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Improving Students' Comprehension on Descriptive Text by Using Graphic Organizers Integrated with Islamic Values

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ABSTRACT

The purpose of this study was to find out whether the use of graphic organizers integrated with Islamic values can improve students' ability to comprehend descriptive texts. Since the true education requires a balance of cognitive development and character development or moral fortitude as the world becomes far from religious path, therefore, this study carried Islamic values as part of classroom English. The subject of this research was grade eight of SMPIT Al-Fauzi Medan of 2023/2024 academic year which consists of 25 students. Classroom action research was implemented following Kurt Lewin's model with action research procedures, namely planning, implementation, observation, and reflection. This research was conducted in two cycles in each cycle consists of two meetings. Data collection techniques in this study used the following instruments: interviews, field notes, questionnaires, and tests. The results of this study integration of media GOSS with Islamic values showed significant improvement on students' comprehension on descriptive texts. Students achieve expected grades which is higher than the minimum criteria 70 gradually at the end of the cycle. The average score of the students on the initial test was 51.25. The average value of students in the first cycle is 58.75. The average value of students in the second cycle is 72.80. Hence, there are positive responses from students and English teachers regarding to the use of media graphic organizers integrated with Islamic values to improve students' comprehension on descriptive text.

Keywords: Reading Comprehension, Descriptive Text, Graphic Organizers, Islamic Values

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1. INTRODUCTION

In English language acquisition, four abilities must be imparted by the educators and mastered by learners: reading, listening, speaking and reading. For both native speakers and new learners of English, it is important to note that reading and listening as receptive skills to understand the texts whether on spoken or written sources. Zimmerman and Hutchins (2003) say that reading comprehension is the capacity to read, process, and understand content. In addition, reading comprehension is a complex task which depends on a range of cognitive and linguistic processes. The complexity can be captured as the product of two sets of skills: decoding and linguistic comprehension (Nation, 2019). Then, Duke & Cartwright (2021) propose active view of reading (AVR) as an active self-regulation, which allows for word recognition, language comprehension, and the processes that bridge them (bridging processes) while reading. Therefore, GOs good comprehension is pivotal if reading has a purpose, if a reader engages with and learns from a text, ultimately, a reader is to enjoy what they're reading.

Many students enjoy stories and can read well, but they occasionally struggle to understand what they've read. Building reading comprehension abilities begins with a firm foundation that extends beyond simply completing multiple choice questions. True comprehension emerges from students' personal lives, experiences, and perspectives on the world. Reading comprehension questions on high-interest materials begin from imagining written language and communicating their comprehension through drawing which leads them carefully chunk the unit studies on intriguing themes to deepen their baseline knowledge. Reading through visualization will develop skills in sequencing, retelling, identifying character traits, understanding setting and plot, creating story maps, identifying the main idea and details, making predictions, drawing inferences from the text.

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Descriptive text is brought to the classroom as reading materials which is a paragraph vividly portrays a person, place, or thing in such a way that the reader can visualize the topic and enter into the writer's experience (Evawina, 2010). Descriptive text looks easy to understand but actually has a high level of difficulty for students at primary and elementary level. Thus, we can understand that students have a level of difficulty in learning descriptive text even though there have been many efforts that have been done by teachers at classroom English to students both from media, techniques, and methods (Hafizah, et.al, 2024). Previous findings support the observation, as Prayudha (2023) finds several key challenges students have in reading descriptive texts, including recalling information, understanding complex text structures, unfamiliarity with the subject matter, lack of fluency, and insufficient use of reading strategies during the learning process.

Several studies show that the use of graphic organizers (GOs) in teaching reading improve students' comprehension (Ayiz, 2024; Min, 2023; Sabarun, et.al., 2023; Alawi, 2011; Yusnaini, 2018; Mutia, 2019; Tayib, 2015; Mahmudah, 2015). Furthermore, Salazar-Rodríguez (2020) found the efficacy of GOs showed discernible enhancement in overall text comprehension. These findings suggest that GOs are effective tools for enhancing students' comprehension and managing the cognitive demands of language learning. Therefore, graphic organizers (GOs) become sufficient media that can help students with difficulties in comprehending descriptive text. GOs media is a pictorial way of constructing knowledge and organization information. These methods, when incorporated in the lesson, provide students with the opportunity to actively participate and contribute to their learning process and it can help to improve the students' capacity for active learning.

The use of GOs improves learning in the classroom. Though very simple to the eye, GOs are powerful tools, highly instrumental in altering and improving the teaching-learning process in the classroom. The Goals of GOs media are to improve reading comprehension and increase conceptual learning in ways that maximize students' involvement (Bromley, et.al., 1999). Furthermore, GOs provide many benefits, for instance; helping students chunk the content of the texts, helping students to classify ideas and communicate, guiding students in demonstrating their thinking process and many others. According to Watkins (2007), there are 5 reasons for using GOs such as tools for critical and creative thinking; organizing information; understanding information and relationships; depicting knowledge and understanding; and self-learning.

In the other hand, religious values are increasingly regarded as an integral, basic element of education, especially in influencing character, morality, and social cohesion. Research indicates that integrating these values helps develop mental resilience, empathy, and ethical decision-making in students. Rather than restricting knowledge, incorporating religious and moral values prepares individuals to contribute positively to a diverse society. Studies demonstrate that incorporating these principles fosters mental resilience, empathy, and ethical decision-making among pupils. Instead of limiting knowledge, integrating religious and moral principles equips individuals to positively participate to a varied community (Siregar, 2024). Therefore, in this study, the materials brought to the classroom are based on the character of Islamic figures and Islamic treasures such as:

Cycle	Islamic Figures	Islamic Treasures
Cycles 1	The Prophet Muhammad SAW	Hajar Aswad
	Muhammad Al Fatih: The Conquest of Constantinopel	Ka'bah
	1. Pharaoh:A Symbol of Arrogance and Tyranny	The Bee (An-Nahl)
Cycle 2	Muammar Qaddafi| Biography, Death and Facts	Madinah
	Mustafa Kemal Attaturk: His Death and Grave Story	Mecca
	Saddam Husein: Biography, Death and Facts	The Al-Qur'an

Many previous studies have been conducted on the topic of reading comprehension with the assistance of graphic organizers; however, hardly any of them are associated with Islamic values. In contrast, Aziz (2025) research, "Advance Organizer Strategy and Reading Comprehension: A Longitudinal Analysis of Madrasa Students' Performance," focused solely on the efficacy of GOs in the context of reading,

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without establishing a connection to Islamic-themed teaching materials. The other previous studies, such as Qi and Jiang (2021), reported a significant achievement in comprehension among junior high school students in China by carrying GOs while reading. Albufalasa (2020) found that students using GOs not only gain higher comprehension scores but also increase motivation. In Iran, Rasouli and Heravi (2018) discern learners who used GOs outperformed peers in both comprehension and information retention. Similarly, Hon and Mukundan (2023) stated that GOs reduced cognitive load and enhanced performance among Malaysian ESL learners. In the Chinese EFL context, Min et al. (2023) further remarked that GOs not only enhanced students' critical thinking skills but also improved their reading comprehension and engagement. The deficiencies of these prior investigations can be summarized as the necessity for curriculum developers to incorporate GOs with Islamic epistemic principles (e.g., Tadabbur reflection) in order to align cognitive strategies with religious pedagogy. These modifications convert GOs into a culturally responsive instrument for Islamic education systems at Islamic schools. Therefore, this classroom research intended to clarify how is the students' reading comprehension on descriptive text by using GOs which is integrated with Islamic values and to what extend does the use of GOs integrated with Islamic values improve the students' comprehension on descriptive text.

2. RESEARCH METHOD

The design used in this study is Classroom Action Research (CAR). According to Kember (2000), action research has several major characteristics; (1) action research is concerned with social practice which it involves direct interaction of teacher and group of students (2) action research is aimed towards improvement (3) action research is a cyclical process which involves some phases of planning, acting, observing, and reflecting (4) action research is pursued by systematic inquiry (5) action. The research design of CAR in this study is a collaborative classroom action research. It means the researcher collaborates with the English teacher of SMPIT Al-Fauzi Medan.

The writer uses the CAR procedure based on Kurt Lewin's design. Lewin (1947) stated that CAR has two cycles in which each cycle contains four phases; planning, acting, observing, and reflecting as follows:

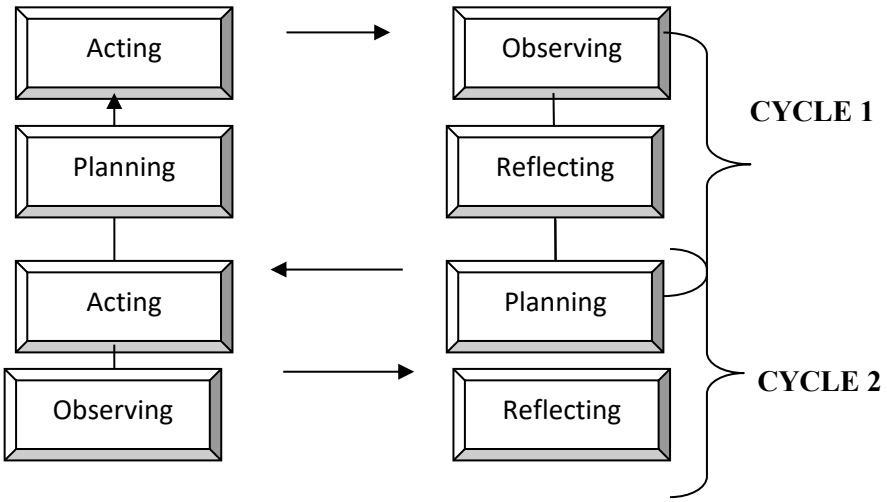

Fig. 3.1
Kurt Lewin's Action Research Design

Lewin's CAR design consists of four phases; planning, acting, observing, and reflecting within one cycle. If the first cycle finished but still found any problem, it is necessary to continue to the second cycle with the same concept of the first cycle. Those are planning, acting, observing, and reflecting. In addition, before entering the cycle of classroom action research, the writer conducts the preliminary study. According to Mills preliminary information gathering is taking time to reflect on your own beliefs and to understand the nature and context of your general idea. It is aimed to gain data about problems faced by teacher and students in teaching-learning activities and needed to be solved.

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Participants

This study is conducted at SMPIT Al-Fauzi located at Jl. Garu II/Nusa Indah No.59, Kecamatan Medan Amplas, Kota Medan, Provinsi Sumatera Utara. The subject of research was students of Class VIII that consist of 25 students. The reason of choosing this school as the subject because there still lack of students' ability in reading skill especially in descriptive text and moreover as one of Islamic school in Medan.

Instruments and data Collection

Technique of collecting data in this study is both qualitative data and quantitative data. The writer uses qualitative data consist of interview, field notes, and questionnaire sheet. While quantitative data consists of students' final reading as a pre-test and post-test.

Data Analysis

Reading comprehension skills of elementary school students is related to the indicators studied. The reading test given in the form of multiple choices to measure the students: (1) Understanding 5W1H Information (Who, What, When, Where, Why, How) based on the descriptive texts they read; (2) identifying characters, events, places, times, reasons, and ways in descriptive text well; (3) Determining the main idea in the descriptive texts; and (4) making conclusions from the text. In the other side, the data gathering through field notes and interview is analyzed by presenting the description of the result of field notes and interview. Questionnaire is analyzed in the form of percentage and presented by the description of the result of questionnaire.

3. RESULTS AND DISCUSSION

The Result of Pre-Interview

In doing the first step, namely pre-interview, the researcher used unstructured interviews. In this interview, below are the conclusion taken based on the interview:

The Questions	Conclusion
What are the general conditions of the class during the teaching and learning process?	Students had varying personalities, so their attitudes toward activity and response varied. However, in general, pupils who enjoy learning English outperform those who dislike it. Students who dislike learning English struggle to understand detailed material.
What difficulties do students experience when reading?	The difficulties faced by grade 8 students include difficulty understanding unfamiliar words or phrases.
How are students' reading ability?	The students' capacity to understand text in onetime reading is still low so they need to repeat reading several times. However, in class, many students must repeat at least two or three times reading.
What teaching media do teachers often use to overcome difficulties in improving students' reading skills	Teacher employed visuals and storytelling media as a medium for learning to read descriptive text, with the goal of helping students understand more quickly and participate more actively in teaching and learning activities.

The conclusion from the interviews with grade eight students is that some students like to learn English, students also experience difficulties in improving their descriptive text understanding, namely lack of vocabulary, low motivation and difficulties to grasp the texts at one time reading.

The Result of Pre-Questionnaire

a) Students' motivation in learning reading especially in reading descriptive text.

Positive	Fair	Less
40%	20%	40%

b) Students' responses whether reading descriptive text is difficult.

Positive	Fair	Less

66.67 %	20%	13.33%

c) Students' responses to difficulties in reading descriptive text can be overcome.

Positive	Fair	Less
22%	13.10%	64.90%

d) Students' responses to the using of GOSS when teaching reading descriptive text.

Positive	Fair	Less
43.33%	36.67%	20%

e) Students' responses to the using of Islamic figures and treasures as the reading materials.

Positive	Fair	Less
58.33%	24.67%	20%

At this initial project, the students showed reluctant responses to the learning activities when reading English text by using GOs integrated with Islamic figure and treasures. Positive responses at all questions showed less than 70%.

The Result of Pre-test

The pre-test in this study was conducted before CAR implementation. In this test students were asked to read a descriptive text then the results from the pre-test shows the average value of the students' pre-test scores is 51.25. There are no students who gained the minimum criteria score 70. The data analysis shows that the students' ability in reading descriptive texts is still very low.

Findings of the First Cycle

a. Planning

At this stage, the researcher employed GOs to help students improve their performance in reading descriptive texts. The researcher also took field notes to monitor the actions of students and teachers during the teaching and learning process, allowing researchers to collect data on whether or not the lesson plans were acceptable for the previously created lesson plans. In addition, the researcher prepared the first post-test to collect data and determine whether or not student scores increased between the pre-test and the first post-test.

b. Acting

In this stage, the researcher carried out the teaching and learning process of descriptive text in the classroom using the lesson plan created. Firstly, the teacher presented the information that had been taught and learned by the students, as well as an explanation of the GOs medium, so that the students understood it. The researcher then explained the descriptive text using GOs as the media. The students are then instructed to arrange and collect sentences into a descriptive paragraph. At the second meeting, students were assigned to create a descriptive narrative about persons using GOs.

c. Observing

During this stage, the researcher observed the teaching and learning process of teachers and students using field notes that included information about the class situation, activity, student focus and response to the material taught by the teacher, and the teacher's delivery when explaining the material to students. Students are a little more engaged, pay attention, and respond to the teacher. Some students in the class struggle to absorb the information. As a result, some pupils remain silent and do not answer while paying attention and completing the assigned tasks. The teacher also taught the content in accordance with the lesson plan, but she did not explain the description text material using GOs media.

However, because they use new instructional medium than before, students are more excited about the teaching and learning of descriptive text. In the second act of the first cycle, the teaching and learning process activities in the classroom revealed that students were more passionate, focused, active, and provided a suitable response to make GOs when reading descriptive text. The teacher also assists pupils in guiding and teaching the making of GOs. At this point, post-test 1 was administered to assess the improvement in student achievement in reading the descriptive texts that had been examined. According to the results of the pre-test, the average value was 51.25 which is clearly below the minimum standard 70.

d. Reflecting

In this stage, researchers and teachers discussed the results and conclusions of the implementation of the actions in cycle 1. In this stage the researchers and teachers also discussed trying to design media to improve student achievement in reading descriptive texts and in order 70%. students in the class can get scores above 70. Because at this time, the results of post-test 1 show that only 13.3% of students have scores above 70. Meanwhile, the teaching and learning process in the classroom is very good. In this case, there must be an increase in efforts that are more than before in the next cycle to improve student achievement.

Findings of the Second Cycle

a. Planning

At this stage, the researcher made a few changes to the previous lesson plans in light of the first cycle's reflection outcomes. However, the Learning Implementation Plan employed in the teaching and learning process remains tied to the use of GOs media to improve students' reading descriptive text achievement. In this cycle, the teacher must deliver an engaging explanation using graphic GOs, text descriptions helped by projectors, and requesting that students bring a dictionary. In addition, at this stage, the researcher developed field notes to document class activities as well as post-test 2 to gather data.

b. Action

The researcher taught descriptive texts with a new theme, namely describing Islamic figures. At the second meeting, students were asked to make a descriptive text with a picture of the specified Islamic treasure, read the description text that had been made and collect their assignments. This assignment becomes the data for post-test 2.

c. Observing

The condition of the class in general in the teaching and learning process is more active, calm, focused and students respond well compared to cycle I. This can be seen from the field notes made by researchers showing students focus in paying attention to the material being taught and provide a good understanding response during the teaching and learning process of reading descriptive text. Students are also very enthusiastic in doing descriptive text reading exercises and most students prefer to choose their favorite Islamic figures and treasures and illustrate descriptive text by using GOs. The teacher also checks students' work from table to table and makes remarks. Students are also neither worried or bored when attempting to learn vocabulary from words they have never heard before. Students can use a dictionary to search up the vocabulary of a word. In the second action cycle II, the teacher administered a post-test 2 to determine the gain in student achievement when reading descriptive text. Based on the findings of post-test 2, the data shows that the average post-test score of two students is 72.80, with 12 out of 15 students scoring above 70.

d. Reflecting

Reflection ensued after receiving the findings of the field notes and post-test 2. Knowing these results made the researchers and teachers very happy, and the attempts to improve student achievement in reading descriptive texts had been successful. The results of post-test 2 suggest that 80% of students score above 70. As a result, the success criteria have been met, with 70% of pupils receiving scores greater than 70. As a result, researchers and teachers opted not to continue the CAR citing its success. Based on the evaluation results between researchers and teachers, it can be concluded that the use of CAR to improve student achievement in reading descriptive texts using GOs is consistent with previous researchers' and teachers' plans and actions. Thus, the activities of the teaching and learning process for pupils reading descriptive texts were carried out successfully.

The Result of Post-Interview

It can be concluded that students are more active and enthusiastic about creating GOs, and they find it easier to write descriptive text using GOs media. Second, discuss the issues students have while using GOs media in the teaching and learning process of reading descriptive text during CAR, as well as potential solutions. The teacher stated that most students struggled to articulate their ideas since they still had a limited vocabulary or little comprehension of it. So, the idea is to require each student to bring a dictionary when learning English, particularly during reading courses. Third, this is the final assessment, which is based on the teacher's perspective on GOs media. The teacher stated that GOs was an extremely successful medium for improving student achievement in reading descriptive literature.

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Media GOs can be a tool for motivating pupils and changing the perspective of those who believe that reading descriptive literature is difficult. Furthermore, English teachers might be encouraged to include GOs into their reading instruction and learning.

The Result of Post-Questionnaire

The results of these questions can be described as follows:

Indicators	Responses	Percentage
students' responses to reading descriptive text using GOs as media	Positive	66.67
	Fair	20
	Less	13.33
student admit GOs can help them to ease their mind to comprehend and recall the content of the text	Positive	86.67
	Fair	13.33
	Less	0
Student responses to the lesson in reading descriptive text	Positive	80
	Fair	6.67
	Less	13.33
Student responses to teaching reading through GOs	Positive	66.67
	Fair	22
	Less	11.33
students feel interested in the teacher's delivery during the teaching and learning process	Positive	80
	Fair	13.33
	Less	6.67
Students feel interested in Islamic figures and treasures	Positive	87
	Fair	13
	Less	0

It can be concluded the students' responses showed positive in the learning activities in improving reading comprehension on descriptive text by using graphic organizers integrated with Islamic values.

The Result of Post-test

The results of the first post-test showed that the average score of the class was 58.75. In this first post-test, there were 2 students who scored above 70 and 13 students scored below 70. The details of the results of reading student description texts in cycle I shows that the average value of post-test 1 is 58.75. In post-test 1, there were only 2 students or 13.33% of the students who scored above 70. While the other 13 students scored below 70.

Based on the results of student achievement in reading descriptive text above, it can be concluded that there is an improvement in the average score of students in reading descriptive text from the preliminary study to cycle II. The average score of students in the preliminary study was 51.25 and the average score of students in post-test 2 in the second cycle was 72.08. That means there is a 42.04% increase in the average score of students in reading descriptive text. From the data above also shows that there are 12 students or 80% of students who get scores above 70. This shows that the objectives of this research have been achieved. The table of student scores in reading descriptive text is as follows:

Table 4.1 The Students' Reading in Descriptive Text Score of Pre-test, Post-test 1, and Post-test 2

No	Name	Score		
		Pre-test	Post-test 1	Post-test 2
1.	S1	68.75	75	87.5
2.	S2	68.75	75	87.5
3.	S3	50	62.5	75
4.	S4	50	56.25	75
5.	S5	62.5	68.75	75

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6.	S6	56.25	62.5	75
7.	S7	43.75	50	56.25
8.	S8	31.25	43.75	50
9.	S9	56.25	62.5	75
10.	S10	50	62.5	75
11.	S11	50	56.25	75
12.	S12	50	56.25	75
13.	S13	43.75	50	73.33
14.	S14	37.5	43.75	62.5
15.	S15	50	56.25	75
TOTAL		**768.75**	**881.25**	**1.092.08**
MEAN		**51.25**	**58.75**	**72.80**

**: The students who passed the Minimum and Maximum Scores above (70)*

The Interpretation of Data

The data diagram summarized by researcher are as follows:

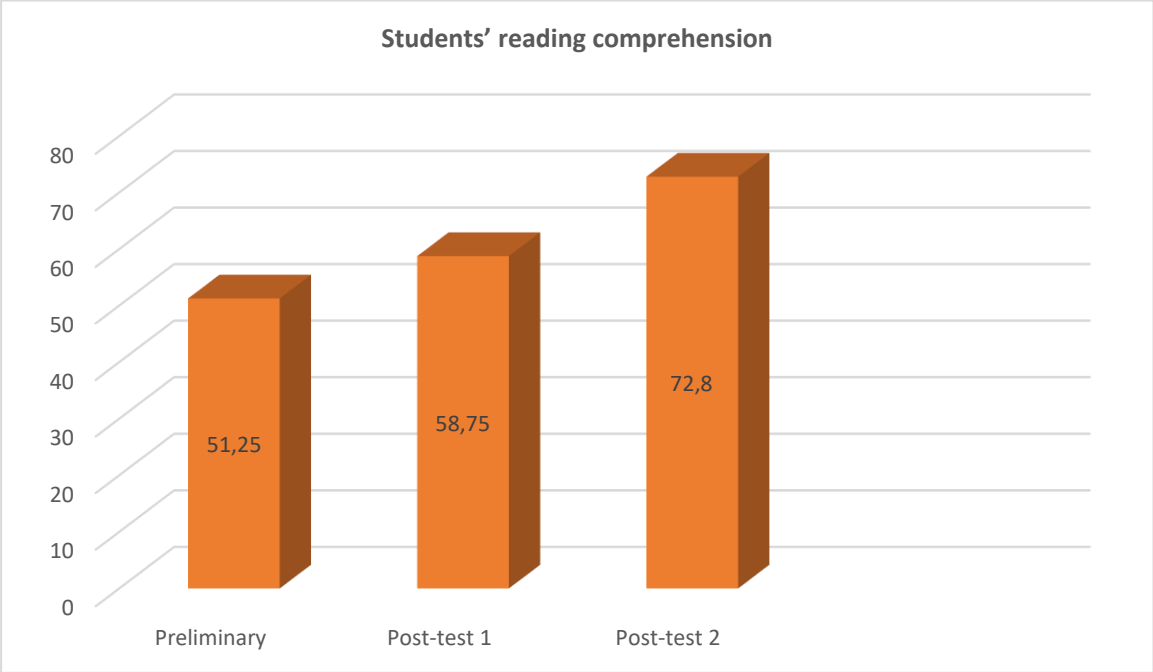

Fig. 4.1. Students' Achievement in Descriptive Text Score

At the preliminary study stage, before carrying out CAR and using GOs media for reading course, a reading test was conducted by the English teacher at SMP IT Al Fauzi at the end of the previous semester. The average score of students on the descriptive text reading test was 51.25. Meanwhile, the percentage of students who scored above 70 was 0%. It means there were no students achieved the standard minimum 70.

Furthermore, in the first post-test stage of cycle 1, it showed that the students' average score was 58.75. It means that there is an increase in students' scores in reading descriptive text from the scores before using GOs and before the first post-test, which is 18.4%. Meanwhile, the percentage of students who scored higher than 70 was 13.33%. That means there are 2 students who get a score above 70 and 86.67% of students get a score below 70. That means there are 13 students who do not get a score above 70. For this reason, it is still necessary to improve student achievement in reading

descriptive texts. Therefore, researchers and teachers must improve student achievement in reading descriptive texts in cycle 2.

