. The learning process is packaged as group discussions and the presentation of the discussion results. After two meetings on the learning process, the third meeting was held to review the material and continue working on the post-test questions. There was a significant difference between the results of the *Pre-test* and *post-test*, as shown in the following diagram:

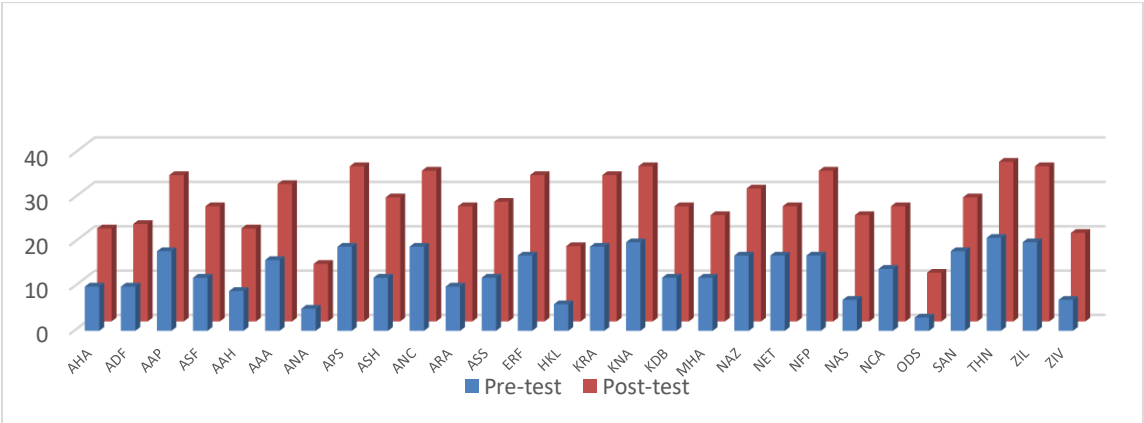


Figure 3. Comparison of *pre-test* and *post-test results*

The post-test consisted of two essay questions with a maximum possible score of 36. This maximum score was determined by allocating points for each FRISCO critical thinking indicator. The pre-test results show that students' performance was low, indicating that their critical thinking skills were still limited. In contrast, the post-test results demonstrated an overall improvement, suggesting that students' critical thinking abilities increased after engaging in learning activities using the math comics. An N-Gain analysis was then conducted to evaluate the effectiveness of the mathematical comics in enhancing students' critical thinking skills.

The effectiveness of the PBL-based math comics was assessed by comparing pre- and post-test scores. Based on this comparison, students' improvement levels could be categorised as "High," "Medium," or "Low." Among the 28 students in the Phase D class who participated in the large-group trial, all showed some improvement, though the levels varied. Of the 28 students, 10 showed a "High" level of improvement, 16 demonstrated a "Medium" level, and 2 students remained in the "Low" category. Although these two students were still in the low group, they generally showed stronger abilities in areas outside mathematics. The following are the N-Gain results calculated from the pre-test and post-test score comparison:

Table 4. N-Gain Calculation Results

No	Student Code	Pre-test	Post-test	Pre-test – post-test	Skor max – pre-test	N-Gain	Criterion
1	AHA	10	21	11.00	26.00	.42	Medium
2	ADF	10	22	12.00	26.00	.46	Medium
3	MONKEY	18	33	15.00	18.00	.83	High
4	ASF	12	26	14.00	24.00	.58	Medium
5	AAH	9	21	12.00	27.00	.44	Medium
6	AAA	16	31	15.00	20.00	.75	High
7	ANA	5	13	8.00	31.00	.26	Low
8	APS	19	35	16.00	17.00	.94	High
9	ASH	12	28	16.00	24.00	.67	Medium
10	ANC	19	34	15.00	17.00	.88	High
11	NOW	10	26	16.00	26.00	.62	Medium
12	IS	12	27	15.00	24.00	.63	Medium
13	YARD	17	33	16.00	19.00	.84	High
14	HKL	6	17	11.00	30.00	.37	Medium
15	KRA	19	33	14.00	17.00	.82	High
16	KNA	20	35	15.00	16.00	.94	High
17	KDB	12	26	14.00	24.00	.58	Medium
18	MHA	12	24	12.00	24.00	.50	Medium
19	NAZ	17	30	13.00	19.00	.68	Medium
20	NET	17	26	9.00	19.00	.47	Medium
21	NFP	17	34	17.00	19.00	.89	High
22	IN	7	24	17.00	29.00	.59	Medium
23	NCA	14	26	12.00	22.00	.55	Medium
24	ODS	3	11	8.00	33.00	.24	Low
25	SAN	18	28	10.00	18.00	.56	Medium
26	YRS	21	36	15.00	15.00	1.00	High
27	ZIL	20	35	15.00	16.00	.94	High
28	ZIV	7	20	13.00	29.00	.45	Medium
	Average N-Gain					0.63	High
	Percentage					63%	Quite Effective