Furthermore, in the second post-test stage of cycle 2, it showed that the average score of students was 72.80. In this case, it shows that the student's improvement score is 14.05 from the first post-test (58.75) or 31.05% experienced an increase in the student's score in the percentage score of the preliminary study. Meanwhile, the percentage of students who scored below 70 was 13.33%. That means there are 86.67% students who get a score above 70. For this reason, the percentage of the class showed an increase of 87.1% from the preliminary study (9.7%) or the first post-test (38.7%) in the percentage class. Finally, in the second post-test stage, the students hit the minimum standard. So, it can be said that the CAR was successful and the cycle was terminated.

It can be stated that the optimalization of using GOs integrated with Islamic values definitely improve the students reading comprehension as their conceptual understanding, long-term memory retention, learning motivation, and critical thinking skills, proving effective across diverse academic abilities.

4. CONCLUSION

The implementation of media GOs in the first year of grade eight of SMPIT Al-Fauzi can be concluded that GOs integrated with Islamic values can improve students' reading skills. It can be proven from the following facts. First, the increase can be seen from the increase in the average reading score of students from 51.25 or 0% of the class, the percentage who passed scored above 70 in the preliminary study, and 58.75 or 13.33% of the class the percentage that pass scores above 70 in the first cycle, to 72.80 or 80% of the class percentage those who pass get scores above 70 in cycle II. Second, the results of the field notes show that class conditions during the teaching and learning process create a positive atmosphere in the classroom, and also make students creative in finding ideas. Third, the results of the questionnaire showed that students gave positive responses to the application of media GOs in the teaching and learning process of reading. In addition, media GOs are an alternative strategy in teaching reading.

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Comparative Study of Secant Method and Newton-Raphson Method in Finding the Molar Volume Value of Gas Using Python

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ABSTRACT

Determining the molar volume of a real gas requires solving the non-linear Van der Waals equation. This study aims to compare the efficiency and accuracy between the Newton-Raphson Method and the Secant Method in solving the Van der Waals equation using the Python programming language. The case study examined is finding the molar volume of methane gas at a pressure of 56 atm and a temperature of 450 K. The comparison parameters used are the number of iterations and the speed of convergence with an error tolerance of 10^{-7}. The results show that the Newton-Raphson Method requires fewer iterations, namely 4 iterations with a computational time of 0.00012 s. Meanwhile, the Secant Method requires more iterations, namely 6 iterations and a computational time of 0.00015 s. The Newton-Raphson Method is less practical because it requires the calculation of the derivative of the function, while the Secant Method is more practical to be applied to Python scripts because it only requires the calculation of the Van der Waals equation function.

Keywords: Methane Gas, Molar Volume, Van der Waals, Secant, Newton Raphson

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1. INTRODUCTION

In mathematics learning, numerical modeling methods are one of the most effective tools to help students solve mathematical models in applied problems in engineering, physics, and chemistry (Kongprawechnon, 2018), (Putawa, 2023). Numerical methods are not a substitute for analytical methods, but an essential complement (Kiusalaas, 2015), (Nur Alisa, 2025). Analytical methods provide theoretical foundations, precision, and structural understanding, while numerical methods equip students with practical tools for real-world problems and develop computational thinking (Moheuddin, 2019), (Wajib Pandia, 2021). The combination of the two in the curriculum creates a more complete, relevant, and application-ready understanding of mathematics (Rika Nadila, 2022), (Azure, 2019).

In thermodynamic studies, for example, the ideal gas physical model is often not accurate enough to describe the behavior of gases at high pressures or low temperatures (Smith, 2017). In an ideal gas, particles are considered small points with no volume, allowing them to move freely in space. Meanwhile, real gases have volume, although quite small, but this volume is related to the degrees of freedom of movement in space. The ideal gas model assumes that there are no attractive or repulsive forces between particles. Particles interact only during perfectly elastic collisions. In real gases, there are attractive forces resulting from chemical bonds between atoms. At low temperatures, for example, kinetic energy decreases, particles move slowly, and attractive forces (Van der Waals or London dispersion) appear. Therefore, the limitations of the ideal gas model are corrected through the Van der Waals equation to correct for intermolecular interaction forces and obtain the molar volume parameter expressed by equation (1) (Wibowo, 2022).

$$\left(P + \frac{a}{V^2}\right)(V - b) = RT \quad (1)$$

where P: pressure (atm)
V: volume (L)
T: temperature (K)
R: gas constant (J/mol.K)
a, b: parameters according to real-world conditions (experiment)

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Mathematically, equation (1) is a third-degree polynomial with respect to volume V. Finding the roots of polynomial or non-linear equations analytically is often quite complex, so numerical methods are a practical solution (Sutrisno, 2023). Two effective and simple numerical methods are the Newton-Raphson method and the Secant method (Chapra, 2021), (Sunandar, 2020).

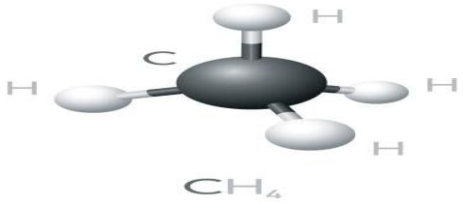

Fig. 1. Methane gas molecules (Wibowo, 2022)

This study examines the performance of the Newton-Raphson method and the Secant method in the Python programming environment to provide recommendations on which method is more optimal in obtaining the root value of a polynomial function (Nwry, 2021), especially in solving the Van der Waals equation in the case of finding the molar volume of methane gas as depicted in Figure 1.

2. RESEARCH METHOD

This study uses a numerical computational approach by comparing two numerical methods. The two methods compared are the Secant Method and the Newton-Raphson Method. In this study, the indicators of the numerical methods that are compared are: the number of iterations, iteration time and convergence speed to reach the root value of the equation. These two methods are used to obtain the polynomial root values of equation (1). The method that is able to obtain the root value with the fastest iterations or the fewest steps is considered the best method , (M., 2023), (Wibowo, 2022), (Khoiriyah, 2021). The convergence tolerance used in this study is 10-7. This means that when the difference between the next root value and the previous root value reaches 10-7, the iteration is stopped and the root value has been found.

2.1 Model Persamaan Polinomial

The Van der Waals equation is rearranged into a function *f(V)* which is in the form of a polynomial function, expressed by equation (2),

$$f(V) = PV^3 - (bP + RT)V^2 + aV - ab = 0. \quad (2)$$

2.2 Numerical Algorithms

1. *Newton-Raphson Method*: Requires one initial guess value *(V_0)* and the first derivative of the function *f'(V).* The iteration formula of the Newton-Raphson Method is stated by equation (3),

$$V_{n+1} = V_n - \frac{f(V_n)}{f'(V_n)}. \quad (3)$$

With *f(V)* expressed by equation (2), the analytical derivative of the function is expressed by equation (4).

$$f'(V) = 3PV^2 - 2(bP + RT)V + a \quad (4)$$

2.*Secant Method*: Requires two initial guess values (V_0, V_1) without needing to find the function derivative. The Secant Method formula is stated by equation (5),

$$V_{n+1} = V_n - f(V_n)\frac{V_n - V_{n-1}}{f(V_n) - f(V_{n-1})} \quad (5)$$

The flowchart of the algorithm for finding the molecular volume value or the root value of a polynomial is described in Figure 2.

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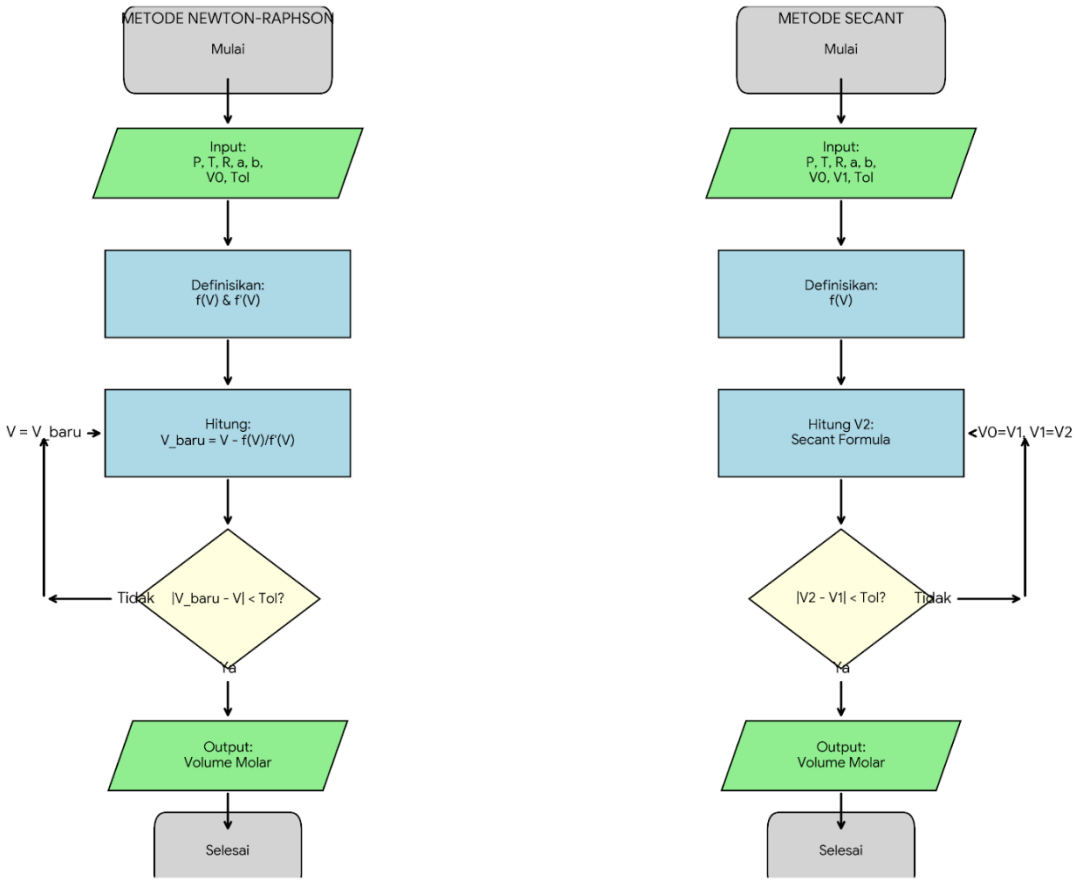

Fig. 2. Algorithm of the Newton-Raphson method and the Secant method

The Newton-Raphson method (Sechenov P.A., 2022):

1. Initialization: Enter the constants *P, T, R*, a, b, the initial guess V_0, and the error/ tolerance ε.
2. Function definition: Write the function/mathematical model *f(V)* and the derivative of the function *f'(V)*.
3. Newton Raphson Iteration: Calculate the volume value: $V_{new} = V_{old} - [f(V_{old})/f'(V_{old})]$.
4. Convergence: Check whether $|V_{new} - V_{old}|$ < error/tolerance ε.
   If Yes, then display the result V_{new} as molar volume. If No, then update $V_{old} = V_{new}$ and repeat step 3.

The Secant method (Sechenov P.A., 2022):

1. Initialization: Enter the constants *P, T, R*, a, b, the initial guess V_0 and V_1, and the error/ tolerance ε.
2. Function definition: Write the function/mathematical model *f(V)*.
3. Secant Iteration: Calculate the volume value: $V_{new} = V_2$ using the slope of the line between $(V_0, f(V_0))$ and $(V_1, f(V_1))$.
4. Convergence: Check whether $|V_2 - V_1|$ < error/tolerance ε.
   If Yes, then display the result $V_{new} = V_2$ as Molar Volume. If No, then update $V_0 = V_1$ and $V_1 = V_2$ and repeat step 3.

2.3 Implementation of Algorithms with Python Programming

Language: Python 3.11 equipped with libraries: NumPy (for computation) and Matplotlib (for visualization)
Case Study: Ammonia (NH_4) gas at P = 56 atm and T = 450 K.
The value of a = 4.17 L2.atm/mol2. The value of a represents the magnitude of the attractive forces between gas molecules.

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3. RESULTS AND DISCUSSION

A snippet of the Python programming script to solve the Van der Waals equation case study to find the molar volume of methane gas is depicted in Figure 3.

```
a = 4.17
b = 0.0371
R = 0.08206  # Konstanta gas ideal (L.atm/mol.K)
P = 56       # Tekanan (atm)
T = 450      # Suhu (K)

# 1. Definisi Fungsi f(V) dari Persamaan Van der Waals
# f(V) = PV^3 - (Pb + RT)V^2 + aV - ab = 0
def f(V):
    return P * V**3 - (P * b + R * T) * V**2 + a * V - a * b

# 2. Definisi Turunan Fungsi f'(V) untuk Newton-Raphson
def df(V):
    return 3 * P * V**2 - 2 * (P * b + R * T) * V + a

# 3. Implementasi Metode Newton-Raphson
def newton_raphson(v0, tol, max_iter):
    history = []
    v = v0
    for i in range(max_iter):
        fv = f(v)
        dfv = df(v)
        if dfv == 0: break
        v_next = v - fv / dfv
        history.append(v_next)
        if abs(v_next - v) < tol:
            return v_next, i + 1, history
        v = v_next
    return v, max_iter, history

# 4. Implementasi Metode Secant
def secant(v0, v1, tol, max_iter):
    history = []
    v_prev = v0
    v_curr = v1
    for i in range(max_iter):
        fv_curr = f(v_curr)
        fv_prev = f(v_prev)
        if (fv_curr - fv_prev) == 0: break
        v_next = v_curr - fv_curr * (v_curr - v_prev) / (fv_curr - fv_prev)
        history.append(v_next)
        if abs(v_next - v_curr) < tol:
            return v_next, i + 1, history
        v_prev = v_curr
        v_curr = v_next
    return v_curr, max_iter, history

# --- Parameter Pengujian ---
tol = 1e-7
max_iter = 100
v0_nr = 0.5          # Tebakan awal NR
v0_sec, v1_sec = 0.4, 0.5  # Tebakan awal Secant
```

Fig. 3. Python script implementing the Newton Raphson method and the Secant Method

Based on the computations carried out with a tolerance of $\varepsilon = 10^{-7}$, the data obtained are as in Table 1.

Table 1. Calculation Results of the Secant Method and the Newton-Raphson Method

Comparison Parameters	Secant Method	Newton Raphson Method
Initial Guess	V_0=0,4 and V_1=0,5	V_0=0,5
Number of Iteration	6	4
Root (Molar Volume)	0.5755 ± 10^{-7} L/mol	0.5755 ± 10^{-7} L/mol
Execution Time (average)	0.00015 s	0.00012 s

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Based on Table 1, the comparative results show that the Newton-Raphson method has better computational efficiency than the Secant method in determining the molar volume of gas, even though both produce identical root values of 0.5755±10-7 L/mol. This advantage is reflected in the fewer number of Newton-Raphson iterations, which are achieved in the fourth iteration while with the Secant method the root value is obtained in the sixth iteration. This has a direct impact on the shorter average execution time (0.00003 s) the time difference between the Newton-Raphson method and the Secant method. In addition, in terms of input parameters, Newton-Raphson is proven to be more practical because it only requires one initial guess (V0=0.5), while the Secant method requires two initial guesses (V0=0.4 and V1=0.5), so that from the number of iterations and iteration time indicators the Newton-Raphson method provides more optimal performance to achieve convergence in this calculation.

The convergence rate of the iteration process of both methods is presented in Figure 4. The mathematical function of the Van der Waals equation and the molar volume value are analytically presented in Figure 5.

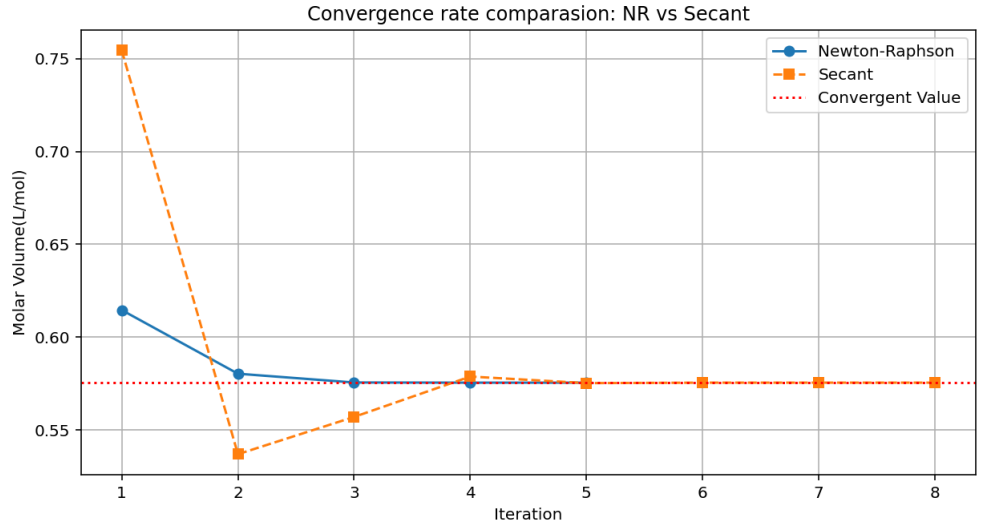

Fig. 4. Convergence rate of the Secant method and the Newton Raphson method

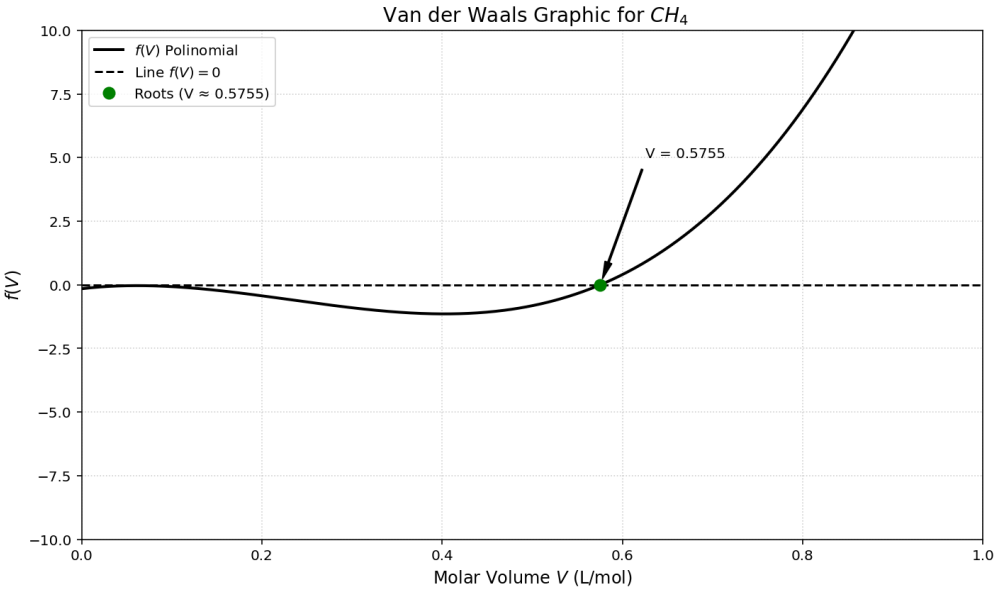

Fig. 5. Graph of the Van der Waals equation and the root value of the function

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A comparative analysis of the Secant Method and the Newton Raphson Method in terms of convergence, ease of implementation in the Python programming language, efficiency and accuracy of numerical solutions is presented in Table 2.

Table 2. Comparison of the Secant Method and the Newton Raphson Method

	Secant Method	Newton Raphson Method
Convergence	Convergence is slower than the Newton-Raphson method, as seen from the greater number of iterations (6 iterations). However, this method has the advantage that it only requires the definition of a mathematical function f(V) that is continuous on the interval V_0 and V_1. In cases where the first derivative of a mathematical function is difficult to determine analytically, the Secant method is recommended for use because it does not require information about the definition of the first derivative of the mathematical function.	Shows quadratic convergence, as seen from the smaller number of iterations (4 iterations). In cases that require long iteration steps, the Newton Raphson method is recommended because it has implications for the computer memory required. However, this method has a weakness if the derivative f'(V) is difficult to determine or is close to zero.
Ease of Implementation in Python Language	Excellent, efficient and practical in writing Python scripts considering that it is enough to write the definition of mathematical functions. *f(V)* (Kiusalaas, 2015)	Excellent, efficient, but less practical if the mathematical derivative function f'(V) involves certain Python library functions
Efficiency	Time to get the solution of the root value of the function or molar volume = 0.00015 s. In large computations, it is less efficient in terms of computation time to achieve numerical convergence.	The time to obtain the solution for the root value of the function or molar volume = 0.00012 s. In large computations, it is very efficient in terms of computation time to achieve numerical convergence (Osniman Paulina Maure, 2024).
Accuracy	Accurate, in the case of finding the molar volume value of CH_4, the value obtained is close to the analytical value, namely V = 0.5755 L/mol with a tolerance of 10^{-7}	Accurate, in the case of finding the molar volume value of CH_4, the value obtained is close to the analytical value, namely V = 0.5755 L/mol with a tolerance of 10^{-7}

4. CONCLUSION

Both methods successfully found the molar volume of methane gas with identical accuracy. The Newton-Raphson method is the best method if speed is the main priority and the derivative function can be easily defined. In the case of finding the molar volume of CH4 gas, at a pressure of 56 atm and a temperature of 450 K, with an error tolerance of 10^{-7} m, the Newton-Raphson method provided

superior results, reaching convergence after 4 iterations with a computational time of 0.00012 s, while the Secant method reached convergence after 6 iterations with a computational time of 0.00015 s. The Secant method is more recommended practically when the derivative function is difficult to determine and write in a Python script.

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Development of an Electronic Student Worksheet on Perimeter and Area for Elementary School Students

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ABSTRACT

Many elementary school students experienced difficulties in measuring the perimeter and area of plane figures. These difficulties were associated with misconceptions, an emphasis on memorizing formulas, and limited meaningful learning experiences across cognitive, affective, and psychomotor domains. This study aimed to analyze the need for developing an electronic student worksheet on perimeter and area for elementary school students. The research employed the analysis stage of the ADDIE development model. Data were collected through teacher interviews and document analysis, including curriculum documents and existing electronic worksheets. The findings indicated that current electronic worksheets provided opportunities to enhance motivation and conceptual understanding; however, they had not systematically integrated character values such as honesty, discipline, and cooperation. The results highlighted the urgency of developing a more constructive electronic student worksheet that integrated mathematical measurement concepts with character development. This needs analysis provided a theoretical and practical foundation for the subsequent design and development stages.

Keywords: Character education, electronic student worksheet, Perimeter and area

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1. INTRODUCTION

Mathematical ability is one of the main indicators of the quality of education at the global level. The results of the 2022 Programme for International Student Assessment (PISA) show that Indonesian students' mathematics achievement is still far below the OECD average, with a score of 379 out of an average of 472 (OECD, 2023). This low achievement reflects the weak numeracy literacy of Indonesian students, especially in relating mathematical concepts to real-life contexts. This condition poses a major challenge for the Indonesian education sector, which is striving to prepare a competitive generation for the 21st century. Efforts to improve the quality of mathematics education are also in line with the global agenda in Sustainable Development Goals (SDGs) point 4, which states that quality, inclusive and equitable education must be ensured and lifelong learning opportunities must be supported for all (UNESCO, 2023).

In the national context, the results of the 2022 Computer-Based National Assessment revealed that the numeracy skills of primary school students are still in the category of requiring special intervention (Kementerian Pendidikan Riset, dan Teknologi, 2024). One of the topics that often causes difficulties is measuring the perimeter and area of flat shapes. Previous studies have reported that students often have misconceptions in distinguishing between the concepts of perimeter and area, as well as difficulty understanding the relationship between formulas and their application in everyday life (Fajari, 2020; Ningtyas et al., 2023).

The results of field studies reinforce these findings. Teachers still predominantly use conventional methods such as lectures and printed worksheets, which tend to make students passive and only memorise formulas without understanding their conceptual meaning. As a result, many students experience difficulties when faced with story-based questions or contextual problems (İlhan & Aslaner, 2020; Nareswari et al., 2021). This fact confirms the need for learning media that is more interactive, contextual, and in line with the cognitive development characteristics of primary school students.

With the development of educational technology, electronic student worksheets have emerged as an alternative solution. Various studies have proven that Electronic Student Worksheets can increase motivation, learning outcomes, and student engagement through interactivity, visualisation of abstract

concepts, and instant feedback (Aliu et al., 2024; Arda Yatul Liani & Mailani, 2023; Gracin & Krišto, 2022; Indriani & Nuryadi, 2022; Susanti et al., 2025). The flexibility of electronic student worksheets, which can be accessed through digital devices such as mobile phones, tablets, laptops, and computers, also opens up opportunities for more dynamic learning, both at school and at home.

Furthermore, mathematics education not only serves to develop cognitive aspects, but should also be a means of shaping constructive character traits in students, such as perseverance, honesty, responsibility, discipline, and cooperation. Research shows that the integration of character education through digital media can have a positive impact on building constructive attitudes in students (Asror et al., 2024; Cipta et al., 2023; Tohri et al., 2022). Therefore, the development of electronic student worksheets should not stop at instructional functions alone, but must be designed as an instrument that supports the formation of students' character.

Theoretically, this development is based on constructivism theory, which emphasises that knowledge is actively constructed by students through direct experience, exploration, and social interaction (Piaget, 1972; Vygotsky, 1978). With this foundation, constructive electronic student worksheets can become a medium that bridges conceptual understanding while fostering character values relevant to the Pancasila Student Profile in the Merdeka Curriculum.

Based on the above description, this study focuses on analysing the need to develop constructive electronic student worksheets on the subject of perimeter and area of flat shapes in primary schools. However, previous studies have not explicitly integrated character education within electronic student worksheets in a systematic and constructivist framework. Unlike previous studies that primarily emphasise the effectiveness or implementation of electronic worksheets, this study specifically highlights the integration of constructivist principles with character education values (such as honesty, discipline, responsibility, and cooperation) within the framework of the Merdeka Curriculum. The analysis was conducted through curriculum mapping, identification of teacher and student needs, and a literature review of relevant studies. This study offers a distinctive contribution by providing a comprehensive needs analysis that combines cognitive, contextual, and character-based dimensions as a foundation for developing innovative electronic student worksheets. The results are expected to provide a strong foundation for the design and development of innovative, contextual electronic student worksheets that are oriented towards character building in students.

2. RESEARCH METHOD

The analysis stage of the ADDIE model in this study consisted of four interconnected steps. First, curriculum analysis was conducted to identify the learning outcomes, learning objectives, and learning objective flow related to perimeter and area in the Merdeka Curriculum. Second, student characteristics analysis was carried out to identify students' cognitive development, misconceptions, and learning preferences based on teacher reports and previous studies. Third, teacher needs analysis was conducted through semi-structured interviews to identify classroom problems, limitations of existing worksheets, and teachers' expectations regarding electronic student worksheet development. Fourth, electronic student worksheet media analysis was conducted through a literature review to identify the strengths, weaknesses, and opportunities for integrating constructivist and character-based elements into the product design.

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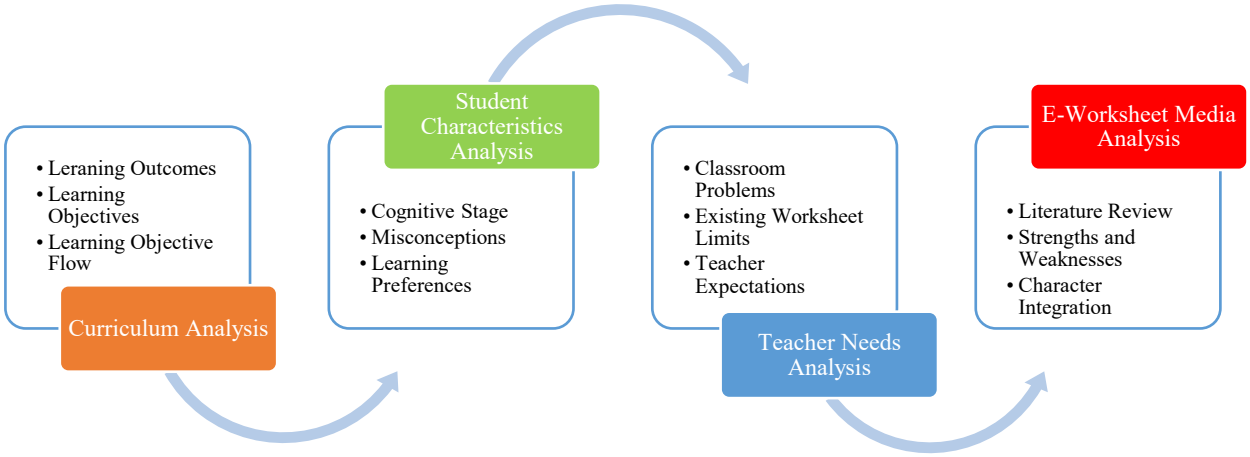

Fig. 1. Four Stages of the ADDIE Analysis Process

The collected data were analysed using two qualitative descriptive techniques, namely content analysis and thematic analysis. Content analysis was applied to curriculum documents and literature review data in order to identify the relevance of learning outcomes, learning objectives, misconceptions, and the strengths and weaknesses of existing electronic student worksheets. Thematic analysis was applied to teacher interview data through three stages: data reduction, coding, and categorisation. This analysis produced several major themes, including students' misconceptions regarding perimeter and area, limitations of existing learning media, and teachers' expectations for interactive and character-based electronic student worksheets. Finally, the findings from all data sources were integrated through triangulation to formulate the conceptual requirements for developing a constructive electronic student worksheet.

3. RESULTS AND DISCUSSION

The Merdeka Curriculum Analysis shows that at the end of Phase C (grades V–VI), students are expected to be able to determine the perimeter and area of various flat shapes (triangles, quadrilaterals, and polygons) and their combinations (Learning Outcomes). This achievement emphasises not only procedural mastery but also conceptual understanding that enables students to relate perimeter and area to everyday contexts.

From the learning outcomes, a number of learning objectives were derived, including: (1) explaining the concept of perimeter through concrete measurements, (2) calculating and comparing the area of flat shapes with unit squares, and (3) solving contextual problems related to perimeter and area, such as calculating the perimeter of a yard or the area of a room carpet.

Furthermore, the learning objective flow is designed as a systematic sequence of achievements. The learning objective flow for this topic includes: (1) identifying objects around us that are flat shapes, (2) measuring the length of sides to find the perimeter, (3) using unit squares to understand area, (4) generalising the perimeter and area procedures into formulas, (5) applying these concepts in real-life situations, and (6) reflecting on the measurement results to reinforce understanding.

However, preliminary study results indicate that implementation in the field is still limited to mastery of formulas without exploration of contextual meaning. Students are often directed to memorise formulas without meaningful experience, resulting in weak conceptual understanding and disrupted transfer to contextual problems (Esra & Şükrü, 2017; Hurrell, 2021). This condition reinforces the urgency of developing digital learning media, such as electronic student worksheets, which can bridge the demands of the curriculum with classroom learning practices.

A. Teacher Need Analysis

The results of the teacher need analysis show that students still often experience confusion in distinguishing between the concepts of perimeter and area, especially when questions are presented in the form of stories or contextual problems. Teachers also assessed that the printed worksheets that have

been used tend to be monotonous and only emphasise memorisation of formulas, thus not encouraging active participation or critical thinking skills in students. This condition shows a gap between the demands of conceptual understanding-based learning and learning practices that are still procedure-oriented.

Most teachers expect electronic student worksheets to be interactive, easily accessible, and equipped with contextual illustrations that can help students understand the relationship between mathematical concepts and their application in real life. Digital media is also seen as facilitating independent and collaborative learning, in line with the spirit of the Merdeka Curriculum, which emphasises project-based learning, differentiation, and strengthening the Pancasila student profile (Kementerian Pendidikan Riset, dan Teknologi, 2024).

These findings are consistent with the research of Cirneanu & Moldoveanu (2024) and Brown (2017) which shows that the use of digital media can significantly increase learning motivation, student engagement, and mathematics learning outcomes. The research by Ramadhani & Rahayu (2024) also confirms that constructivist-based electronic student worksheets can strengthen students' critical thinking skills, while Susanti et al. (2025) found that the integration of electronic student worksheets in geometry learning encourages active student engagement through visualisation and interactive exercises.

Thus, teachers' needs indicate the need for innovation in the form of developing constructive electronic student worksheets that not only serve as a means of understanding the concepts of perimeter and area of flat shapes, but also support the achievement of the Merdeka Curriculum's objectives in building numeracy skills, logical thinking, and holistic character building in students.

B. Analysis of Student Characteristics

Primary school students, especially those in Grade 5, are at the concrete operational stage according to Piaget's theory of cognitive development (Piaget, 1972; Santrock, 2018). At this stage, students' thinking abilities are still highly dependent on real objects, direct experiences, and concrete visual representations. Therefore, mathematics learning on the subject of perimeter and area of flat shapes requires media that can present realistic, simple, and interactive visualisations so that abstract concepts are easier to understand.

Interviews with teachers revealed that students tend to be more enthusiastic when learning involves visual stimuli such as pictures, animations, and simple games. Conversely, when learning focuses solely on lectures and memorising formulas, students quickly become bored and find it difficult to understand how concepts relate to everyday applications. For example, students often get confused when asked to calculate the perimeter of a fence or the area of a carpet, even though they have memorised the formula used.

In addition, the characteristics of the current generation of students also show that they are no longer unfamiliar with digital technology. Many primary school students are accustomed to operating mobile phones, tablets, and computers, both for playing games and accessing simple learning applications. This shows that the use of digital media in learning, including through electronic student worksheets, has great potential because it is in line with the habits and initial skills that students already possess.

The difficulties experienced by these students are in line with the findings of Hanan & Alim (2023) and Ningtyas et al. (2023) which reveal that misconceptions on the topics of perimeter and area generally arise due to the lack of contextual media in learning. This condition reinforces the importance of providing constructive electronic student worksheets that not only presents practice questions but also provides visual illustrations, digital simulations, and contextual activities that are in line with the cognitive characteristics and digital skills of primary school students.

Thus, the development of electronic student worksheets is expected to bridge students' limitations in understanding abstract concepts through interactive digital media that is based on real experiences and relevant to their habits in using technology.

C. Electronic Student Worksheets Media Analysis

The analysis of electronic student worksheets media in this study was conducted through a review of a number of relevant scientific articles. The results of this literature synthesis were used to map the

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roles, advantages, and aspects that must be considered in the development of constructive electronic student worksheets.

A review of the literature shows that electronic student worksheets plays a significant role in improving student learning outcomes, motivation, and engagement in mathematics learning. Compared to printed student worksheets, electronic student worksheets is able to provide interactivity, clearer visualisation of concepts, and instant feedback that helps students understand abstract concepts such as the perimeter and area of flat shapes more concretely (Aliu et al., 2024; Arda Yatul Liani & Mailani, 2023; Gracin & Krišto, 2022). With these advantages, teachers can more easily deliver context-based learning that promotes students' conceptual understanding.

In terms of facilities, electronic student worksheets is highly flexible as it can be accessed through various digital devices, such as mobile phones, tablets, laptops, and computers. This accessibility allows for more dynamic learning both at school and at home. Research Aliu et al. (2024) and Susanti et al. (2025) confirms that the availability of various digital devices provides great opportunities for students to learn independently or collaboratively without being limited by space and time. Therefore, the development of electronic student worksheets must take into account compatibility with various digital devices commonly used by students and teachers.

In addition to technical aspects, electronic student worksheets must also integrate constructive character values that are essential in learning. Constructive character includes perseverance, honesty, responsibility, discipline, and cooperation, which can be instilled through contextual problem exploration, group discussions, and reflection. Research by Bonanzinga et al. (2022), Tohri et al. (2022), and Asror et al. (2024) confirms that digital media is effective in fostering constructive attitudes in students, so that electronic student worksheets not only performs cognitive functions but also becomes a means of character building through interactive activities, visualisation, and instant feedback.

Furthermore, the development of electronic student worksheets needs to consider three main aspects, namely didactic, constructive, and technical (Hosnan, 2016; Majid, 2014; Prastowo, 2015). These three aspects can be further detailed in Table 1 below:

Table 1. Didactic, Constructive, and Technical Aspects in the Development of Constructive Electronic Student Worksheets

No	Aspect	Indicator	Statement	Description
1	Didactic	Alignment with the learning outcomes of the Merdeka Curriculum	"The material on perimeter and area is presented by linking mathematical concepts to real-life contexts."	Constructivism: knowledge is built through students' real experiences (Piaget, 1972;Vygotsky, 1978).
		Application of contextual learning	"Questions are presented in the form of everyday problems, such as calculating the cost of a house fence or classroom carpet."	Contextual learning helps students connect concepts with their experiences (Johnson, 2002).
		Integration of constructive character values (honesty, responsibility, cooperation)	"Instruction emphasises the importance of cooperation and honesty in completing tasks."	Character education reinforces attitudes of responsibility, honesty, and discipline (Bonanzinga et al., 2022; Tohri et al., 2022)
2	Constructive	Activities encourage independent exploration	"Students are asked to find the perimeter patterns of several flat shapes before being	Constructivism: knowledge is not transferred but actively

			introduced to the formula."	constructed by students (Bruner, 1996).
		Providing space for reflection and discussion	"At the end of each worksheet, there are reflection questions: what difficulties did the students encounter and what strategies did they use?"	Reflection strengthens metacognition in learning (Schunk, 2012).
		Developing a constructive attitude: Responsibility: completing tasks on time a. Cooperation: sharing roles within the group b. Discipline: following instructions properly c. Honesty: not copying classmates' answers	"Students are asked to work in groups to complete contextual problems, with clearly defined roles."	Constructive values support the formation of the Pancasila Student Profile (Kementerian Pendidikan Riset, dan Teknologi, 2024)
3	Technical	Attractive, simple, and interactive display design	Multimedia learning theory emphasises simple visuals so that students focus on the material	"electronic student worksheets uses soft colours, simple icons, and clear navigation." (Mayer, 2009).
		Accessibility via mobile phones, tablets, laptops, computers	"LKPD is designed to be compatible with various web-based or application-based digital devices."	Flexible access enhances the reach and effectiveness of digital learning (Aliu et al., 2024)
		Multimedia features (images, videos, animations) to visualise concepts	"Extensive flat shape materials accompanied by video animations about the use of carpets in the classroom."	Digital media helps bridge abstract concepts to concrete ones (Susanti et al., 2025)

Thus, the electronic student worksheets media analysis confirms that the development of this product must meet didactic, constructive, and technical standards while also considering digital tools and the integration of character values. This provides a strong theoretical and practical foundation for the design of constructive electronic student worksheets in the next design stage.

D. Integrated Summary

When integrated, the results of the curriculum analysis, teacher needs, student characteristics, and electronic student worksheets media analysis show a coherent narrative, namely "The development of constructive electronic student worksheet is urgently needed to bridge the gap between conceptual understanding and contextual application of perimeter and area of flat shapes in primary schools." This integrated presentation confirms that curriculum requirements, challenges in classroom learning practices, student readiness, and evidence from media analysis all point to the same conclusion.

In summary, these findings reinforce the literature emphasising the importance of student- centred, character-based, and technology-integrated learning media in mathematics education. Furthermore, this study shows that constructive character-based electronic student worksheets, when designed based

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on didactic, constructive, and technical principles, can develop not only cognitive achievements but also values such as honesty, responsibility, discipline, and cooperation.

Table 2. Integrated Summary of the Analysis of Curriculum, Teachers, Students, and Electronic Student Worksheet Media in Relation to Development Needs

No	Data Source	Key Findings	Integrated Integration
1	Curriculum Analysis	The Merdeka Curriculum requires students to master the concepts of perimeter and area both procedurally and contextually. The curriculum has the strength of emphasising conceptual understanding and real-life application. However, in practice, the implementation in schools is still often limited to formula memorisation and has not fully reflected the intended contextual approach.	The curriculum analysis indicates that an electronic student worksheet is needed to bridge the gap between curriculum expectations and classroom practice by promoting conceptual and contextual understanding.
2	Teacher Needs Analysis	Teachers reported that students still have difficulty distinguishing between perimeter and area, especially in contextual problems. Existing printed worksheets are considered monotonous and mostly focus on procedural exercises. The strength of current practice is that teachers already recognise the importance of contextual and interactive learning. However, the weakness lies in the limited availability of digital learning media that support these needs.	These findings indicate that teachers need interactive and contextual electronic student worksheets that can support students' conceptual understanding and strengthen the Pancasila Student Profile.
3	Student Characteristics Analysis	Fifth-grade students are at the concrete operational stage and tend to learn more effectively through visual, contextual, and interactive activities. They are also familiar with digital devices such as mobile phones, tablets, and computers. However, students still experience misconceptions regarding perimeter and area because learning is often presented abstractly and procedurally.	These findings show that electronic student worksheets are appropriate for students' cognitive development and digital habits, making abstract concepts easier to understand through interactive and visual representations.
4	Analysis of Electronic Students Worksheet Media	Previous studies indicate that electronic student worksheets have several strengths, including increasing learning motivation, improving conceptual understanding, providing interactive visualisations, and being accessible through various digital devices. However, most existing electronic student worksheets still have weaknesses, such as focusing mainly on procedural exercises, lacking	These findings indicate the need to develop an electronic student worksheet that not only utilises digital and interactive features, but also integrates contextual learning, constructivist activities, and character values relevant to the Merdeka Curriculum.

	contextual problems, and not systematically integrating constructivist and character education elements.

4. CONCLUSION

This study aimed to analyse the need for developing a constructive electronic student worksheet on perimeter and area of plane figures for elementary school students using the analysis stage of the ADDIE model. The findings confirmed that although the curriculum emphasised conceptual and contextual understanding, existing printed student worksheets remained procedural and less supportive of meaningful learning experiences. Teachers reported limitations in instructional media, and students, who were at the concrete operational stage and familiar with digital devices, required interactive and contextual learning support. The literature review further supported the effectiveness of electronic student worksheets in enhancing motivation, learning outcomes, and constructive character formation.

These results indicate a clear gap between curriculum expectations and classroom practice, thereby confirming the urgency of developing a constructive electronic student worksheet that integrates conceptual understanding, contextual application, and character education. The development of such digital learning media is expected to support numeracy literacy while fostering values such as honesty, responsibility, discipline, and cooperation in line with the objectives of the Merdeka Curriculum.

The findings also provide prospects for further development and broader implementation. Future research may focus on the design, validation, and experimental testing of the developed electronic student worksheet across different grade levels and subjects to evaluate its effectiveness and sustainability in improving students' mathematical understanding and character development

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Design and Development of Ethnomathematics E-Modules Through Lombok's Traditional Culinary Heritage

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ABSTRACT

This study aims to develop and evaluate an ethnomathematics-based e-module that integrates Lombok's traditional culinary heritage to enhance elementary students' understanding of three-dimensional geometry within the context of the Merdeka Curriculum. Employing a research and development (R&D) design using the ADDIE model, the study involved needs analysis through interviews with teachers, the principal, and students; design and development of an interactive digital e-module enriched with cultural elements and augmented reality; implementation through limited trials involving six students and field testing with twenty-one students; and evaluation through expert validation and N-gain analysis. The validation results demonstrate that the e-module meets feasibility criteria, with expert assessments yielding scores of 83% for material validity, 88% for media validity, and 80% for language validity. Limited trials produced N-gain scores ranging from 0.34 to 0.92 (mean = 0.69), while field testing yielded N-gain values between 0.00 and 0.84 (mean = 0.47), categorized as moderate improvement. These findings indicate that the e-module is effective in strengthening students' conceptual understanding, although learning gains vary according to learners' initial abilities and digital literacy. The study implies that integrating ethnomathematics with digital learning media can create meaningful, culturally relevant mathematics instruction.

Keywords: E-module, Ethnomathematics, Culinary heritage, Digital learning

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1. INTRODUCTION

Education is very important for every individual because it is a lifelong necessity (Rawas, 2024). Humans continue to undergo changes influenced by the development of the times. Therefore, an education system is needed that is designed to be able to adapt to these dynamics. Entering the 21st century, education faces various challenges, one of which is the demand for teachers to innovate in the learning process. As time goes by, science and technology are like two inseparable components (Buzzoni, 2024). Technological advances have further reinforced this demand, requiring teachers to be able to utilize technology as a means of improving the quality of learning. Digital teaching materials such as e-modules have become strategic instruments for bridging the gap between curriculum requirements and the needs of students in the modern era (Chatzidaki et al., 2025).

Students in the modern era need learning media that are in line with the times, namely, technology-based learning. Parents and teachers can strengthen students' attitudes and character by equipping them with digital literacy (Yulia et al., 2022). One type of learning media that keeps up with the times is the E-module learning media (Prabasari et al., 2023). E-modules are learning media that provide visualizations and can be accessed through electronic devices (Pratamadita & Dwiningsih, 2022). E-modules are digital modules consisting of text, images, or both, containing digital electronic material accompanied by simulations that can be used effectively in learning (Zhitfi, 2025). The integration of e-modules with ethnomathematics through Lombok's traditional culinary heritage is one relevant solution to address this issue.

Ethnomathematics is a concept that combines mathematics with culture and the surrounding environment, making mathematics learning more effective and enjoyable for students (Yanti, 2025). Ethnomathematics is a science derived from the mathematical thinking of a community group

(Simbolon, 2024). One form of ethnomathematics application can be seen in traditional cuisine, which not only serves as a source of sustenance but also as a cultural expression rich in values, reflecting the history and identity of a community (Syifa & Maharbid, 2025). Traditional food is an important element of cultural tourism because it presents authenticity and local stories (Jasmani et al., 2024). *Cerorot* is one of Lombok's traditional foods that represents a geometric shape, specifically a cone, through its physical structure (Subarinah et al., 2022).

Based on previous research, the development of e-modules in ethnomathematics has been widely undertaken by a number of researchers. (Aini et al. (2023) investigated e-modules to improve understanding of mathematical concepts, Fitrianawati & Setiyawati (2021) studied the development of electronic modules on geometry material, and (Hastuti et al., 2024; Nizaar et al., 2021) studied the development of thematic modules based on the Direct Instruction model, Suryawan et al. (2023) investigated the development of multimodal digital modules based on ethnomathematics problems, while Sutarto et al. (2022) focused on improving metacognitive abilities through electronic modules). Pratama et al. (2024) developed an e-module based on traditional Indonesian food, with results showing a validity rate of 88%, a practicality rate of 84%, and effectiveness in improving students' mathematical literacy. However, these studies have limitations, namely that they have not fully optimized the integration of interactive technology, the visualizations tend to be static, and they have not explored more specific local cultural contexts such as traditional Lombok cuisine.

Fitrianawati & Setiyawati (2021) explained that his research results showed that the electronic module developed met the appropriate criteria based on the assessment of six validators on aspects including material content, presentation, suitability of the electronic module with the concept of ethnomathematics, effectiveness of media in learning strategies, physical appearance, and language. Suryawan et al. (2023) emphasizes that based on the material validity test, a validity of 4.45 was obtained, and the media validity test obtained a validity of 4.87, which is included in the very high category. Hamid (2024) shows that the results of research on ethnomathematics-based electronic modules on number patterns meet the criteria for use in learning based on expert reviews and are able to attract the interest of students.

Kurniawati & Mahmudi (2025) presenting research results: (1) The RME e-module features contextual problem solving, the development of mathematical models from real-world problems, students building their own models, interactive activities, and connections between topics or subjects (2) The products and instruments meet the validity criteria; (3) The practicality of the E-Module achieved a score of 90% based on teacher assessment and 81.01% based on student assessment, and the implementation of learning reached 94.44%, thus meeting the practicality criteria; (4) The t-value in the hypothesis test is less than 0.05, so the E-Module meets the effectiveness criteria. Madu et al. (2025) emphasize that the developed e-module has been validated and proven practical by expert validators and practitioners, and has received positive feedback from students. Effectiveness tests show a significant improvement in student learning outcomes after using the e-module. Gesty (2025) explains that ethnomathematics-based modules can be an innovative solution in improving the quality of mathematics learning in the digital age.

Based on the results of several previous studies, more focus has been placed on the technical aspects of validating and testing the effectiveness of e-modules. However, these studies have not highlighted their integration with more specific local wisdom, such as the traditional culinary heritage of Lombok. Therefore, this study aims to present a comprehensive description of the effectiveness of integrating local culture into digital e-modules, so that mathematics learning is not only understood from a cognitive perspective, but also more contextual and meaningful to the daily lives of students. This study is expected to strengthen understanding of how ethnomathematics-based e-module innovations can improve the quality of learning, while also serving as a relevant, collaborative, and digitally literate 21st-century learning strategy.

2. RESEARCH METHOD

This study applies the research and development (R&D) method to develop an interactive multimedia learning media product based on Android by adapting the ADDIE model (Analysis, Design, Development, Implementation, Evaluation (Nasution 2023). Research and development (R&D) methods are structured and systematic approaches aimed at producing practical solutions and creating

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new products or improving existing products through a validated process (Setyosari et al. 2023). The following is the R&D research procedure using the ADDIE approach method in Figure 1.