Furthermore, the results of the N-Gain interpretation can be seen in the following figure:

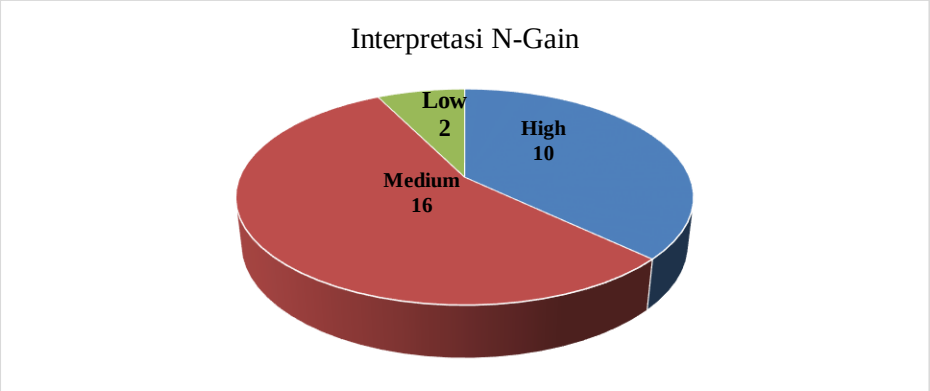


Figure 4. N-Gain interpretation criteria

Thus, it can be concluded that students' critical thinking skills have improved by learning to use PBL-based mathematical comics.

3.5 Evaluation Stage

The evaluation aims to produce PBL-based math comics to improve students' critical thinking skills by utilising *Canva* and *Liveworksheets* applications that have met validity, practicality, and effectiveness [12]. The evaluation carried out at each stage has led to a comprehensive process to produce products suitable for learning. The evaluation carried out in each stage includes:

a. Evaluation of the Analysis Stage

The analysis stage involves identifying existing gaps. Based on the gaps identified, the author developed a research idea: a PBL-based mathematics comic to improve students' critical thinking skills. The author examines the solution to the gap by identifying other opportunities within the education unit. The identification results that the author found were in the form of efforts by mathematics teachers to make worksheets, but they had not met the students' attraction to learn mathematics.

b. Design Stage Evaluation

At the design stage, the author submits a product design to a team of experts for validation. The evaluation results are presented as suggestions, comments, and responses from a team of experts on the product design. Based on the results of this validation, the author revised PBL-based math comic products to enhance students' critical thinking skills. Among the suggestions received was to make the comic flow contextually and to show the stages of PBL. The author revises based on the suggestions received.

c. Evaluation of the Development Stage

At the development stage, the evaluation is conducted to present the results of the design revision to the expert team. Furthermore, the author received suggestions and comments for the revised product.

d. Evaluation of the Implementation Stage (*Implementation*)

Researchers conducted small group trials. Receive input and feedback from mathematics teachers and from students on practicality. At this stage, the product is more likely to receive support from both teachers and students if it is deemed suitable and practical to use.

4. CONCLUSION

This development research has produced a PBL-based mathematical comic to improve students' critical thinking skills, and it can be used in mathematics instruction, especially for the Pythagorean Theorem. The PBL-based mathematical comic media developed is reported to have met quality standards through material and design validation, with very high validity. Mathematics comics are also declared practical through practical tests conducted by teachers and students, with very practical criteria. In addition, math comics also obtained quite effective criteria through the N-Gain score test. However, this mathematics comic media should still be developed into other products, leveraging technological advances and variations to support more engaging mathematics learning.

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