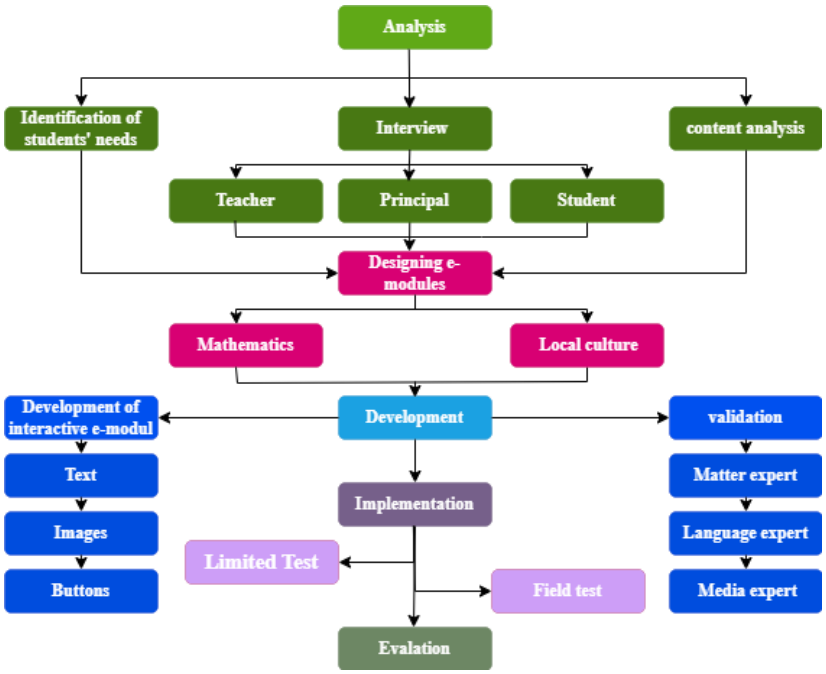

Fig. 1. Stages of ADDIE Model Development

Figure 1 shows that ADDIE consists of five stages. The first stage is analysis, which involves identifying learner needs and analyzing the material (Adeoye et al. 2024). The needs analysis was conducted at SD Negeri 15 Mataram through semi-structured interviews with teacher (T), principal (P) and student (S) to determine the needs for mathematics teaching materials to be developed. The material analysis was conducted by examining the main material to be taught, the opportunities for applying ethnomathematics, and the relevance of Lombok's traditional culinary heritage as a learning context. During the design stage, an e-module was developed that combines mathematical concepts with local culture. Next, during the development stage, interactive digital e-modules were created, complete with text, images featuring illustrations of traditional Lombok cuisine, along with navigation buttons.

During the implementation stage, researchers tested the e-module on students during one session. The tests consisted of a limited class test with six students and a class test with 21 students to obtain data on the product's effectiveness using pre-tests and post-tests in the form of 15 multiple-choice questions to assess changes in mathematical understanding of mathematical concepts. Meanwhile, the evaluation stage is carried out through revisions to the e-module based on the results of expert validation and user feedback. The research instruments consisted of a validation questionnaire given to subject matter, media, and language experts, and learning outcome tests in the form of pre-tests and post-tests. Validity analysis was conducted using a Likert scale to determine the suitability category of the e-module. Product effectiveness was measured by comparing the pre-test and post-test results using the N-gain statistical test.

3. RESULTS AND DISCUSSION

A. Analysis

During the analysis stage, researchers conducted three main types of analysis on October 18, 2025, at SD 15 Mataram, including e-module needs analysis, student needs analysis, and curriculum analysis, with respondents consisting of a teacher, a student, and a principal to obtain information on e-module needs.

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1. The e-module needs analysis aimed at determining the types and characteristics of e-modules feasible for mathematics learning in elementary schools. Based on the results of interviews with the teacher (T), it was conveyed that:

   "The difficulty faced by children in elementary school, especially those in class 5B, is short-term memory or forgetfulness, so they have to be taught several times before they truly understand. Teaching materials on spatial construction must include content, three-dimensional images, examples, and formulas".

   This statement shows that teachers want e-modules that not only present theory, but also include three-dimensional visualizations and real-world examples so that students can more easily understand spatial concepts and reinforce these concepts repeatedly.

2. An analysis of student needs was conducted to identify student preferences for learning media that are interesting and in line with technological developments by interviewing a student in class 5 B. Based on the interview results, (S) stated that:

   "I like learning that incorporates animation and has original content".

   This indicates that students prefer interactive teaching materials that feature animations and real objects, making learning more lively and enjoyable.

3. Curriculum analysis was conducted by interviewing the school principal to ensure the suitability of the e-module development with the implementation of the Merdeka Curriculum. Based on the interview results, (P) stated that:

   "Class 5 has been using the Merdeka Curriculum in accordance with its learning outcomes (CP), but it has not been maximized, so it would be better to increase the use of interactive learning media".

   This statement shows that the principal wants to improve the quality of learning through the use of more varied and innovative media.

Next, observations were made on traditional Lombok cuisine with the aim of identifying relevant and feasible types of food to be used as examples in the e-module. Based on the results of observations at the *Kebon Roek Lombok* traditional market, data was obtained on the variety of traditional Lombok cuisine as shown in Figure 2.

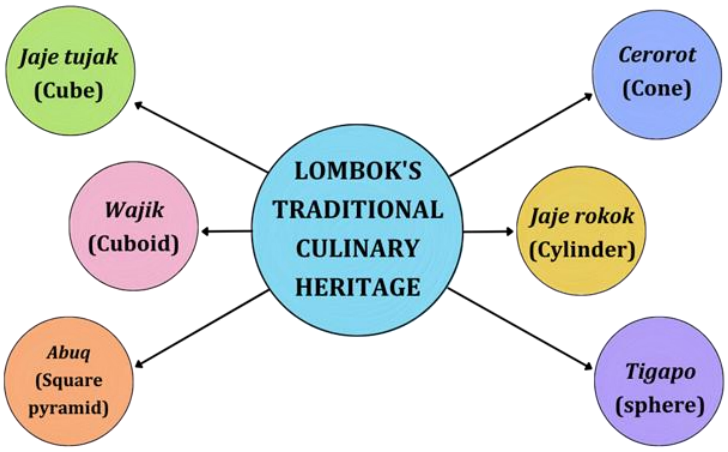

Fig. 2. Lombok's Traditional Culinary Heritage in Geometric Form

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Figure 2 shows six types of Lombok's traditional culinary heritage that represent different shapes, namely *Jajek Tujak*, which is cube-shaped; *Wajik*, which is cuboid; *Abuq*, which is square pyramid; *Cerorot*, which resembles a cone; *Jaje Rokok*, which is a sylinder without a base or top; and *Tigapo*, which is a sphere.

B. Design

The second stage was design. Researchers designed e-modules using the Canva platform through several structured steps, as listed in Table 1.

Table 1. Ethnomathematics E-module Design Flow

No.	Design Flow
1	Setting learning objectives based on the results of needs analysis and the learning outcomes of the Merdeka Curriculum
2	Developing an e-module framework (outline of chapters and subchapters, cover, content structure, and exercises)
3	Designing storyboards (display flow, page navigation, image placement, and visual elements)
4	Developing evaluation instruments
5	Choosing a visual style (colors, fonts, icons, and illustrations)

Table 1 explains that the design process for the ethnomathematics e-module began with setting learning objectives based on an analysis of student needs and the achievements of the Merdeka Curriculum. Next, an e-module framework was developed, which included an outline of chapters, subchapters, cover, material presentation, and exercises. In the content section, the researcher integrated elements of traditional Lombok cuisine and added examples of 3D-based spatial structures using *Assemblr EDU* (https://edu.assemblrworld.com/home) . The next stage involves designing a storyboard that organizes the display flow, navigation, and placement of visual elements, and compiling evaluations. The final stage is selecting visual styles such as colors, icons, and illustrations to make the e-module attractive and support effective learning. The following is the outline design for the cover of Ethnomathematics e-module in Figure 3.

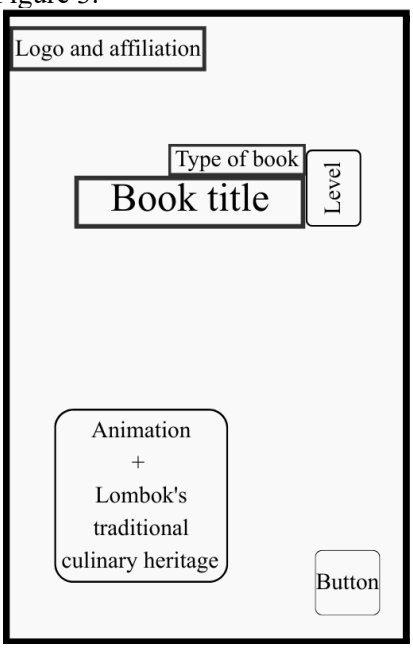

Fig. 3. Ethnomathematical Outline Design for The Cover of The Ethnomathematics E-module

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Figure 3 explains that the cover design applies a proportional layout, combines elements of local culture, and follows the principles of visual hierarchy, thereby effectively reinforcing the character of the e-module as educational material oriented towards local wisdom. The logo and institutional affiliation serve as the official mark of the e-module developer, while the type of book and e-module title are displayed in a more prominent size as the center of attention. The level indicates the target user group. The ethnomathematics-themed illustration reflects the relationship between mathematical concepts and the traditional culture of Lombok. The navigation buttons facilitate page transitions in digital use.

C. Development

The third stage is development. In this stage, researchers develop the content of the e-module according to the outline that has been prepared, such as the cover, e-module content, 3D images, and interactive exercises. Based on the design results, the following are the results of the development of the ethnomathematics e-module as shown in Figure 4.

a. Cover

b. cone material display

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c. Cone display in QR code *d. Practice display*

Fig. 4. Ethnomathematics E-module Display

Figure 4, explain that:

1. Section a, shows the initial stage of cover development using the Canva platform. The design was carried out by considering visual aspects such as color selection, illustrations, local cultural nuances, and layout, resulting in a design that is in harmony with the outline design.
2. Section b presents material on cone shapes through an ethnomathematics approach. The local cultural object featured is *Cerorot*. *Cerorot* is a traditional snack from Lombok, made from coconut milk and flour mixed with brown sugar. Its shape resembles a cone. This comparison is intended to make it easier for students to understand the relationship between real shapes and mathematical models. An additional feature is a QR code to load a three-dimensional model.
3. Section c integrates augmented reality technology through *Assemblr EDU* to display a three-dimensional representation of a cone. The use of augmented reality technology provides students with the opportunity to observe geometric objects interactively and view them from various angles, with the support of devices such as mobile phones, computers, or other digital technologies.
4. Section d contains exercises, where each student will complete the missions presented in the e-module. Students are given challenges in the form of contextual questions that relate spatial concepts to examples of traditional Lombok snacks. The instructions displayed in the dialog box guide students to identify one of the square pyramid snacks, so that the exercise not only emphasizes cognitive aspects, but also strengthens the connection between mathematics and local culture. The presentation of the mission in an interactive visual format is designed to increase students' motivation, engagement, and critical thinking skills when completing learning tasks.

D. Implementation

At this stage, the testing process covers two areas, namely the expert area and the student area. The expert area consists of three types of validation, namely: (1) material expert validation by a primary school teacher education lecturer who has expertise in mathematics, (2) language expert validation by a lecturer in Indonesian Language Education, and (3) media expert validation by a lecturer in Physics Education who has expertise in technology development. Data collection for validation was carried out through a questionnaire consisting of 12 statements with a score range of 1–5, and the assessment results

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were calculated to obtain a percentage of feasibility. The following are the results of the material, media, and language expert validation, as shown in Table 2.

Table 2. Expert Validation Results

1.	Subject matter expert validation	
	Aspects evaluated	Percentage
	Curriculum alignment	86%
	Presentation of material	80%
	Quality and appeal of content	90%
	Average	**83%**
2.	Media expert validation	
	visual	95%
	Readability and clarity	90%
	functionality	80%
	Average	**88%**
3.	Language expert validation	
	Language	83%
	Readability	77%
	Clarity of information	80%
	Average	**80%**

Table 2 contains the results of expert validation of the material, media, and language of the ethnomathematics e-module. The curriculum suitability aspect obtained an average percentage of 86% with a "Feasible" qualification, the material presentation aspect obtained an average percentage of 80% included in the "Feasible" qualification, and the content quality and attractiveness aspect achieved an average percentage of 90% with a "Highly Feasible" qualification. This is consistent with a study (Fawaid et al., 2025) which states that the 90%–100% range falls into the “Highly Feasible” category and the 75%–89% range into the “Feasible” category. Overall, the average of the three aspects in the subject matter expert validation was 83% and was in the "Feasible" category. These findings indicate that the ethnomathematics e-module on spatial figures is "valid" from a subject matter assessment perspective.

The results of media validation of the ethnomathematics e-module show that the visual aspect received an average percentage of 95% with a rating of "Highly Feasible," the readability and clarity aspect received an average percentage of 90% with a rating of " Highly Feasible," and the functionality aspect received an average percentage of 80% with a rating of "Feasible.". The average of these three aspects is 88% in the "Feasible" category. This indicates that the ethnomathematics e-module on spatial figures is "valid" from a media assessment perspective.

The results of language validation of the ethnomathematics e-module show that the linguistic aspect obtained an average percentage of 83% with a "Feasible" rating. In terms of readability, an average percentage of 77% was obtained, which is classified as " Highly Feasible," while the clarity of information aspect achieved an average percentage of 80% with a "Feasible" rating. Overall, the average of these three aspects was 80% and was categorized as "Feasible". These findings indicate that the ethnomathematics e-module on spatial figures is "valid" from a language assessment perspective.

The next step is to conduct a limited trial involving 6 respondents, as well as a field trial involving 21 respondents from SD Negeri 15 Mataram elementary school who used the ethnomathematics e-module on Thursday, November 12, 2025. In the limited trial phase, researchers involved six 5A students selected based on their mathematical ability, including three male students and three female students with high, medium, and low levels of mastery of the material. Next, in the field test stage, the researcher involved 21 students from class 5B to measure the effectiveness of the ethnomathematics e-module on spatial figures in learning conditions. The researcher collected data by administering a pre-test and post-test consisting of 15 questions to all students. The results of the limited trial and field test are presented in Figure 5.

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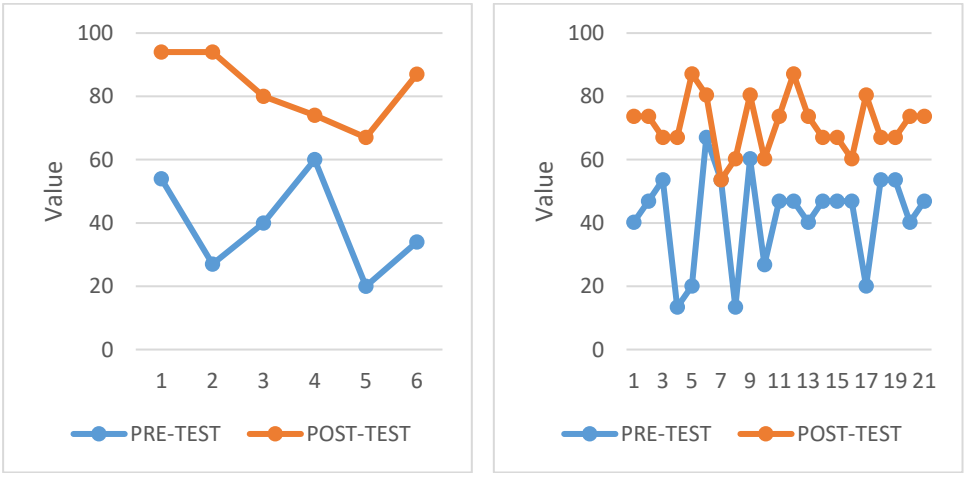

a. limited test *b. field test*

Fig. 5. Graphs of Pre-Test and Post-Test Results for Limited Testing and Field Testing

Figure 5 shows the results of limited trials and field tests with pre-test and post-test instruments consisting of 15 multiple-choice questions. In the limited trial, the pre-test scores ranged from 20% to 60%, indicating that the initial abilities of the students were still relatively low. After participating in learning using the ethnomathematics e-module, the post-test scores increased significantly to 67%–94%. In the field test, the pre-test scores ranged from 13% to 67%, and after the learning intervention, the scores increased to a range of 67% to 87%. The increase in both test stages shows the positive effect of using the ethnomathematics e-module on students' understanding. Based on the score graph above, the N-gain values in Tables 2 and 3 can be obtained.

Table 3. Descriptive Statistics Limited Test

	N	Minimum	Maximum	Mean	Std. Deviation
Ngain_score	6	,34	,92	,69	,21
Ngain_persen	6	33,75	91,53	69,74	21,45
Valid N (listwise)	6				

Table 4. Descriptive Statistics Field Test

	N	Minimum	Maximum	Mean	Std. Deviation
Ngain_score	21	,00	,84	,47	,19
Ngain_persen	21	,00	83,85	47,33	19,25
Valid N (listwise)	21				

Table 3 shows the results of descriptive statistical analysis in a limited trial involving six respondents who obtained N-gain scores ranging from 0.34 to 0.92, with an average value of 0.69 and a standard deviation of 0.21 in the "moderate" category. The percentage of N-gain ranged from 33.75% to 91.53%, with an average value of 69.74% and a standard deviation of 21.45%. This variation illustrates that respondents experienced an increase in understanding despite differences in individual abilities.

Table 4 shows the results of descriptive statistical analysis in the field test involving 21 respondents. The N-gain value ranged from 0.00 to 0.84 with an average value of 0.47 and a standard deviation of 0.19 in the "moderate" category. N-gain in percentage form ranged from 0% to 83.85%, with an average of 47.33% and a standard deviation of 19.25%. The range of values varies, indicating

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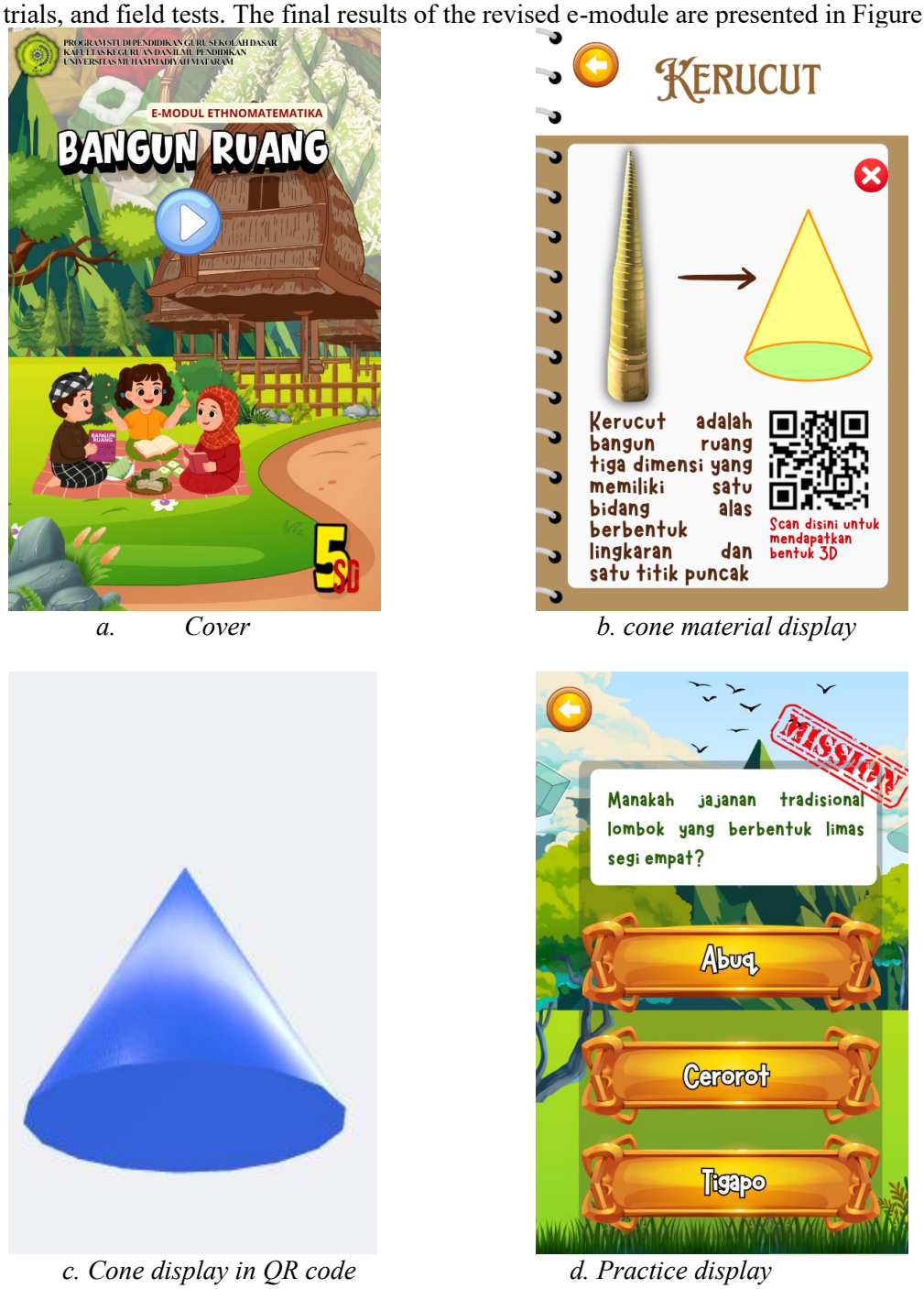
differences in students' ability to absorb the material due to differences in initial abilities and motivation. The field test results had a positive impact on improving learning outcomes, although further strategies are needed to ensure equitable improvement among all students.

E. Evaluation

At this stage, researchers refined the ethnomathematics e-module based on the validity results, limited trials, and field tests. The final results of the revised e-module are presented in Figure 6.



a. Cover *b. cone material display*

c. Cone display in QR code *d. Practice display*

Fig. 6. Display of The Revised E-module Ethnomathematics

Figure 6 shows a number of improvements to the e-module display. On the cover, the navigation buttons that were previously located in the lower right corner have been moved to the center to improve accessibility and visual clarity for users. The class level, which was originally located next to the title, has also been repositioned at the bottom to make the layout structure neater and more proportional. In

the exercise section, the question format has been changed from fill-in-the-blank to multiple choice. Each answer clicked will display automatic feedback. If the answer is incorrect, the system will direct the student to try again, while if the answer is correct, the student will be directed to the next page. This revision aims to increase interactivity, provide immediate feedback, and strengthen students' understanding of concepts in the learning process.

Based on the validity results, the ethnomathematics e-module on spatial figures was declared to meet the eligibility criteria. This validity was reflected in the experts' assessment results. In terms of material, it obtained an average percentage of 83% with a "feasible" qualification. This finding is consistent with the research (Bidiyah et al., 2024) which reported that similar products in flat building materials also achieved an average validation score of 83% from validators. In terms of media, the e-module scored 88% in the "highly valid" category, in line with the research. Khair et al. (2023) which obtained an average validity score of 80% in the development of ethnomathematics modules based on Lombok culture. Meanwhile, the language aspect scored an average of 80%, higher than the study (Triwahyuningtyas et al., 2020) which only reached 75% in the content expert validation in the development of two-dimensional modules based on ethnomathematics for elementary school students.

Limited trials involving six respondents showed that N-gain values ranged from 0.34 to 0.92, with an average of 0.69 and a standard deviation of 0.21, indicating an improvement in student ability. The N-gain values in percentage ranged from 33.75% to 91.53%, with an average of 69.74% and a standard deviation of 21.45%. In a field test involving 21 respondents, N-gain values ranging from 0.00 to 0.84 were obtained, with an average of 0.47 and a standard deviation of 0.19. These values fall into the "moderate" category and indicate an increase in understanding after using the e-module. The N-gain data in percentage supports these findings with a range of 0% to 83.85% and an average of 47.33% and a standard deviation of 19.25%. These results are in line with the findings (Ekadayanti et al., 2024), which show that the Buton traditional house-based ethnomathematics module is valid, practical, and effective in improving students' numeracy. These findings are also reinforced by research (Tanjung et al., 2025), which shows that the Panai tribe's ethnomathematics module has a significant effect on improving critical thinking skills and learning outcomes in arithmetic sequences and series. Thus, the developed ethnomathematics e-module is considered valid, practical, and effective in strengthening students' mathematical competence.

4. CONCLUSION

Based on the results of the evaluation conducted, the ethnomathematics e-module on three-dimensional shapes can be deemed to meet the criteria of validity, practicality, and effectiveness, as evidenced by high levels of suitability in terms of content, media, and language, as well as a moderate improvement in student learning outcomes in both the pilot test and the field test. The development of this e-module integrates Lombok’s traditional culinary heritage with the use of augmented reality technology, which significantly enriches the visualization of geometric concepts, enhances interactivity, and provides a more contextual and meaningful learning experience. Compared to previous studies that generally focused on the validation and effectiveness of ethnomathematics-based e-modules, this study offers improvements in the design of digital learning that is more adaptive, interactive, and oriented toward meaningful learning experiences. Thus, the main contribution of this study lies in the refinement of a locally-based digital learning design that is adaptive to the demands of 21st-century learning, while also providing a critical understanding that the successful implementation of e-modules is influenced by students’ prior knowledge, learning motivation, and digital literacy..

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Geometry Learning through Extended Reality (XR): A Mini Review of Its Impacts, Implementation Challenges, and Future Developments

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ABSTRACT

Extended Reality (XR) which includes AR, VR, MR, has become one of the important innovations in the development of mathematics learning media, especially in the field of geometry. This review aims to analyze the impact, implementation challenges, and future development directions of XR in geometry learning. A PRISMA-based systematic review was conducted with thematic analysis of literature from reputable international journals. The results of the study show that XR improves the effectiveness of learning and spatial thinking skills, student engagement, and learning motivation through interactive visualization and immersive learning experiences. However, negative impacts that need to be considered, include the dependence on technology, physiological and cognitive disorders, and heightened distraction that affects performance. Implementation challenges include limited infrastructure, teacher readiness, device access, costs, appropriate pedagogical design, and curriculum support for optimal XR integration. Future developments suggest that XR holds strong transformative potential through integration with artificial intelligence (AI), adaptive learning systems, and educational metaverse environments. This study highlights the need for structured XR integration strategies and further research on long-term effectiveness and appropriate XR-based pedagogical design in mathematics learning, particularly geometry.

Keywords: augmented reality, extended reality, future developments, geometry learning, impacts and challenges

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1. INTRODUCTION

Difficulties in learning geometry remain a persistent challenge in mathematics education, particularly in understanding three-dimensional (3D) objects and their spatial relationships. Many students struggle to visualize 3D structures, interpret their components, and relate different geometric elements within space, largely due to limitations in spatial reasoning skills (Chivai et al., 2024; Fujita et al., 2020, 2022; Hasanah et al., 2025; Jablonski & Ludwig, 2023; Lowrie & Logan, 2023). These challenges often lead to superficial understanding, where students rely on memorizing formulas rather than developing meaningful conceptual knowledge of volume, surface area, cross-sections, and transformations.

A key issue underlying these difficulties is the continued reliance on two-dimensional (2D) representations in geometry instruction. In many classrooms, geometric concepts are introduced through static images, diagrams, and textbook-based models, which require students to mentally reconstruct three-dimensional forms (Ng et al., 2020; Sarkar et al., 2020). Two-dimensional representations require students to mentally reconstruct three-dimensional forms, a process that places a high cognitive load on learners with limited spatial ability. Consequently, students may resort to memorizing formulas rather than developing meaningful conceptual understanding, which limits their ability to transfer knowledge to new or unfamiliar geometric problems.

In this context, Extended Reality (XR) technologies, comprising Virtual Reality (VR), Augmented Reality (AR), and Mixed Reality (MR), offer promising alternatives for enhancing geometry learning. XR technologies allow students to interact with geometric objects in more dynamic, interactive, and immersive ways, enabling them to observe, manipulate, and explore three-dimensional forms directly within a virtual or augmented environment (Simonetti et al., 2020; Su et al., 2022). Through XR-based learning environments, abstract geometric concepts can be transformed into concrete visual experiences, helping students bridge the gap between symbolic representations and spatial understanding.

The development and application of XR in mathematics education have progressed rapidly in recent years. Research indicates that XR enables learners to physically interact with physical–virtual

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objects or visualize three-dimensional objects that can be rotated, zoomed, and examined from multiple perspectives in real time (Anwar et al., 2025; Jagatheesaperumal et al., 2024; Shaghaghian et al., 2022). Such immersive interactions support active learning and reduce cognitive load by externalizing spatial information, thereby allowing students to focus more on conceptual reasoning rather than mental reconstruction. This immersive experience plays a crucial role in strengthening students' spatial awareness and fostering deeper understanding of geometric relationships.

Among XR technologies, Augmented Reality (AR) has gained particular attention due to its ability to integrate virtual objects into real-world contexts without isolating learners from their physical environment. Studies have shown that AR can enrich learning experiences by increasing engagement, motivation, and conceptual clarity, especially in geometry learning where visualization is essential (Gao et al., 2023; Lampropoulos et al., 2022). By overlaying virtual geometric models onto physical spaces, AR allows students to connect mathematical concepts with tangible experiences, making learning more meaningful and accessible. Therefore, XR, particularly AR, holds significant potential as an instructional medium for geometry education. The continuum and relationships among XR components are illustrated in Figure 1.

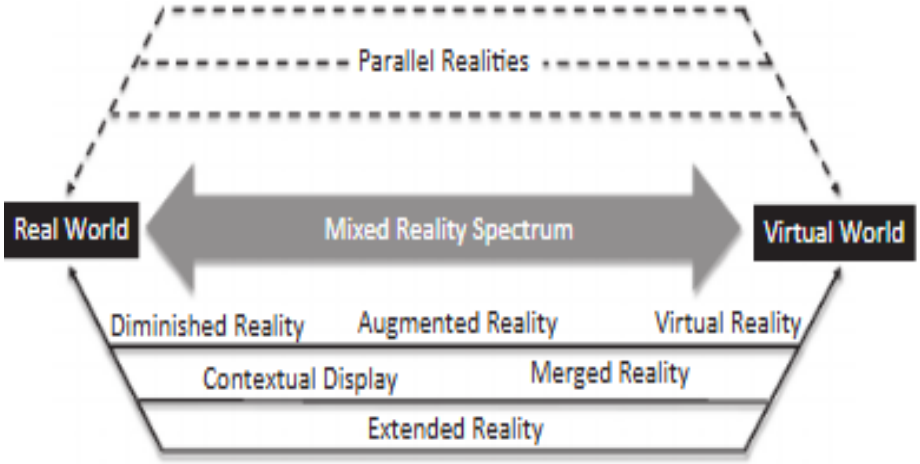

Fig. 1. Mixed Reality Spectrum from Real to Virtual World in Extended Reality (XR) Framework.
Source: Adapted from (Kress & Chatterjee, 2021)

Figure 1 illustrates the Mixed Reality Spectrum, which represents a continuum showing the gradual transition from the real world to the fully virtual world through various forms of digital reality collectively referred to as Extended Reality (XR). Along this spectrum, technologies differ in the extent to which digital elements are integrated into the physical environment and the level of user interaction they afford. At one end of the spectrum is the real environment with minimal digital augmentation, such as simple overlays of information, while at the other end lies fully immersive virtual environments that completely replace the real world. Between these extremes are Augmented Reality (AR) and Mixed Reality (MR), which blend real and virtual elements in varying proportions. This spectrum highlights that XR is not a single technology, but rather a range of technologies that support different instructional goals by enabling learners to interact with digital representations in contextually meaningful ways (Kress & Chatterjee, 2021). In educational settings, particularly in geometry learning, this gradual integration allows educators to select appropriate XR modalities that align with students' cognitive readiness, learning objectives, and instructional design.

Although XR offers many advantages in education, particularly in enhancing visualization and interactivity, its use in geometry learning also presents several challenges that need careful consideration. A number of studies have reported negative physiological and cognitive effects associated with prolonged XR use, such as cybersickness, which includes symptoms like dizziness, nausea, and visual discomfort (Fan et al., 2023; Oh & Son, 2022; Spilka & SpilkaIs, 2023). These effects are often caused by a mismatch between users' physical movements and their perceived motion in

virtual environments, leading to sensory conflicts that reduce comfort and learning efficiency. From a cognitive perspective, unstructured or poorly designed XR experiences may distract students from conceptual understanding, as learners may focus excessively on visual effects, animations, or interactivity rather than on underlying mathematical ideas (Pérez-Juárez et al., 2023). While immersive visuals can initially increase motivation, overly complex or visually dense XR environments risk overwhelming students' cognitive load. Therefore, XR-based learning environments must be carefully balanced with clear instructional guidance, scaffolding, and reflection activities to ensure that technology supports, rather than hinders, meaningful mathematical learning. Furthermore, without appropriate pedagogical integration, XR may encourage superficial engagement with content and foster dependency on technology rather than promoting deep cognitive processing and reflective thinking, which are essential aspects of meaningful learning (Hasanah et al., 2025).

Several previous studies have examined the positive impacts of XR use in mathematics education, particularly in the domain of geometry learning, where spatial visualization plays a significant role. Research has consistently shown that Augmented Reality (AR) can support students' understanding of three-dimensional geometric objects by allowing them to visualize, manipulate, and explore shapes that are difficult to represent adequately using static images or physical models alone (Flores-Bascuñana et al., 2019; Park & Lee, 2020; Tarng et al., 2024; Thamrongrat & Law, 2019; Yaniawati et al., 2023). These studies emphasize, however, that the effectiveness of AR depends heavily on its alignment with curriculum goals and pedagogical strategies. Similarly, studies on Virtual Reality (VR) have found that immersive environments can enrich learning experiences by providing students with a strong sense of presence and spatial awareness, which can enhance conceptual understanding. At the same time, excessive exposure to VR environments has been associated with mental fatigue and reduced learning efficiency when students spend too long in fully immersive settings. Moreover, although the use of XR in education continues to expand, many existing review studies focus primarily on short-term learning gains or immediate positive outcomes (Bulut & Borromeo F, 2023; Huang & Tseng, 2025; Mouali et al., 2024). As a result, the potential negative impacts and long-term implications of XR use in mathematics education remain underexplored. While technological advancements in XR are expected to create new educational opportunities, systematic investigations into prospects and sustainable implementation in geometry learning are still limited.

Although numerous studies have discussed the benefits of XR in geometry learning, few have critically examined the potential negative impacts and long-term challenges associated with its use. Most existing review studies tend to highlight the technical capabilities and pedagogical advantages of XR, such as improved visualization and increased student engagement, while paying less attention to risks, including cognitive overload, reduced conceptual focus, and long-term dependency on immersive technologies. In addition, limited attention has been given to how XR technologies might evolve in the future and how such developments could influence geometry learning over time. Therefore, this study aims to address these gaps by analyzing both the positive and negative impacts of XR in geometry learning, as well as the practical and pedagogical challenges involved in its implementation. The novelty of this study lies in its focus on integrating both the benefits and potential limitations of XR within a single analysis, while also considering the longer-term implications of XR use for geometry learning, which have received limited attention in previous studies.

Furthermore, this article seeks to project future directions for XR development that are more pedagogically integrated, sustainable, and contextually appropriate. By doing so, this study is expected to serve as a valuable reference for educators, researchers, and technology developers who seek to optimize the use of XR in mathematics education while carefully considering both its benefits and potential risks.

2. RESEARCH METHOD

This review was conducted based on the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines, which are widely recognized as a rigorous framework for conducting systematic literature reviews in educational and scientific research. Although this study did not involve a quantitative meta-analysis, the PRISMA framework was adopted to ensure transparency, consistency, and traceability throughout the process of identifying, screening, selecting, and analyzing

relevant studies. The use of PRISMA helps minimize bias and provides a clear methodological pathway that allows other researchers to replicate or evaluate the review process.

The literature search was conducted using several major and reputable electronic databases, including Scopus, SpringerLink, ScienceDirect, IEEE Xplore, Emerald. These databases were selected to ensure broad coverage of high-quality peer-reviewed publications in the fields of education, technology, and mathematics. A comprehensive keyword strategy was employed by combining terms such as “Geometry Learning" or "Geometry Teaching" or “Geometry Education” and "Extended Reality" or "XR" or "Augmented Reality" or “AR” or "Virtual Reality" or “VR” or "Mixed Reality" or “MR” and “impact” or “effect” or “influence” or “implication” or “potential development” or “prospective development” or “future development” or “future directions” or “challenges” or “difficulties” or “obstacles” or “constraint” or “limitation”. This combination of keywords was intended to capture not only studies focusing on learning outcomes, but also those discussing implementation issues and future directions of XR in educational contexts.

The search was limited to articles published between 2016 and 2026 to reflect the rapid development of XR technologies and their recent adoption in education. Only articles written in English were included to maintain consistency and accessibility in analysis. The inclusion criteria encompassed empirical studies employing quantitative, qualitative, or mixed-method approaches, as well as systematic or narrative literature reviews that explicitly addressed the use of XR in geometry learning, mathematics education, or closely related instructional contexts. Furthermore, the selected studies were required to discuss at least one of the following aspects: the impact of XR on learning, the challenges associated with its implementation, or the prospective development of XR technologies in education.

Studies were excluded if they focused on XR applications outside educational settings, such as medical training, industrial simulation, or entertainment, without clear relevance to learning or pedagogy. In addition, articles that had not undergone a peer-review process, such as unpublished manuscripts or non-academic reports, were excluded to ensure the reliability and academic quality of the reviewed literature.

The article selection procedure was conducted in three systematic stages. The first stage involved initial identification based on keyword search results across all databases. In the second stage, titles and abstracts were screened to assess their relevance to the research focus. The final stage consisted of full-text reading to determine the suitability of each article based on its alignment with the research objectives and inclusion criteria. After selection, data from the included studies were analyzed using thematic analysis. This process involved categorizing and synthesizing findings into key themes related to the impacts, challenges, and future developments of XR in geometry learning, enabling a structured and comprehensive interpretation of existing research trends. The flow of the study is presented in Figure 2.

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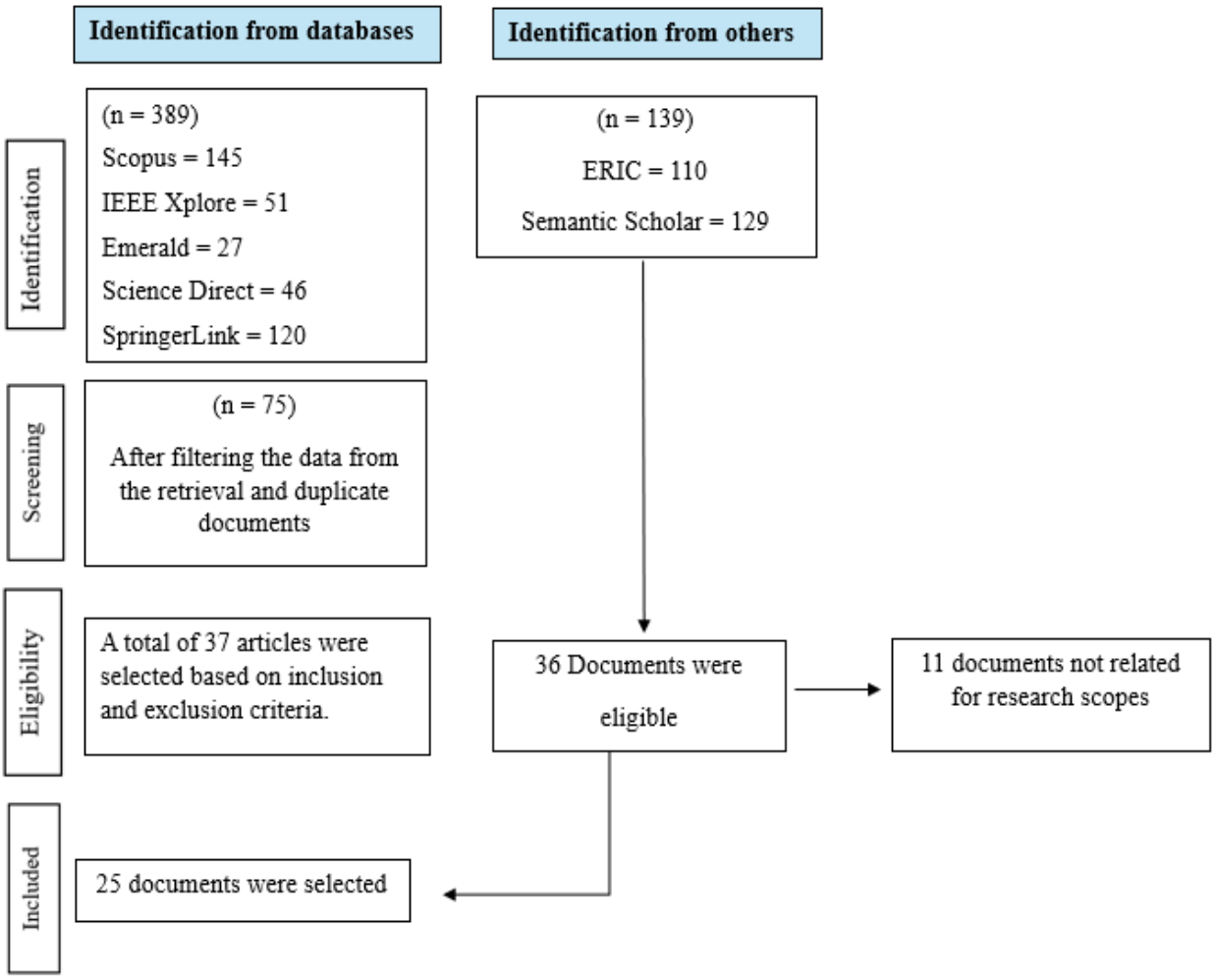

Fig. 2. The flow of the study selection and analysis process

3. RESULTS AND DISCUSSION

A. Positive Impacts of Using XR in Geometry Learning

The use of Extended Reality (XR) in geometry learning has been shown to have a significant positive impact on learning effectiveness, particularly in helping students understand abstract geometric concepts that are often difficult to grasp through conventional instruction. Technologies such as Augmented Reality (AR) and Virtual Reality (VR) enable students to visualize three-dimensional geometric objects interactively, allowing them to explore shapes, surfaces, and spatial relationships dynamically rather than passively observing static representations. This interactive visualization helps bridge the gap between abstract mathematical symbols and concrete spatial understanding, which is often a challenge in traditional geometry instruction(Arvanitaki & Zaranis, 2020; Demitriadou et al., 2020; Ding et al., 2024; Tarng et al., 2024).

Empirical studies have consistently reported that students who learn geometry using AR experience significantly higher levels of conceptual understanding compared to those taught using traditional methods. For example, experimental research has shown that AR-based instruction enhances students' ability to identify geometric properties, visualize transformations, and understand relationships among three-dimensional objects (Gargrish et al., 2021; İbili et al., 2020; Rossano et al., 2020) This improvement is largely attributed to the ability of AR to overlay digital geometric models onto real-world environments, enabling students to observe and manipulate objects from multiple perspectives in real time.

Similarly, VR technology supports geometry learning by offering immersive environments in which students can interact intuitively with abstract concepts, complex structures, and dynamic geometric processes. Through immersive visualization, students are able to experience geometric ideas

such as rotation, scaling, and spatial transformation in a more embodied way, which supports deeper cognitive processing (Wong et al., 2024). Such immersive experiences allow learners to construct meaning through exploration and interaction, aligning with constructivist learning principles.

In addition to enhancing conceptual understanding, XR technologies have been shown to increase student motivation and engagement. The immersive and interactive nature of XR creates a more stimulating learning environment that captures students' attention and encourages active participation. Several studies indicate that students demonstrate higher levels of interest, curiosity, and persistence when learning geometry through XR-based activities compared to traditional instruction (Cárdenas-Sainz et al., 2023; Hmoud et al., 2023; Taborda et al., 2025). This heightened engagement is particularly important in geometry learning, where students often experience anxiety or lack of confidence due to the abstract nature of the subject.

Furthermore, XR has been found to significantly support the development of spatial thinking skills, which are central to geometry learning. Skills such as mental rotation, spatial visualization, shape projection, and understanding spatial relationships between geometric elements can be strengthened through direct interaction with three-dimensional models (Baumgartner et al., 2022; Darwish et al., 2023) By allowing students to manipulate objects in three dimensions, XR helps learners develop a more accurate and flexible mental representation of geometric forms, thereby enhancing their spatial reasoning abilities (Cunha et al., 2024).

Through interactive simulations, XR transforms geometry learning from an abstract and symbolic process into a more concrete and experiential activity. Students can experiment with geometric objects, observe cause-and-effect relationships, and test hypotheses through virtual manipulation, which supports inquiry-based and experiential learning approaches (Gittinger & Wiesche, 2024). As a result, students are better able to connect geometric concepts to real-world contexts, such as architecture, engineering, and everyday Social problem-solving (Chonchaiya & Srithammee, 2025; Walkington et al., 2024; Zhang et al., 2024).

Moreover, XR-based geometry learning often incorporates gamified and exploration-oriented elements that further enhance student motivation. Game-like features such as challenges, levels, and immediate feedback encourage students to engage more deeply with the learning material and sustain their interest over time (Fidan & Tuncel, 2019; Lampropoulos et al., 2022). These elements support both intrinsic motivation and self-directed learning, which are important factors in successful mathematics education.

Research also suggests that XR supports active learning by accommodating different learning styles, particularly visual and kinesthetic learners. The combination of visual immersion and physical interaction enables students to actively construct knowledge rather than passively receive information (Barbu et al., 2025; Iqbal & Campbell, 2023b, 2023a) Additionally, XR allows learners to progress at their own pace, revisit concepts as needed, and engage collaboratively with peers, thereby supporting personalized and inclusive learning environments.

However, while these findings confirm the effectiveness of XR in enhancing geometry learning, they also reflect a dominant focus in existing literature on positive outcomes, with limited attention to potential drawbacks and long-term implications.

B. Negative Impacts and Challenges of XR Implementation

In contrast to the positive emphasis in previous studies, this section highlights the less explored negative impacts and challenges associated with XR implementation. Although Extended Reality (XR) has considerable potential to enhance learning effectiveness, particularly in geometry education, numerous studies have highlighted several negative impacts that must be carefully considered. One of the most frequently reported issues relates to physiological and cognitive effects experienced by users, especially when XR technologies are used intensively or over extended periods. Research indicates that XR usage may trigger anxiety and stress among teachers, particularly when they feel unprepared to operate or integrate the technology effectively into classroom instruction (Fernández-Batanero et al., 2021). In younger learners, XR exposure has also been linked to changes in emotional responses and behavioral patterns, which may interfere with sustained attention and learning regulation (Ventouris et al., 2021). Additionally, XR environments can become a source of distraction, as students may focus more on

visual effects and interactive features rather than on underlying mathematical concepts, ultimately affecting learning performance (Pérez-Juárez et al., 2023).

Beyond these immediate effects, there is growing concern regarding over-reliance on technology in learning contexts. When XR tools are used excessively without appropriate pedagogical scaffolding, students may become dependent on digital visualization, reducing their ability to engage in mental imagery, abstract reasoning, and independent critical thinking (Abbas et al., 2024; Gerlich, 2025). In geometry learning, this dependency can be particularly problematic, as spatial reasoning skills ideally involve the ability to mentally manipulate shapes without constant external visual support. Furthermore, the rapid expansion of XR applications, especially Augmented Reality (AR) and Virtual Reality (VR), has not always been accompanied by sufficient pedagogical frameworks to guide effective integration into existing curricula. As a result, XR use may remain superficial or entertainment-oriented rather than conceptually meaningful. In addition, multiple studies have reported physical side effects such as eye strain, dizziness, balance disorders, and cybersickness, including nausea and disorientation, especially with prolonged VR use (Oh & Son, 2022; Spilka & SpilkaIs, 2023; Fan et al., 2023). These issues highlight the importance of regulating XR use to ensure that its benefits do not come at the expense of learners' physical well-being and cognitive focus.

In addition to individual-level impacts, systemic challenges significantly affect the implementation of XR in educational settings. One major barrier is the limitation of infrastructure, accessibility of devices, and financial cost(Walkington et al., 2024). XR technologies often require expensive hardware such as VR headsets, MR devices, motion sensors, and compatible computing systems, making them difficult to adopt widely, particularly in under-resourced schools and developing regions (Lindner et al., 2019). This situation risks exacerbating the digital divide, where only certain institutions can benefit from advanced educational technologies, potentially widening inequalities in educational quality and learning opportunities (Assefa et al., 2025). Empirical findings by (Radianti et al., 2020) further demonstrate that many schools face significant obstacles in acquiring and maintaining XR equipment, while recent studies confirm that these challenges remain prevalent (Wang et al., 2024).

Another critical challenge involves the readiness and professional competence of teachers. Effective integration of XR requires not only access to technology but also sufficient pedagogical and technological expertise. Many educators lack formal training or prior experience with XR, limiting their confidence and ability to design meaningful XR-based learning activities. This issue aligns with findings by Hasanah et al. (2024), who identified gaps in teachers' Technological Knowledge within the TPACK framework, often caused by limited or inadequate professional development opportunities. Without proper training, XR may be underutilized or misused, reducing its potential impact on learning outcomes. Therefore, continuous professional development programs, technical support, and pedagogical guidance are essential to help teachers integrate XR thoughtfully and effectively into classroom practice (Doerner & Horst, 2022; Nikou et al., 2024; Schwaiger et al., 2024). Addressing these challenges is crucial to ensuring that XR adoption in geometry learning is both sustainable and pedagogically sound.

C. Future Developments of XR in Geometry Learning

In recent years, the use of Extended Reality (XR) technology in education has increasingly shifted toward the development of more adaptive, intelligent, and integrated learning systems (Hanid et al., 2025; Jamah et al., 2022; Wong et al., 2024). This shift is particularly important in addressing the limitations identified in previous studies, which have focused on short-term benefits while overlooking long-term sustainability, potential risks, and future implementation challenges of XR in geometry learning. This reflects the growing recognition that learning technologies should not merely function as visualization tools, but also respond dynamically to learners' cognitive needs, learning pace, and conceptual difficulties. In geometry learning, where students often struggle with abstract spatial relationships, adaptive XR systems offer the possibility of providing immediate feedback, scaffolding, and differentiated learning pathways. By adjusting visual complexity, interaction levels, or learning sequences, XR environments can better accommodate diverse learners and promote deeper conceptual understanding.

One promising direction in XR development is its integration with artificial intelligence (AI). The combination of XR and AI enables the creation of immersive learning environments that are not

only interactive but also personalized and responsive to individual student profiles (Alkaeed et al., 2024; De Pisapia, 2024; Memarian & Doleck, 2024; Zhou & Divekar, 2025). AI-driven XR systems can analyze students' interaction patterns, detect misconceptions, and adapt instructional content accordingly. In geometry learning, this means that students may receive tailored visual representations, adaptive problem sets, or targeted prompts that support their spatial reasoning processes. Such personalization has the potential to enhance learning efficiency and reduce cognitive overload, particularly for students with lower spatial abilities.

Furthermore, XR technologies are increasingly being integrated into cloud-based learning platforms and mobile learning environments, expanding access to immersive geometry learning beyond physical classrooms (Meccawy, 2022; Theodoropoulos et al., 2022). This development opens opportunities for remote and hybrid learning models where students can engage with three-dimensional geometric objects anytime and anywhere. Through mobile AR applications or cloud-based VR systems, students can explore geometric concepts collaboratively, even when learning from various locations. This flexibility is especially valuable for addressing educational inequities, as it allows broader access to high-quality learning experiences without requiring advanced physical infrastructure at every school.

Looking ahead, XR is also expected to play a significant role in the emergence of educational metaverses. In these virtual environments, geometry learning can take place within shared, persistent, and interactive three-dimensional spaces that support real-time collaboration (Wang et al., 2024). Within a metaverse-based learning context, students can jointly manipulate geometric objects, discuss spatial relationships, and solve problems collaboratively, thereby fostering social interaction and collective knowledge construction. Such environments align well with constructivist and socio-cultural learning theories, which emphasize learning as an active and collaborative process.

Recent studies further highlight that XR will become an important catalyst in STEM education, particularly in subject areas that demand complex spatial visualization and multidimensional reasoning (Hasanah et al., 2024). Geometry, as a foundational domain within STEM, stands to benefit significantly from XR-based innovations that enable students to visualize, manipulate, and experiment with spatial forms that are otherwise difficult to represent through traditional two-dimensional media. However, the successful adoption of XR in geometry learning requires careful alignment with pedagogical principles, learning objectives, and curriculum standards.

Despite its promising prospects, XR adoption must be accompanied by systematic teacher training and thoughtful curriculum integration to ensure that it functions as an effective pedagogical solution rather than merely a technological novelty (Caena & Redecker, 2019; Haleem et al., 2022). Teachers need sufficient technological, pedagogical, and content knowledge to design meaningful XR-supported learning activities and to guide students in reflective and purposeful use of the technology. In addition, considerations related to students' cognitive readiness, ethical use of technology, and balanced screen time are essential to maximize learning benefits while minimizing potential risks (Szymkowiak et al., 2021).

In the future, XR development in education is likely to be increasingly intertwined with other advanced technologies such as artificial intelligence and big data analytics, enabling the creation of highly adaptive and data-driven learning ecosystems. AI-powered XR environments may support real-time learning analytics, predictive feedback, and continuous assessment, allowing educators to make informed instructional decisions. Moreover, the growing use of Mixed Reality (MR), which blends real-world contexts with virtual elements, offers particularly strong potential for geometry learning by providing contextualized and application-oriented experiences. MR allows students to connect abstract geometric concepts directly with physical environments, thereby strengthening conceptual transfer and real-world relevance.

Nevertheless, to realize the full potential of XR in geometry education, a coordinated and collaborative approach involving technology developers, educators, researchers, and policymakers is essential (Barbu et al., 2025). Decisions related to content selection, instructional design, software development, hardware solutions, and classroom implementation must be made holistically and contextually (Kluge et al., 2023). In addition, long-term empirical research is needed to examine the sustained effectiveness, cognitive impact, and pedagogical value of XR-supported geometry learning. Such efforts are crucial to ensure that XR technologies contribute meaningfully and sustainably to the future of mathematics education.

Overall, the findings indicate that XR provides substantial pedagogical benefits in geometry learning by enhancing conceptual understanding, spatial reasoning, motivation, and learner engagement. However, in contrast to prior studies that emphasize positive outcomes, this review also reveals several critical limitations and challenges associated with XR use. These include the risk of cognitive overload, potential distraction from core mathematical concepts due to excessive visualization and reported physiological effects such as discomfort and fatigue during prolonged use.

These findings directly address the identified research gap by demonstrating that XR in geometry learning is not exclusively beneficial but presents a complex interplay between pedagogical affordances and potential constraints. While XR supports constructivist and student-centred learning environments, its effectiveness is highly dependent on careful instructional design, scaffolding, and alignment with learning objectives.

Furthermore, the results extend beyond short-term learning outcomes by highlighting concerns related to sustainability and long-term implementation, including the need to prevent overreliance on technology and to ensure that students maintain deep conceptual understanding and reflective thinking. This underscores the importance of integrating XR thoughtfully within pedagogical frameworks rather than treating it as a standalone technological solution. Therefore, the findings not only confirm the strong potential of XR to support contextual and student-centred mathematics learning, but also provide a more balanced perspective that incorporates its limitations, challenges, and future implications—areas that have been underexplored in previous research.

4. CONCLUSION

The use of Extended Reality (XR), encompassing Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR), demonstrates substantial potential in enhancing the effectiveness of geometry learning within mathematics education. The findings of this review indicate that XR-based learning environments contribute positively to the development of students' spatial thinking abilities, including mental rotation, spatial visualization, and the understanding of relationships among three-dimensional geometric objects. By enabling learners to interact directly with virtual geometric representations, XR facilitates deeper conceptual understanding that is often difficult to achieve through conventional two-dimensional instructional media such as textbooks or static diagrams. In addition, the immersive and interactive characteristics of XR have been shown to increase student engagement, learning motivation, and active participation, particularly among learners who benefit from visual and kinesthetic learning modalities.

Despite these promising benefits, the implementation of XR in geometry learning is not without challenges and potential negative impacts. This study highlights several critical concerns, including technical and financial constraints related to the procurement and maintenance of XR devices, such as head-mounted displays and supporting hardware. Moreover, prolonged or unregulated use of XR technologies may lead to negative physiological and cognitive effects, including eye strain, dizziness, cybersickness, and cognitive overload, which can ultimately reduce learning effectiveness. From a pedagogical perspective, XR may also become a source of distraction if instructional design does not adequately align immersive features with clear learning objectives. Without appropriate scaffolding and guidance, students may focus more on visual novelty rather than on meaningful conceptual understanding.

Another significant issue identified in this review is the unequal access to XR technologies across different educational contexts. Institutions located in under-resourced or developing regions often face limitations in infrastructure, internet connectivity, and teacher readiness, which can widen existing educational disparities. As a result, while XR has the potential to democratize access to high-quality visualization-based learning, its uneven implementation may paradoxically exacerbate inequalities in technology-based education if not accompanied by inclusive policies and support systems.

Looking forward, the future development of XR in geometry learning is expected to move toward greater integration with advanced technologies such as artificial intelligence (AI), adaptive learning systems, big data analytics, and educational metaverses. These technological advancements offer opportunities to create more personalized, responsive, and data-driven learning experiences that adapt to individual students' needs, learning pace, and cognitive profiles. Furthermore, the emergence of collaborative virtual environments within educational metaverses has the potential to transform

geometry learning into a shared, interactive, and socially mediated experience that transcends physical and geographical boundaries.

Considering these developments, it is essential for educators, educational technology developers, and policy makers to adopt a structured, inclusive, and sustainable approach to XR integration. Teacher professional development, curriculum alignment, and pedagogically grounded content design are critical to ensuring that XR functions not merely as a technological novelty, but as an effective instructional tool that supports meaningful learning. Finally, this study underscores the need for further longitudinal and empirical research examining the long-term cognitive, pedagogical, and socio-emotional impacts of XR use in geometry learning. Such research will be instrumental in strengthening both the theoretical foundations and practical applications of XR in mathematics education, particularly in fostering deeper conceptual understanding and equitable learning opportunities in geometry.

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Detecting Differential Item Functioning in the Measurement of Ethnomathematical Knowledge among Preservice Teachers: A Rasch Analysis.

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ABSTRACT

This study examines Differential Item Functioning (DIF) in an instrument developed to measure preservice mathematics teachers' ethnomathematical knowledge in Jambi. Anchored in the Rasch measurement framework, this study employs a quantitative ex post facto design to evaluate item-level measurement invariance of an ethnomathematics assessment instrument. Rasch-based procedures: item and person parameter estimation, fit statistics, and DIF analyses were employed to assess item equivalence across gender, educational background, and teaching experience, and to quantify the magnitude of any detected DIF. Data from 150 preservice teachers were analyzed using Rasch estimation and Mantel–Haenszel DIF on a culturally contextualized ethnomathematics instrument. Descriptive analyses indicated strong psychometric properties of the instrument, with person reliability = 0.81, item reliability = 0.97, and fit statistics falling within acceptable ranges. DIF analyses revealed several items with statistically significant DIF predominantly across gender, while the majority of items demonstrated stable functioning across the examined participant subgroups. Graphical DIF plots revealed heterogeneous item-response patterns in the ethnomathematics instrument, highlighting the need for culturally responsive item revision to reduce bias. Findings demonstrate the Rasch model's effectiveness in detecting item-level bias in instruments measuring preservice teachers' ethnomathematical knowledge and substantiate targeted refinement of measurement instruments.

Keywords: DIF, Ethnomathematics, Rasch Model

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1. INTRODUCTION

Ethnomathematics has emerged as a pivotal discipline that bridges mathematics and cultural heritage, contributing significantly to the preservation and revitalization of indigenous knowledge systems (Rosa et al., 2016; Rosa & Orey, 2021). Defined as the study of mathematical practices embedded within cultural contexts, ethnomathematics explores how traditional societies conceptualize and utilize mathematical ideas in everyday activities such as measurement systems, architectural patterns, handicrafts, and ceremonial traditions (Bahar et al., 2023; Ergene et al., 2020; Putra & Mahmudah, 2021; Salam et al., 2022; Sunzuma & Maharaj, 2019). This culturally grounded perspective not only enhances our understanding of mathematics as a human endeavor but also serves as a means of safeguarding intangible cultural heritage through educational integration (Ramalisa et al., 2023).

Teachers serve as pivotal facilitators in bridging the gap between abstract mathematical concepts and cultural realities. By integrating ethnomathematical principles into curricula and instructional strategies, educators can transform mathematical learning into a more contextualized, meaningful, and engaging experience for students (Ergene et al., 2020; Mania & Alam, 2021; Prahmana, 2022). This integration involves leveraging local narratives, artifacts, and community practices, which not only enhances pedagogical effectiveness but also fosters an inclusive environment that celebrates cultural diversity a hallmark of contemporary multicultural education (Atmaja, 2023; Mosimege & Egara, 2023; Nur et al., 2020; Putra & Mahmudah, 2021). Consequently, it is imperative for preservice teachers to develop a robust grasp of both the theoretical foundations and practical applications of ethnomathematics. Ensuring that their knowledge measures are free from bias is a critical step in preparing them to implement culturally responsive education effectively in a globalized world (Mania & Alam, 2021; Ramalisa et al., 2023).

Given the deeply contextual nature of ethnomathematics, developing a standardized measure of this knowledge presents unique psychometric challenges. Since these assessments inherently draw upon cultural narratives and local practices, there is a heightened risk that certain items may inadvertently favor specific demographic or cultural groups over others (Desai et al., 2021). To address this concern and ensure the validity of the findings, Differential Item Functioning (DIF) analysis becomes an indispensable methodological approach. DIF functions by identifying test items that exhibit different statistical properties across diverse subgroups, even when those individuals possess the same underlying ability level (Skaggs & Williams, 2023). In the realm of ethnomathematics, utilizing DIF is essential not merely as a statistical check, but as a commitment to assessment equity; it guarantees that the instrument remains culturally neutral and accurately reflects the preservice teachers' professional competence rather than their cultural or linguistic familiarity (Nicol et al., 2024).

Several methods can be employed to detect DIF in assessment instruments, one of the most widely recognized being the Rasch Model (Ramalisa et al., 2023). The Rasch Model offers distinct advantages for DIF analysis, making it an effective and rigorous approach for ensuring fairness in the measurement of ethnomathematical knowledge among prospective mathematics teachers. One of the model's key strengths lies in its principle of measurement invariance, which enables the estimation of respondent abilities independently of the specific set of items administered (Falani et al., 2022). This allows for more accurate detection of item-level bias across groups.

Moreover, the Rasch Model maintains parameter separability, meaning that item characteristics are estimated independently from the distribution of respondent abilities (Keliat et al., 2023). This property enhances the objectivity of the analysis by ensuring that sample-specific factors do not influence item functioning. Compared to traditional (classical) approaches, the Rasch Model demonstrates greater sensitivity in detecting DIF, thereby allowing for more precise identification of differential item performance across subgroups.

Additionally, the application of the Rasch Model contributes significantly to both the validity and reliability of the measurement instrument (Falani et al., 2022; Keliat et al., 2023). By supporting the development of culturally fair assessment tools, it ensures that prospective teachers are evaluated in a manner that truly reflects their understanding of ethnomathematics free from cultural or contextual bias. Its ability to produce linear, interval-scaled measures also facilitates clearer interpretation of results, further reinforcing its value as a psychometrically sound approach. For these reasons, the Rasch Model has been selected as the primary method for DIF analysis in this study.

A preliminary bibliometric analysis using VOSviewer software (Falani et al., 2022; Keliat et al., 2023) highlights a significant research gap: the absence of DIF analysis in ethnomathematical instruments specifically tailored to the Jambi cultural context. Jambi possesses a distinct cultural identity characterized by a rich tapestry of Malay-Islamic influences, manifested in intricate geometric patterns of Batik Jambi (such as the Angso Duo and Kapal Sanggat motifs) and the sophisticated architectural symmetry of the Rumah Larik or Panggung houses. These cultural artifacts are not merely aesthetic; they embody complex ethnomathematical concepts, including transformational geometry, tessellation, and spatial logic. Despite this potential, no existing studies have examined how these specific local nuances might influence the functioning of assessment items.

This research gap warrants serious attention, as an assessment that fails to account for these unique cultural markers may result in item bias, thereby obscuring the true ethnomathematical competence of preservice teachers. Since prospective teachers are the primary agents in bridging local wisdom with formal mathematics, the development of contextually grounded and psychometrically valid tools is vital. By ensuring that instruments are free from DIF relative to Jambi's specific cultural characteristics, this study not only promotes assessment equity but also serves as a model for safeguarding regional cultural heritage through rigorous, culturally responsive educational measurement.

A systematic bibliometric analysis of 532 scholarly articles indexed in global databases between 2020 and 2025, as visualized in Figure 1, provides empirical evidence of a significant research lacuna concerning the application of Differential Item Functioning (DIF) analysis within ethnomathematical contexts. The visualization revealed a lack of structural co-occurrence and node connections between the term "ethnomathematics" and other critical keywords associated with psychometric bias or teacher competency (Donthu et al., 2021). This isolation indicates that while ethnomathematics has gained

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traction as a pedagogical concept, its rigorous psychometric evaluation, specifically regarding the ethnomathematical knowledge of prospective teachers in localized contexts like Jambi, remains at a nascent stage of academic inquiry. Compared to global trends in mathematical literacy assessments which increasingly utilize IRT-based diagnostics (Masters, 2020), the absence of DIF-related nodes in this dataset underscores a critical 'measurement void.' This study, therefore, addresses this gap by synthesizing cultural mathematics with advanced psychometric modeling to ensure a fair and non-biased evaluation framework (Alkharusi, 2020; Retnawati et al., 2018).

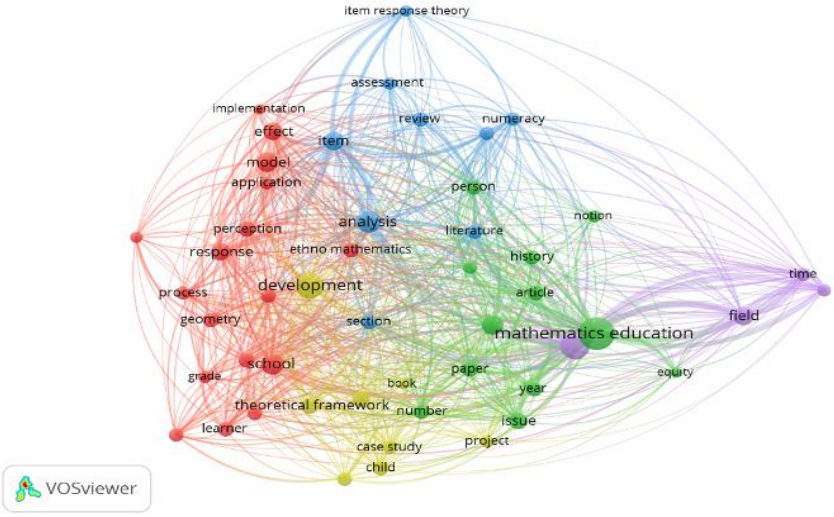

Fig 1. Network Visualization Vosviewers

In light of the background presented above, the objective of this study is to analyze DIF in an instrument designed to measure ethnomathematical knowledge among prospective mathematics teachers, with specific reference to the cultural dimensions of the Jambi region. To achieve this, the Rasch Model is implemented as the primary analytical framework, given its robustness in detecting item bias and ensuring psychometric fairness across culturally diverse groups.

2. RESEARCH METHOD

A. Research types and design

This study is a quantitative research (Soesana et al., 2023) that implements the Rasch Model to identify Differential Item Functioning (DIF). DIF occurs when items in a test behave differently for different groups, for example, based on culture or gender. Furthermore, this study uses an Ex Post Facto research design, where there is no manipulation of independent variables, but rather an analysis of data that has been collected. This model is suitable for identifying DIF patterns based on respondent groups such as cultural background or learning experience.

B. Rasch Model research model

In the DIF analysis using the Rasch Model in this study, the mathematical equation used is usually based on the one-parameter logistic model (1PL), which can be expressed as (Andrich, 2009):

$$P(X_{ni} = 1) = \frac{e^{(\theta n - \beta_i)}}{1 + e^{(\theta n - \beta_i)}} \quad (1)$$

$P(X_{ni} = 1)$ is the probability that an individual nn answers item i correctly. θ_n is an individual's ability n. β_i is the difficulty level of the item i. In the context of DIF, differences in i item difficulty parameters between two groups (e.g., based on gender or educational background) may indicate bias in the questions. DIF in this study was further tested by comparing estimates of item difficulty parameters between different groups using the Likelihood Ratio Test (LRT) or Mantel-Haenszel Test.

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C. Research procedures

There are four main stages in this study, which include: Preliminary Research, Instrument Development and Permits, Data Collection and Analysis, Dissemination and Publication (Oriondo & Dallo-Antonio, 1984).

1) Preliminary research. This stage includes five main activities: first, analysis of mathematics learning, which identifies how ethnomathematics concepts have been integrated into the curriculum and teaching methods; second, analysis of Jambi culture, which traces cultural elements relevant to local-based mathematics learning; third, exploration of the Rasch Model concept, which includes parameter estimation mapping and instrument calibration mechanisms; fourth, DIF analysis, which focuses on detecting bias in test items based on respondent characteristics; and finally, analysis of the ethnomathematics concept, which links mathematical understanding with cultural perspectives to create more representative instruments. Through these stages, the study aims to develop a more reliable and fair measurement tool that can be used to improve the effectiveness of ethnomathematics teaching for prospective teachers in Jambi.
2) Instrument Development. At this stage, the research focused on developing a Rasch Model-based measurement tool to ensure validity and fairness in measuring the ethnomathematics knowledge of prospective mathematics teachers. This process began with the design of items based on ethnomathematics concepts and the cultural characteristics of Jambi, ensuring that the concepts were relevant to the learning context. Next, theoretical and empirical validity tests are conducted to assess the suitability of the instrument, followed by a preliminary analysis of the difficulties and abilities parameters on the Rasch scale to identify potential biases. The final development of the instrument includes determining the scoring rubric and DIF testing mechanism to ensure that the measuring tool provides fair results and can be used for more accurate knowledge evaluation. The results of this stage will form the basis for further analysis to improve the reliability and effectiveness of the evaluation of prospective mathematics teachers.
3) Collection and analysis of DIF data. At this stage, this study used the Rasch Model to identify DIF in the measurement instrument for prospective mathematics teachers' ethnomathematics knowledge. Data were collected through prospective teachers' responses to items designed based on the concepts of ethnomathematics and Jambi culture. After that, parameter estimation was carried out using the Rasch model to determine the levels of difficulty and ability, as well as to detect differences in item functions between respondent groups. DIF analysis was conducted by comparing parameter estimates between groups using Rasch analysis. The results of this analysis will form the basis for improving the instrument so that it is more optimal in measuring ethnomathematics knowledge validly and reliably. DIF data analysis in this study was conducted using WINSTEP 3.73 software (Linacre, 2011).
4) Dissemination and publication. At this stage, research results are communicated through various media to ensure their impact on the development of ethnomathematics learning. Key findings are presented in academic forums, seminars, and conferences to obtain feedback and increase the relevance of the research. In addition, publications are made in reputable scientific journals to support the development of reliable measurement instruments for prospective mathematics teachers.

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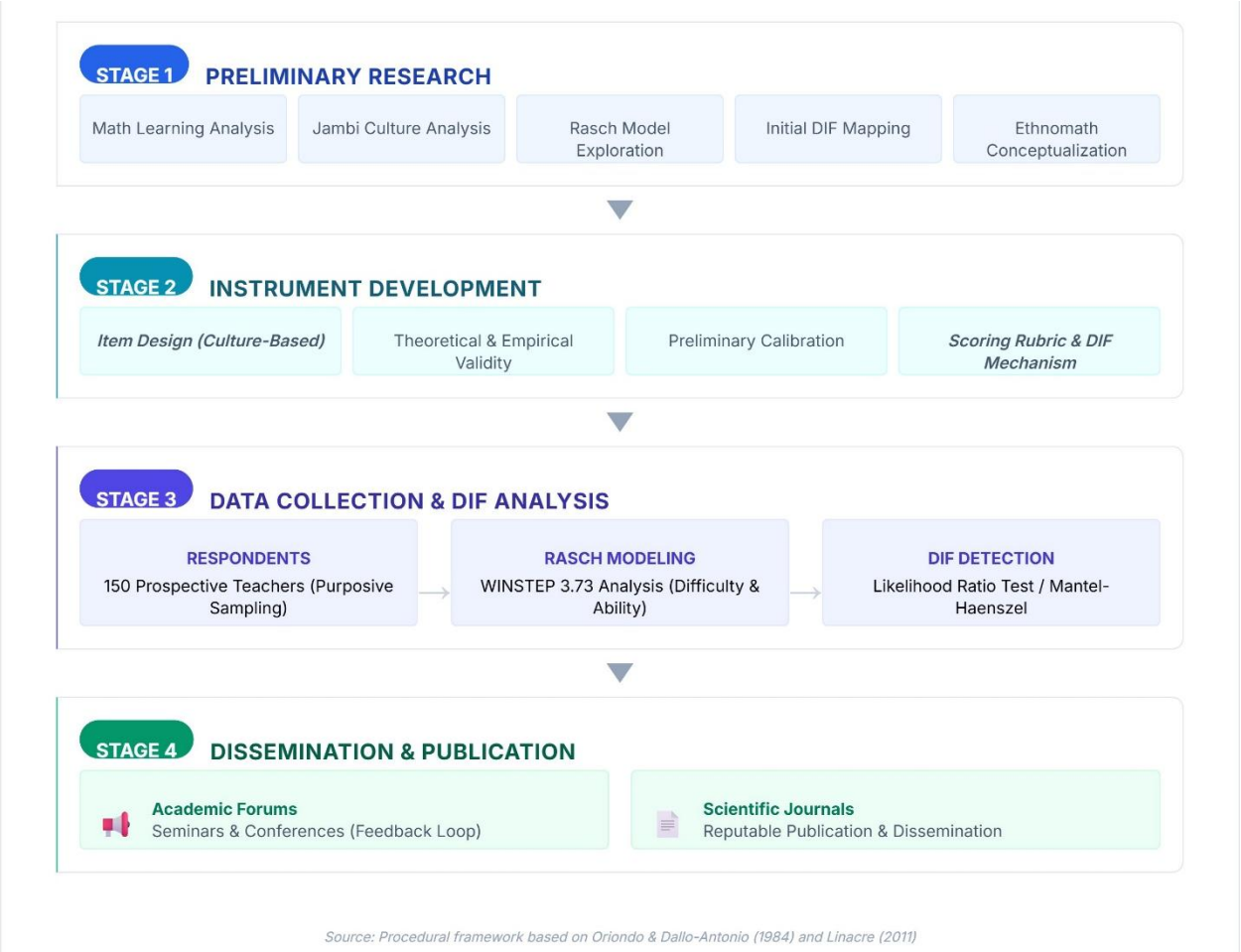

Fig 2. Research Procedural Flowchart: Etnomathematics DIF Analysis

D. Research respondents

The respondents or participants in this study were 150 prospective mathematics teachers, comprising mathematics education students and teacher education students from Jambi Province. The sampling technique employed was purposive sampling, ensuring that individuals selected had relevant academic backgrounds aligned with the study's objectives. Data collection was conducted using an ethnomathematics knowledge test instrument, which was designed to meet established criteria for validity and reliability.

3. RESULTS AND DISCUSSION

A. Descriptive statistics of respondents

This section presents descriptive statistics of the respondents, providing a comprehensive overview of their demographic and professional attributes. This section serves to contextualize the study by presenting key characteristics such as gender, educational attainment, and teaching experience within school environments. These variables are essential for understanding the composition of the sample and for interpreting subsequent findings with greater precision. By examining these foundational aspects, the study ensures analytical rigor and enhances the validity of its conclusions within the broader educational research framework.

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Table 1. Summary Table of Respondents' Descriptive Statistics

Category	Subcategory	Number of Respondents	Percentage (%)
Gender	Male	33	22%
	Female	117	78%
Educational Status	Undergraduate Student (S1)	71	48%
	Master's Student (S2)	31	21%
	Teacher Professional Education (PPG)	41	27%
	S1 Graduate	5	3%
	S2 Graduate	2	1%
Teaching Experience	Has taught in an educational institution	89	59%
	Has not taught in an educational institution	61	41%
Total Respondent		150	100%

The demographic analysis of the 150 respondents reveals a significant gender disparity, with female participants (78%) substantially outnumbering males (22%). In terms of educational attainment, the majority of the sample consists of undergraduate students (48%), followed by those enrolled in teacher professional education (27%) and master's programs (21%), while a small fraction (4%) had already completed their degrees. Furthermore, professional background data indicates that 59% of respondents possess prior teaching experience in formal educational institutions, whereas 41% have yet to engage in formal pedagogical roles.

The predominance of female respondents in this study is consistent with the global trend toward the "feminization of the teaching profession," particularly in mathematics and primary education. This finding aligns with the research by Nicol et al., (2024), which highlights that female preservice teachers often constitute the largest demographic in teacher education cohorts. From a psychometric standpoint, this imbalance underscores the need to conduct Differential Item Functioning (DIF) analysis to ensure that ethnomathematical assessment instruments do not harbor latent gender biases that could compromise the validity of competency measures. Furthermore, the substantial representation of participants with prior teaching experience (59%) provides a unique vantage point for assessing ethnomathematical knowledge. Unlike studies that rely solely on inexperienced undergraduates, this diverse sample allows for a more nuanced investigation into how professional experience mediates the interpretation of cultural mathematics. This result reinforces the arguments of Rosa et al., (2016), who posit that pedagogical readiness is a product of the intersection between academic theory and field-based practice. By including both novice and experienced practitioners, this study strengthens the generalizability of the Rasch-based findings, positioning the instrument as a reliable tool for diverse pedagogical contexts in the Indonesian educational landscape.

B. Summary of the measured item and person

This subsection provides a summary of the measured items and persons, offering a foundational overview of the data collected through the assessment instrument. The analysis includes key metrics

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that reflect both item-level performance and individual respondent outcomes, enabling a comprehensive evaluation of the instrument's psychometric properties.

Table 2 presents a comprehensive summary of the measurement results for 150 individuals, highlighting key statistical indicators relevant to the assessment's psychometric quality. The data include total scores, person measures, model error, and fit statistics (Infit and Outfit), both in terms of mean square (MNSQ) and standardized values (ZSTD). The mean total score was 31.8, with a standard deviation of 5.8, indicating a moderate spread of performance across respondents. The person measure ranged from -2.68 to 3.92 logits, suggesting a wide range of ability levels within the sample.

Table 2. Summary of 150 Measured Person

	Total Score	Count	Measure	Model Error	Infit		Outfit	
					MNSQ	ZSTD	MNSQ	ZSTD
Mean	31.8	43.0	1.70	0.47	0.96	0.0	1.10	0.2
S.D	5.8	0.0	1.11	0.08	0.26	1.0	1.26	1.3
Max.	40.0	43.0	3.92	0.74	1.75	3.3	9.14	6.4
Min	6.0	43.0	-2.68	0.38	0.51	-2.3	0.14	-1.5

Person reliability = 0.81
Cronbach Alpha (KR-20) person Raw Score "Test" reliability = 0.85

The fit statistics further support the internal consistency of the measurement model. The mean Infit MNSQ was 0.96 and Outfit MNSQ was 1.10, both of which fall within the acceptable range of 0.5 to 1.5, indicating that the data fit the Rasch model reasonably well. The corresponding ZSTD values (0.0 for Infit and 0.2 for Outfit) reinforce this interpretation, as they remain close to the expected value of zero, suggesting minimal distortion in the measurement process. The psychometric findings of this study provide empirical weight to the argument that the Rasch model offers a more stable framework for ethnomathematical assessment compared to Classical Test Theory (CTT). The Infit and Outfit MNSQ values (0.96–1.10) obtained in this study are strikingly consistent with the research of Sumintono & Widhiarso (2014), who emphasize that fit indices within this range guarantee that the items are productive for measurement. This stability suggests that the ethnomathematical tasks designed for preservice teachers functioned as a unidimensional construct, effectively minimizing construct-irrelevant variance.

Moreover, the high item reliability (0.97) and person reliability (0.81) reinforce the findings of Herdoost (2016) and Irwing et al., (2018), which suggest that reliability coefficients above 0.80 indicate an instrument's readiness for high-stakes educational diagnostics. This high level of precision is critical when assessing "ethnomathematical knowledge," a domain often criticized for its subjective nature. By achieving a Cronbach's Alpha of 0.85, this study strengthens the position of Biddix (2017), proving that cultural-based mathematics items can achieve the same, if not higher, level of dependability as standardized curricula items.

Table 3 provides a detailed summary of 43 measured items, offering key insights into the psychometric properties of the instrument used in this study. The table includes descriptive statistics such as total score, item count, item measure, model error, and fit indices (Infit and Outfit), both in mean square (MNSQ) and standardized (ZSTD) formats. These metrics collectively serve to evaluate the quality and consistency of item performance across the sample of 150 respondents (Sumintono & Widhiarso, 2014).

The mean total score for the items was 111.0, with a standard deviation of 35.8, indicating a broad distribution of response values. All items were administered uniformly, as reflected by the consistent count of 150. A notable point of discussion is the wide logit range (-2.89 to 5.02), which demonstrates an excellent "item-person map" alignment. This spread reflects the principles discussed

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by Fischer et al., (1999) and Van Der Linden (2010), where a balanced distribution of difficulty ensures the instrument's construct validity. Compared to previous studies that often showed "ceiling effects" (where items are too easy for preservice teachers), the current instrument successfully captures the entire spectrum of ethnomathematical proficiency. This alignment ensures that the subsequent Differential Item Functioning (DIF) analysis is performed on a statistically sound foundation, providing a credible benchmark for future ethnomathematical research in diverse cultural settings

Fit statistics further reinforce the integrity of the measurement model. The average Infit MNSQ was 0.99 and Outfit MNSQ was 1.10, both of which fall within the acceptable range of 0.5 to 1.5, indicating that the items functioned as expected under the Rasch model. The corresponding ZSTD values (0.0 for both Infit and Outfit) suggest minimal deviation from model expectations, with only minor fluctuations observed in the standard deviations.

Most notably, the item reliability coefficient was 0.97, which reflects an exceptionally high level of internal consistency. This value indicates that the items reliably differentiate among respondents and that the instrument is stable across repeated administrations. Such a high reliability index is critical for ensuring the validity of subsequent analyses and for supporting the generalizability of the findings. In sum, the data presented in Table 3 affirm the robustness of the measurement instrument and its suitability for rigorous empirical investigation (Taherdoost, 2016).

Table 3. Summary of 43 Measured Item

	Total Score	Count	Measure	Model Error	Infit		Outfit	
					MNSQ	ZSTD	MNSQ	ZSTD
Mean	111.0	150.0	0.00	0.29	0.99	0.0	1.10	0.0
S.D	35.8	0.0	1.83	0.11	0.16	1.5	1.00	1.7
Max.	147.0	150.0	5.02	0.61	1.37	4.4	5.44	5.1
Min	8.0	150.0	-2.89	0.18	0.73	-2.7	0.19	-2.7

Item reliability = 0.97

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C. Differential item functioning classification

Table 4. DIF Summary Based on Gender, Education Level, and Teaching Experience

Item Number	Gender			Education level			Teaching experiences		
	DIF χ^2	Prob.	t=ZSTD	DIF χ^2	Prob.	t=ZSTD	DIF χ^2	Prob.	t=ZSTD
1	0,27	0,60	-0,66	1,94	0,38	-0,45	2,75	0,10	0,71
2	1,79	0,18	0,17	2,63	0,45	-0,92	1,16	0,28	0,10
3	0,05	0,82	-1,08	0,82	0,84	-1,73	0,01	0,92	-1,25
4	0,65	0,42	-0,29	2,31	0,31	-1,26	0,00	1,00	-1,47
5	5,45	0,02	1,07	7,91	0,09	-0,42	0,00	1,00	-1,53
6	0,42	0,52	-0,54	8,77	0,07	-0,17	2,31	0,13	0,54
7	2,71	0,10	0,59	3,41	0,18	-0,37	0,00	1,00	-1,46
8	4,84	0,03	1,01	1,12	0,57	-0,85	1,45	0,23	0,27
9	1,36	0,24	0,07	1,23	0,54	-0,91	0,07	0,80	-0,97
10	3,56	0,06	0,64	1,95	0,58	-1,53	0,08	0,78	-0,94
11	0,67	0,41	-0,34	2,77	0,43	-1,32	0,04	0,85	-1,10
12	0,01	0,92	-1,29	0,58	0,45	-0,45	0,72	0,40	-0,13
13	0,26	0,61	-0,70	5,50	0,24	-0,68	2,10	0,15	0,49
14	0,59	0,44	-0,37	1,22	0,75	-2,05	0,24	0,63	-0,61
15	7,10	0,01	1,33	1,98	0,74	-2,36	0,22	0,64	-0,65
16	0,34	0,56	-0,56	1,31	0,52	-1,04	0,09	0,77	-0,90
17	0,00	1,00	0,00	0,37	0,54	-0,26	1,57	0,21	0,33
18	0,00	1,00	0,00	1,91	0,38	-0,60	0,95	0,33	0,02
19	3,06	0,08	0,63	5,53	0,06	0,22	0,02	0,90	-1,22
20	0,77	0,38	-0,23	4,14	0,12	-0,17	0,09	0,77	-0,90
21	0,03	0,86	-1,13	1,82	0,77	-2,57	1,51	0,22	0,26
22	0,02	0,90	-1,25	2,03	0,36	-0,49	0,87	0,35	-0,04
23	1,22	0,27	-0,04	8,01	0,05	0,21	3,10	0,08	0,80
24	0,75	0,39	-0,26	1,99	0,37	-0,64	0,19	0,67	-0,69
25	0,21	0,65	-0,77	0,96	0,92	-2,45	0,25	0,62	-0,59
26	1,66	0,20	0,22	1,34	0,25	0,46	2,12	0,15	0,55
27	0,75	0,39	-0,28	3,67	0,30	-0,82	0,30	0,59	-0,53
28	5,89	0,02	1,19	2,52	0,28	-0,29	0,00	0,95	-1,37
29	2,11	0,15	0,31	5,26	0,15	-0,60	2,97	0,08	0,78
30	0,00	1,00	0,00	0,34	0,56	-0,67	0,15	0,70	-0,75
31	0,66	0,42	-0,31	3,15	0,20	-0,09	0,15	0,70	-0,76
32	0,44	0,51	-0,50	2,61	0,46	-1,28	3,79	0,05	1,00
33	0,50	0,48	-0,46	1,15	0,77	-1,80	1,32	0,25	0,19
34	0,38	0,54	-0,60	1,69	0,64	-1,63	0,18	0,67	-0,71
35	0,68	0,41	-0,33	1,08	0,03	0,16	0,42	0,52	-0,40
36	3,19	0,07	0,69	0,00	1,00	0,00	1,12	0,29	0,11
37	0,89	0,35	-0,21	6,79	0,08	0,00	0,82	0,37	-0,09
38	0,37	0,54	-0,53	0,00	1,00	0,00	0,25	0,62	-0,59
39	1,71	0,19	0,22	0,85	0,65	-1,26	0,12	0,73	-0,81
40	0,25	0,62	-0,74	0,97	0,61	-0,94	2,54	0,11	0,62
41	0,65	0,42	-0,29	0,61	0,43	0,01	2,62	0,11	0,73
42	0,07	0,78	-0,98	0,00	1,00	0,00	0,00	1,00	0,00

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43	0,00	1,00	-1,44	0,97	0,61	-1,16	0,00	1,00	-1,51

Table 4 presents a DIF analysis based on three respondent characteristics: gender, education level, and teaching experience. The table reports DIF statistics for each item, including the Chi-Square value, associated probability (Prob.), and standardized t-value (ZSTD). These indicators are critical for evaluating whether items function equivalently across subgroups, thereby ensuring fairness and validity in the measurement instrument (Naga, 2012)

The probability values (Prob.) serve as the primary reference for determining statistical significance in DIF analysis. A conventional threshold of $p < 0.05$ is typically used to identify items with significant DIF. Based on this criterion, several items exhibit notable DIF across gender, such as Item 5 (Prob. = 0.02), Item 8 (Prob. = 0.03), Item 15 (Prob. = 0.01), and Item 28 (Prob. = 0.02). These findings suggest that responses to these items may be influenced by gender-related factors, warranting further investigation into potential bias or differential interpretation.

In contrast, DIF based on education level and teaching experience appears less pronounced. Although some items show relatively low probability values, such as Item 23 (Prob. = 0.05) and Item 32 (Prob. = 0.05) for teaching experience, most items yield probabilities well above the significance threshold, indicating minimal DIF. For education level, while Item 35 shows a very low probability (Prob. = 0.03), the corresponding ZSTD value (0.16) remains within acceptable bounds, suggesting limited practical impact.

The ZSTD values complement the probability analysis by indicating the magnitude and direction of DIF. Values exceeding ±2.0 may signal substantial DIF, yet most items in this table fall within the range of −1.5 to +1.5, reinforcing the overall stability of item functioning across subgroups. Taken together, the DIF analysis supports the general fairness of the instrument, with only a few items requiring closer scrutiny to ensure measurement equivalence across gender, education level, and teaching experience. This reinforces the psychometric integrity of the instrument and its suitability for use in diverse respondent populations (Rust & Golombok, 2018).

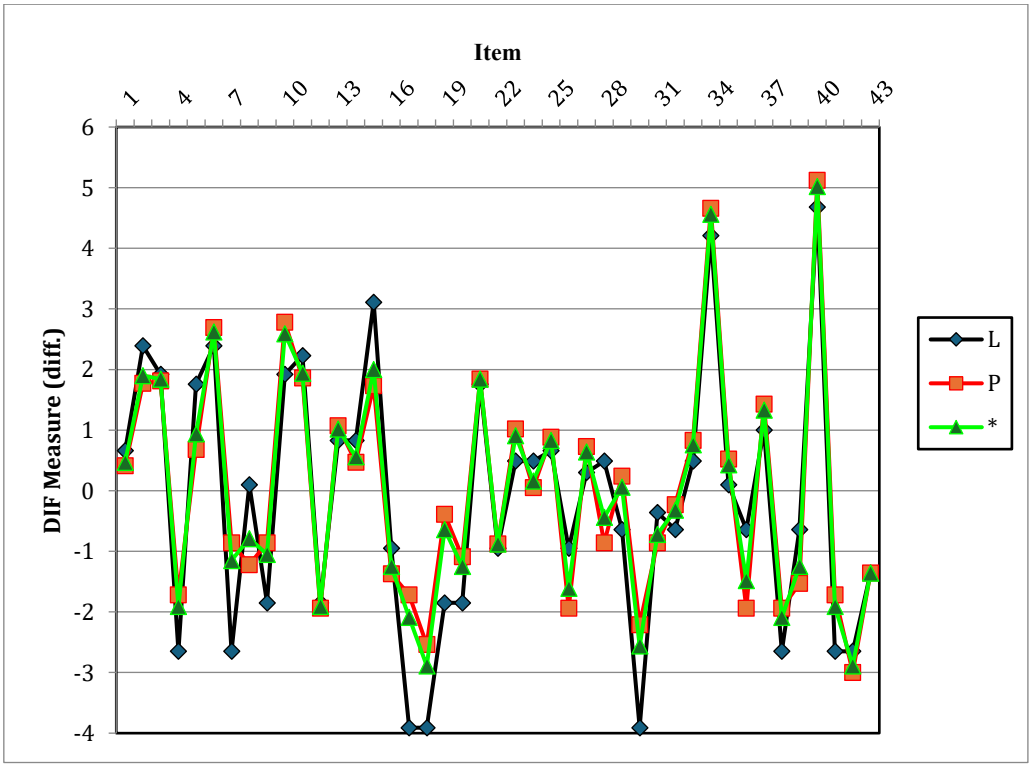

Fig 3. Person DIF Plot Based on Gender.

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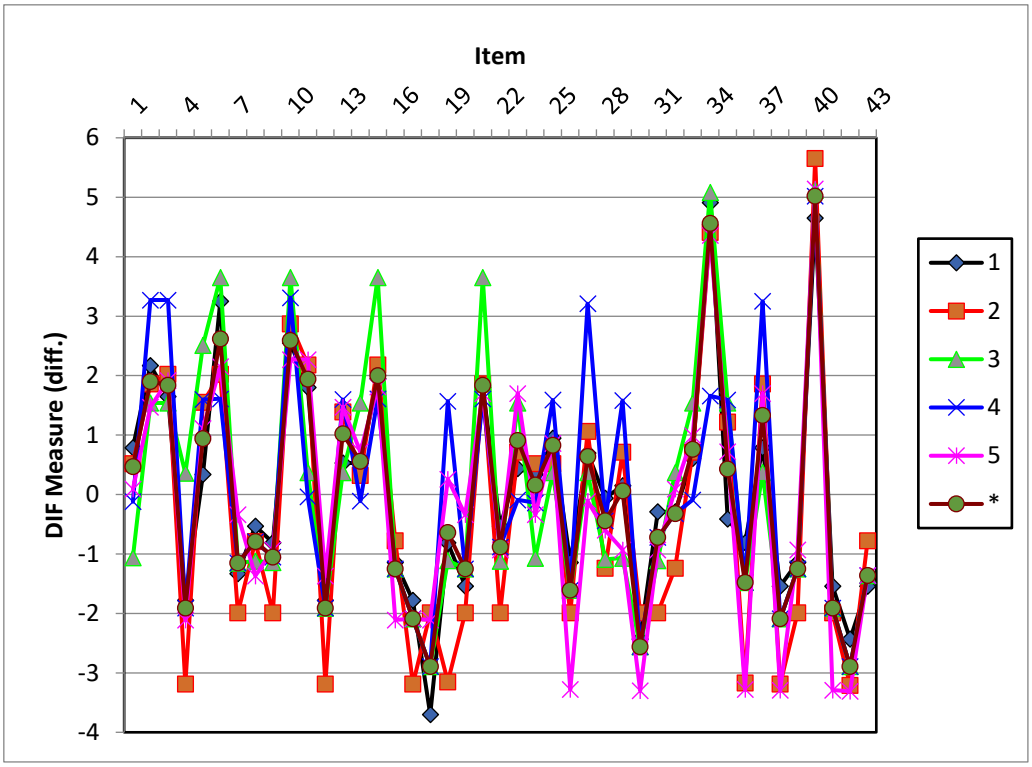

Fig 4. Person DIF Plot Based on Teaching Experiences

Figures 3 and 4 provide a detailed graphical representation of DIF across 43 items, facilitating a nuanced examination of measurement invariance at the item level among gender groups and multiple respondent categories. These visualizations serve as essential psychometric tools in evaluating the fairness and validity of assessment instruments, particularly in contexts where construct comparability across subgroups is critical (Kline, 2015).

Figure 3 depicts DIF measures by gender, with three distinct curves represented by blue diamonds (L), red squares (P), and green triangles. The green curve reveals substantial variability, with several items exceeding the ±3 threshold, indicating potential differential functioning across gender groups. Such deviations may reflect systematic bias or differences in item interpretation influenced by gender-specific experiences. In contrast, the blue and red curves exhibit relative stability, suggesting consistent item performance and supporting the assumption of measurement equivalence for those subgroups. Items associated with extreme DIF values in the green curve merit further scrutiny to ensure content neutrality and linguistic clarity (Cohen et al., 1993; Rustam et al., 2019).

Figure 4 extends the analysis to six respondent groups, each distinguished by unique symbols and colors. The DIF values range from –5 to +5, offering a broader scale for detecting item sensitivity. Several curves intersect and diverge markedly, suggesting that certain items may not function uniformly across groups. This pattern points to potential construct-irrelevant variance, which could undermine the validity of score interpretations. Items consistently demonstrating high DIF across multiple groups should be prioritized for revision, as they may be influenced by latent cultural, contextual, or cognitive factors (Dorans et al., 2013).

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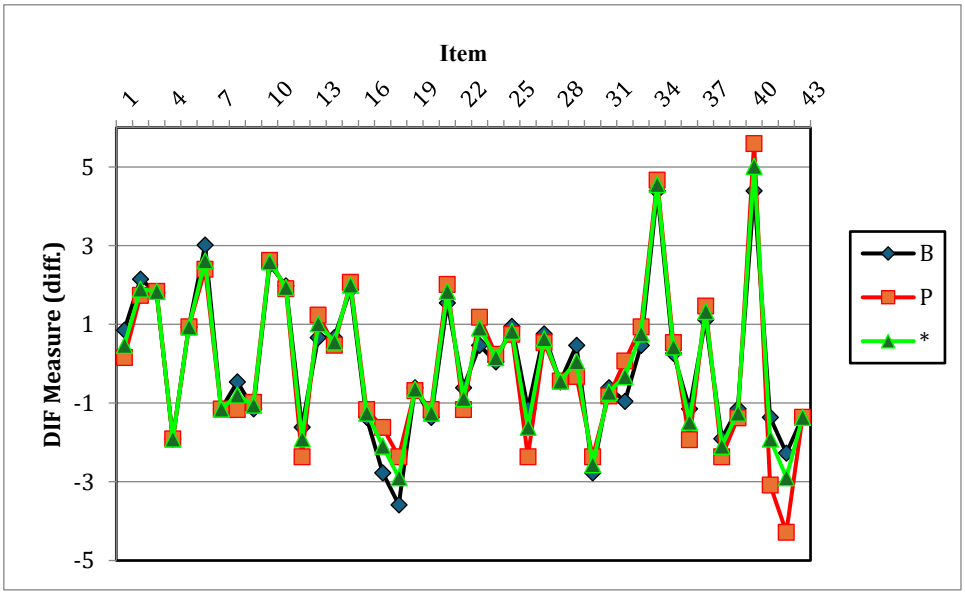

Fig. 5. Person DIF Plot Based on Education Level

Figure 5 refines the DIF analysis by comparing three additional groups: blue diamonds (B), red squares (P), and green triangles. Once again, the green curve exhibits the most fluctuation, with a prominent peak at item 37 and a sharp decline at item 41. These variations suggest that specific items may be interpreted differently depending on group affiliation, potentially affecting the fairness of the measurement. The relative consistency of the blue and red curves reinforces the reliability of those items within their respective groups, while the volatility observed in the green curve underscores the need for targeted psychometric evaluation.

Taken together, the three DIF plots highlight the importance of rigorous item-level analysis in ensuring equitable measurement across diverse respondent populations. Items flagged for extreme DIF should undergo systematic content review and, where necessary, be revised to enhance interpretive consistency. This approach is particularly relevant in the context of assessing preservice teachers' ethnomathematical knowledge, where cultural and contextual factors may influence item comprehension. The findings contribute to the refinement of Rasch-based instruments and support the development of valid, bias-free tools for evaluating domain-specific competencies in teacher education.

Despite the methodological rigor and psychometric robustness demonstrated in this study, several limitations warrant acknowledgment. First, the use of purposive sampling, while appropriate for targeting preservice mathematics teachers familiar with ethnomathematical content, may restrict the generalizability of findings beyond the Jambi region. Second, the reliance on quantitative DIF analysis, though effective in detecting statistical item bias, does not capture the nuanced cognitive and cultural interpretations that may underlie DIF. Third, the absence of qualitative triangulation, such as think-aloud protocols or expert validation panels, limits the depth of insight into item-level discrepancies. Additionally, the study's focus on three respondent characteristics (gender, education level, and teaching experience) may overlook other influential variables, such as linguistic background or regional dialects, which could affect item comprehension. Future research should address these limitations by employing mixed-method approaches, expanding the respondent base across diverse cultural settings, and incorporating qualitative techniques to enrich the interpretive validity of DIF findings.

4. CONCLUSION

In conclusion, this research transcends a mere summary of psychometric outputs by elucidating the critical tension between cultural contextualization and measurement invariance in the measurement of ethnomathematical knowledge among preservice teachers. While the Rasch Model successfully validated the instrument's overall structure, the identification of significant Differential Item Functioning (DIF) provides a pivotal theoretical contribution: it challenges the monolithic assumption that ethnomathematical content inherently ensures assessment equity. These findings suggest that

cultural stimuli are not interpreted uniformly; rather, they are filtered through diverse socio-cognitive lenses shaped by gender, educational background, and prior experience, which can inadvertently introduce construct-irrelevant variance even within culturally grounded tasks. Practically, this underscores a necessary paradigm shift in the development of culture-based assessments, where "contextual relevance" must be strictly balanced with "statistical neutrality" through rigorous DIF screening to prevent localized biases from undermining teacher competency evaluations. By establishing a "bias-aware" framework for ethnomathematical measures, this study offers a robust blueprint for teacher education programs to develop equitable instruments that are both mathematically rigorous and culturally sensitive. Ultimately, while this study provides a foundational step in ensuring fairness, the transition from detecting to explaining these biases necessitates future qualitative integration, such as cognitive interviews, to ensure that ethnomathematical assessments truly reflect mathematical proficiency rather than demographic affiliation across the heterogeneous landscape of mathematics education.

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Development of a Website for Solving Mathematical Problems to Enhance Vocational High School Students' Motivation

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ABSTRACT

This study aims to enhance mathematics learning outcomes by developing a problem-solving learning website to motivate students on sequences and series material at SMK Ksatrian Purwokerto. The research method employs an R&D approach using the ADDIE model and purposive sampling. Samples were drawn from Class XI TKJ 3 as the control group and Class XI TKJ 5 as the experimental group (website). The problem-solving strategy utilized Polya's steps. Hypothesis testing was conducted using an independent t-test to analyze mean differences, with the One-Sample Kolmogorov-Smirnov test for normality as a prerequisite. Results indicate that the data met assumptions of normality and homogeneity, and the implementation of the website-based problem-solving approach significantly improved students' cognitive scores and learning motivation on sequences and series material compared to the control group. Correlation analysis reveals a positive influence between problem-solving ability and learning motivation.

Keywords: ADDIE; Cognitive; Problem solving; Polya; Website

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1. INTRODUCTION

Students are expected to master the subject matter and possess critical thinking skills, creative problem-solving abilities, collaborative communication skills, and the capacity to take the initiative in various social, professional, digital information, and educational contexts (Widiasanti et al., 2023). Mathematics education in Era 5.0 has emerged as a response to the rapid technological advancements of the 21st century and societal demands for high-quality education. Industry 4.0 has transformed all aspects of life into digital domains (Javaid et al., 2024; Yaqub & Alsabban, 2023). Learning in vocational high schools employs an industry-based curriculum. The industry-based vocational high school curriculum for Computer Engineering and Networking (TKJ) expertise competency is designed based on the link and match principle by synchronizing the curriculum structure with business and industrial world competency standards (DU/DI). Mathematics learning in vocational high schools (SMK) is characterized by its abstract and monotonous nature, primarily delivered through conventional lecture methods (Darmawan et al., 2019), particularly in topics such as algebra, sequences and series, and statistics. Furthermore, instructional materials fail to integrate with vocational fields—such as applications of mathematics in automotive engineering, graphic design, telecommunications, and computer networking—resulting in students' difficulty comprehending concepts and low academic performance (Di Pietro & Castaño Muñoz, 2025). Many students perceive mathematics as an intimidating and challenging subject to understand (Du et al., 2025). This perception induces tension during classroom instruction, thereby discouraging many learners from posing inquiries, articulating viewpoints, or engaging actively in the pedagogical process (Darling-Hammond et al., 2020). Consequently, elevated levels of mathematical anxiety lead to disaffection with the subject, culminating in diminished conceptual understanding (Aini et al., 2024). This phenomenon contributes to diminished student learning motivation, as mathematics is perceived as a burdensome subject, ultimately fostering despair and disengagement toward the discipline.

The main problems faced by students at SMK Kesatrian Purwokerto are low learning motivation, cognitive aspects of learning motivation, and computational skills. Students demonstrate low interest and perseverance in mathematics lessons, impacting their inadequate numerical abilities. This results in numerical competency achievement scores that fail to meet the standards and potentially hinder

students' mathematics skill grades. Cognitive aspects—including attention, working memory, cognitive flexibility, and metacognition—form the primary foundation for effective problem solving .

Mathematical problem-solving ability mediates the relationship between affective factors, such as student anxiety, mathematical reasoning, and learning motivation. Problem-solving is a cognitive process that involves the use of linguistic information, problem identification, application of problem-solving strategies, and goal achievement based on identified information (Alivana & Masriyah, 2025; Amalina et al., 2026; Estiningrum et al., 2019; Lubis & Rangkuti, 2024; Vula et al., 2017). Mathematical problem-solving engages cognitive, metacognitive, affective, and cognitive flexibility interactions, from understanding the problem and representing situations to selecting strategies, monitoring, and evaluating solutions, contingent upon students' reasoning abilities, spatial processing, learning memory, and attention (Kholid et al., 2025; Rini et al., 2021). The self-regulation process in mathematical problem-solving using Polya's method comprises four stages (Polya, 1978). The indicators of problem-solving steps consist of four phases: understanding the problem, devising a plan, carrying out the plan, and looking back (Haqiqiyah & Putri, 2025; Polya, 1978; Riyadi et al., 2021). Factors influencing students' learning motivation include deficiencies in arithmetic and geometry computation abilities, such as determining the nth term or sum of sequences. A prime example is students' difficulties with arithmetic sequence problems and applying the formula $a_n=a+(n-1)b$ for arithmetic series and geometric ratios (Schlimm, 2026). Computer and networking majors in vocational high schools (SMK) find it difficult to understand the concept of sequences and series (Adiastuty et al., 2025; Mucti & Hermansyah, 2023; Rifai et al., 2025; Sari et al., 2022) and geometric series networks (Amsari et al., 2022). Low cognitive abilities among SMK students manifest in basic operations and abstract modeling. This leads to students' inability to comprehend studied problems and unachieved academic outcomes (Heriyana et al., 2025). Furthermore, to enhance the quality and learning outcomes of SMK students, website-based learning technology is employed.

Websites for mathematics learning serve as instructional media that deliver visual mathematics content, exercises, and interactive activities. Web-based mathematics learning visualization, encompassing text, images, videos, and quizzes offers accessibility at any time to enhance students' conceptual understanding, mathematical literacy, and learning competencies (Irmawan et al., 2022; Loor et al., 2024). Web-based learning (WBL), also known as e-learning (electronic learning), constitutes the application of internet technology in educational processes. WBL involves the utilization of internet technology, with learning processes actively engaged by students (Fauziah, 2020; Puspitasari et al., 2018). Websites represent multimedia documents (text, images, audio, animations, videos) accessed via the HTTP (Hypertext Transfer Protocol) using browser software (Bishop, 2020; Perna et al., 2022).

Previous research indicates that website-based learning in vocational high school (SMK) mathematics negatively impacts students' cognitive attitudes, including motivation, self-efficacy, and abstract concept comprehension (Chiu, 2023). This results in students experiencing concentration difficulties, limited teacher interaction, and unstable internet connectivity. Developmental research on E-modules in vocational SMK for linear equation material reveals shortcomings. Deficiencies in smartphone-based E-modules for mathematics learning include students' lack of focus due to small screen displays and slow loading times, along with limited samples (Sumandya & Mahendra, 2020). Utilization of the interactive QuizWhizzer medium in mathematics classrooms proves less effective, as it causes student fatigue during online sessions (Saputra & Subekti, 2024).

Previous studies on developing mathematics websites for vocational secondary school (SMK) students have highlighted negative outcomes, such as poorly designed, non-intuitive user interfaces, content lacking relevance to vocational disciplines, and insufficient long-term assessments of motivation improvement. These flaws have intensified mathematics learning difficulties in SMK contexts, where learners struggle to relate abstract topics like algebra, sequences and series, and statistics to real-world technical or business applications (Yanti & Bayu, 2022). The present research overcomes these limitations through the adoption of an intuitive user-centered design, Industry 4.0-aligned content (e.g., IoT-integrated simulations for sequence and series calculations in telecommunications engineering) (Cimino et al., 2025), and real-time analytics capabilities to track and elevate SMK students' learning motivation. Beyond affirming the platform's intrinsic interactivity, this approach empirically confirms the enduring capacity of web-based technologies to counteract student

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disengagement and underachievement (Rotar, 2025). The novelty of this research lies in demonstrating that students can enhance mathematical learning motivation and cognitive achievement through website-based.

2. RESEARCH METHOD

This research employs a quantitative approach utilizing a descriptive quantitative research design. It further adopts a research and development (R&D) method The development procedure utilizes the ADDIE model, consisting of five systematic stages:

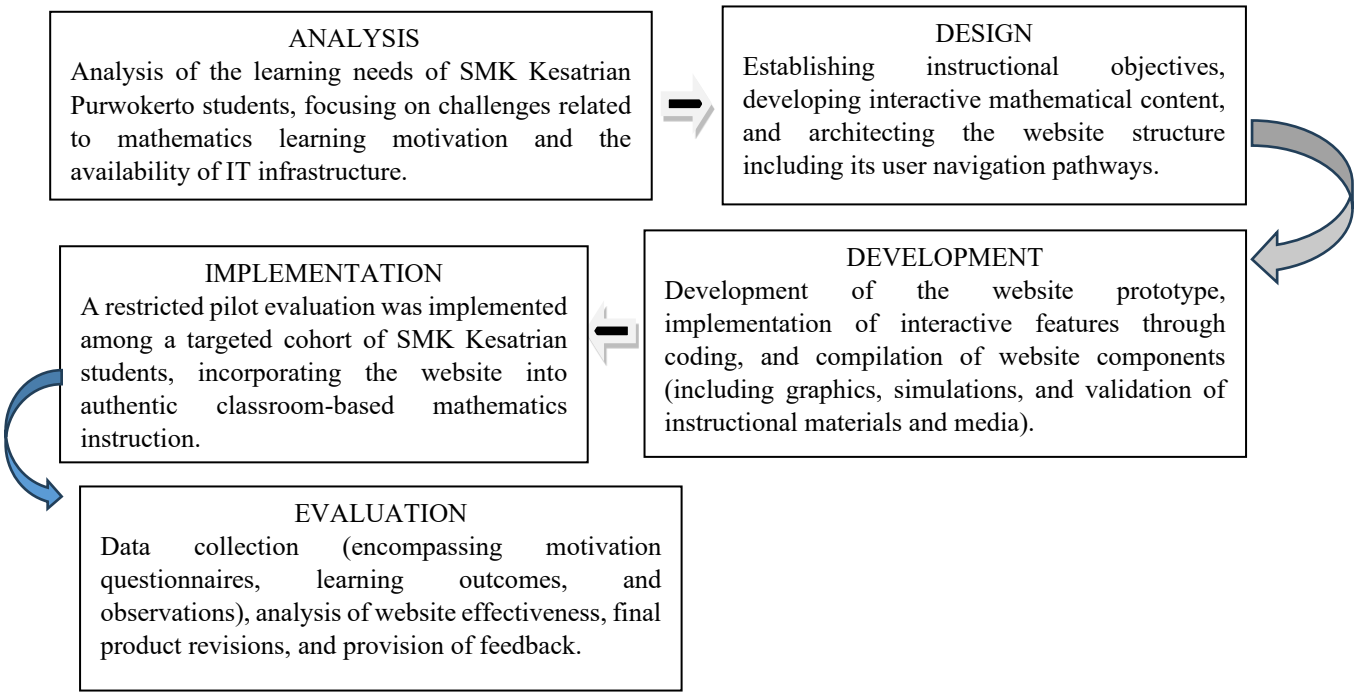

Fig. 1. Diagram of ADDIE Procedures

This research aims to enhance students' learning outcomes by developing a website-based instructional and mathematical problem-solving medium to boost student motivation on sequences and series material, contextualized for vocational high school (SMK) students, focusing on numerical sequences and series. To preserve the natural classroom environment, purposeful sampling was employed. This non-probability technique enables researchers to select volunteers based on characteristics pertinent to the study. Research subjects comprised Class XI students majoring in Computer and Network Engineering at SMK Ksatrian Purwokerto. The study was conducted across two Class X Computer and Network Engineering (TKJ) classes during the odd semester of the 2025/2026 academic year: the experimental class and the control class. Class X TKJ 1 served as the experimental group, utilizing Polya's problem-solving strategy alongside the website intervention, whereas Class X TKJ 2 functioned as the conventional control group without the Polya method. Data for this study were collected from Class XI TKJ 3(control) and XI TKJ 5 Industry class (Experiment website) at SMK Ksatrian Purwokerto. The experimental class comprised 30 students. The data collected consisted of posttest results on arithmetic and geometric sequences and series material. The following table presents posttest results from both experimental and control classes.

Teachers and students fill out the practicality questionnaires. The percentages derived from their responses are computed and subsequently classified in accordance with established practicality criteria.

Data collection techniques involved administering treatments to both the experimental and control classes. Upon completion of instruction, a final written essay posttest was administered. Prior to implementation, the instrument underwent validation by the mathematics teacher and supervising lecturer to ensure data validity for research purposes. The following outlines the sequential steps

employed in this study: (1) Conducting school observations and interviews with the mathematics teacher. (2) Developing instructional materials, specifically the lesson plan (RPP) and test specifications. (3) Preparing teaching materials on arithmetic and geometric sequences and series. (4) Implementing instruction with Polya's problem-solving steps plus website intervention in the experimental class, versus conventional learning without Polya steps in the control class. (5) Administering a conventional posttest in both experimental and control classes. (6) Conducting observations and interviews to gather qualitative data on students' experiences, impressions, responses, encountered obstacles, and perceived benefits. (7) Processing and analyzing research data. (8) Compiling the research findings report.

Hypothesis testing in this research employed an independent samples t-test to analyze mean differences. Prior to t-test analysis, normality testing utilized the Kolmogorov-Smirnov test. Normality testing determined whether student learning outcomes followed normal distribution, followed by homogeneity testing to ascertain whether both samples exhibited equivalent variances.

3. RESULTS AND DISCUSSION

The ADDIE method stages in developing a mathematics problem-solving learning website proved systematic and effective: analysis identified student needs and competency gaps in sequences and series topics; design formulated learning objectives, problem scenarios, and interactive module structures; development produced multimedia content, guided exercises aligned with Polya's steps, and real-time feedback features; implementation involved field trials in the experimental class to ensure applicability and accessibility; and evaluation employed quantitative and qualitative instruments to assess cognitive improvements and motivation. Empirically, the ADDIE application yielded structured and adaptive materials that facilitate student problem-solving, reduce cognitive load, enhance conceptual mastery, and boost motivation and learning outcomes in sequences and series material.

A. Analysis Stage

This research phase systematically investigated challenges at SMK Ksatrian Purwokerto, focusing on curriculum analysis and comprehensive needs assessment. Curriculum analysis aims to ensure e-module alignment with the implemented curriculum (Azamfirei et al., 2025; Karakuş, 2021). This process involves identifying syllabus-tailored development materials and analyzing student characteristics through syllabus review (Tan et al., 2025; Wotring & Chen, 2021).

Observation and interview results reveal that sequences and series instruction in Class XI Computer and Network Engineering (TKJ) remains dominated by lectures and routine exercises, hindering connections between sequence/series concepts and vocational contexts. Observations and interviews with Class XI mathematics teachers revealed that learning processes continue to rely primarily on textbooks as the main resource, with minimal utilization of electronic learning media. Instruction predominantly employs lecture-based methods. Furthermore, students face difficulties comprehending course content, particularly sequences and series concepts. They exhibit confusion in applying formulas for both arithmetic sequences and arithmetic series. (Ario et al., 2025) notes that students struggle to select appropriate formulas for problem-solving, as they cannot distinguish between arithmetic and geometric sequences, resulting in frequent errors in question responses. This enables students to independently explore connections between sequence/series concepts and computer networking components (Haleem et al., 2022). The website is developed as a responsive application accessible via smartphones and personal computers, allowing students to learn anytime, anywhere.

B. Design Stage

During this phase, the website "Mathematical Sequences and Series in Computer Network Engineering Components" was developed, featuring structured content that covers fundamental sequence and series concepts as well as their practical applications in computer network component design. Each activity targets the development of problem-solving and learning motivation indicators as outlined in the research proposal. The four problem-solving indicators used are understanding the problem, devising a solution plan, implementing the plan, and reviewing the solution. Key factors influencing student motivation include intrinsic motivation, extrinsic motivation, perseverance and discipline, as well as interest and engagement in learning. The design follows a problem-solving website framework with these sequential steps:

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Table 1. Problem-solving stages

Stage	Explanation of Problem Solving
Understand the problem	Students solve contextual problems on sequences and series in computer networking, identifying the problem and understanding sequence/series concepts.
Planning the completion	Students devise strategies or steps for the given problem, including selecting appropriate sequence/series formulas.
Carrying out the plan	Students implement the devised solution, executing the formulated steps to achieve resolution.
Looking back	Students evaluate results by reviewing solution effectiveness and accuracy, making necessary revisions.

The developed website product comprises several sections: an initial section (login menu, homepage, references, and contact us); content management section (course creation and management, teaching management, material upload and management, quiz creation and management, review of student submissions and registration); and evaluation section (exercises, tests, and problem-solving activities). At the module's conclusion, supporting components include a glossary, references, and module developer information. The problem-solving website development is planned with integrated material serving as the primary foundation. Evaluation instrument design includes analysis and trial worksheets integrated with student answer sheet photo uploads to the website. All components are systematically arranged in a storyboard to ensure logical and sequential material delivery. This material management enhancement aims to foster students' cognitive work in problem-solving and increased motivation, optimizing mastery of learned knowledge (Ninnuan & Montree, 2022).

C. Development Stage

This stage entails implementing the product design and evaluating its feasibility through validity assessment. The website is accessible via personal computers, laptops, desktops, and smartphones. The following presents the website's cover and menu interface:

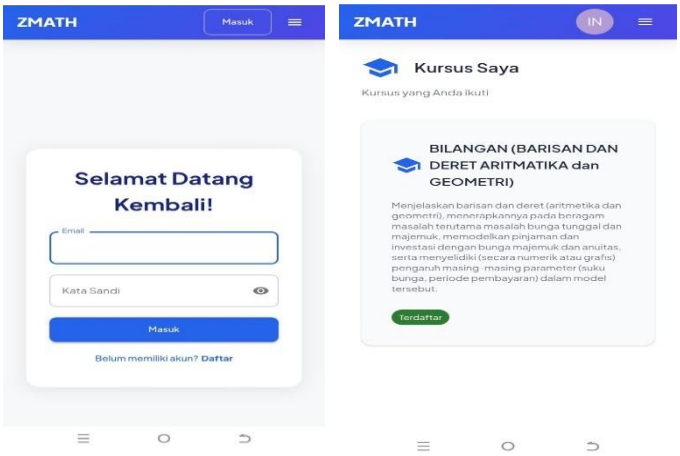

Fig. 2. Display on a smartphone

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Consistent with (Daryanes et al., 2023) research, this development stage encompasses activities to realize the previously created product design. The objective is to produce a revised draft of the instructional materials based on expert feedback, enabling subsequent testing. The website pages demonstrate responsive design and user-centered interface principles

.

Fig. 3. Student's my courses menu display

Figures 1 and 2 illustrate interactive learning content with clear navigation and interaction systems. The website offers various visual schematics to aid users and is optimized for smartphones, tablets, and other mobile devices to enable flexible learning. User testing confirms its compatibility with smartphones, validates usability, and yields positive feedback on interactivity, accessibility, and responsiveness. Content integrates YouTube videos and PDF formats. The "My Courses" menu facilitates problem-solving skill development within computer networking contexts, sustaining student confidence across challenges (Mahapoonyanont et al., 2010)

D. Implementation Stage

The website was implemented with Class XI students specializing in Computer Network Engineering at SMK Kesatrian Purwokerto using a posttest-only control group design. One class was designated as the experimental group utilizing the website, while the other served as the control group receiving conventional instruction. Both classes followed identical problem-based learning (PBL) models, with the control class excluding website media integration.

This study comprised two primary groups: a control group and an experimental group, each consisting of 30 students. The control group (n=30) served as a non-intervention comparator, whereas the experimental group (n=30) received a targeted treatment to assess the independent variable's efficacy. Equal sample sizes across groups ensured balanced representation and minimized bias in comparative outcome analyses.

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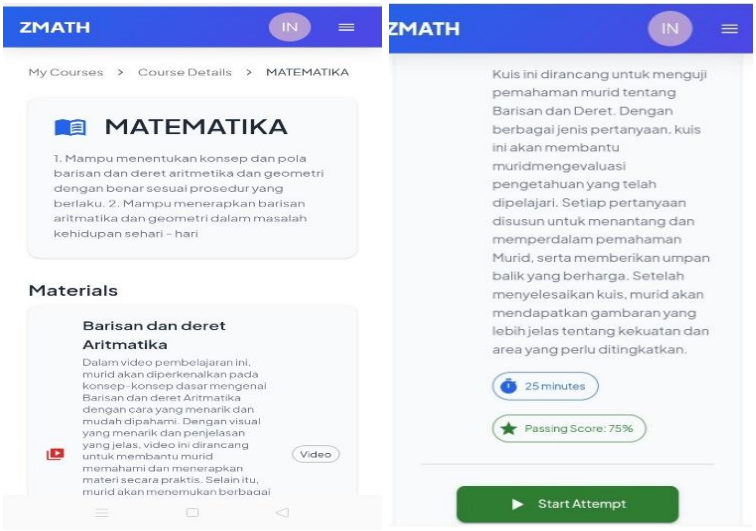

Fig. 4. Student website design

Before instruction commencement, teachers in the experimental class received training on utilizing the website and its supporting tools. Subsequently, students underwent website training. Student activities on the website formed part of a systematic scaffolding process designed to enhance mastery through successful learning experiences. During the initial session, students were introduced to the website menus, material access procedures, and navigation to the "My Courses" section.

Students engaged in problem identification and data detection activities. For data detective tasks, they completed case study simulations of computer network component design. Students received basic computation instructions to validate component positioning using arithmetic and geometric sequence formulas. At this stage, they were guided to comprehend data and build confidence through successful mastery of contextual mathematical concepts (Abdulrahaman et al., 2020). During the second session, the design critique focused on analytical attributes, encouraging students to provide data-based arguments that substantially reinforced their technical confidence.

Following instructions, students completed a written test that measured cognitive performance through a problem-solving quiz consisting of four questions, each assessing one indicator: understanding the problem, planning the solution, implementing the plan, and reviewing the outcome. Subsequently, students responded to user response questionnaires and motivation surveys. Selected students were then interviewed to deepen the qualitative findings.

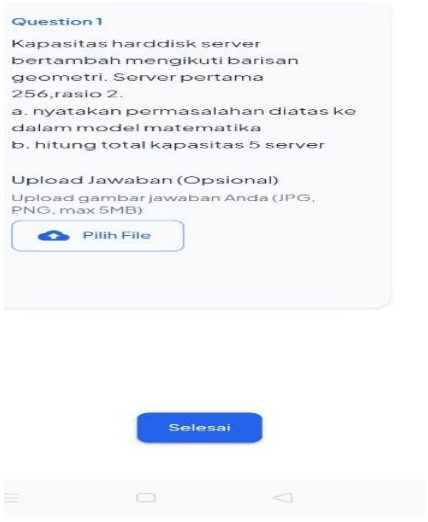

Fig. 5. Student Quiz Design Image

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E. Evaluation Stage

The purpose of this evaluation is to determine whether the developed website can enhance students' mathematical conceptual understanding in the material of arithmetic sequences and series. The final stage of this research involves reviewing website quality based on expert validation and practitioner questionnaires to determine necessary modifications. If required, the website undergoes revision to produce optimal learning media. The website is deemed practically ready if the media assessment falls within "practical" or "highly practical" categories. Results measuring student website usage practicality levels are presented in detail in Table 3.

The final stage also assesses website quality through expert validation and feasibility questionnaires to ascertain modification needs. Revisions ensure optimal learning media production. The website is considered feasible and ready if the media evaluation falls within "good" or "very good" categories. The results of the feasibility measurement for student website usage are detailed in Table 2.

Table 2. Website Feasibility Results for Problem Solving

No	Assessment Aspects	Percentage	Category
1	Clarity	75%	Good
2	Ease of use	92%	Very Good
3	Display quality	80%	Good
4	Navigasi	75%	Good
5	Program management	85%	Good
Average (Persentage))		**82%**	**Very** Good

The average feasibility test results for website-based mathematics problem-solving validity achieved "Very good" status. The highest validity score for learning problem-solving was ease of use (92%), enabling students to access and study the material directly and effortlessly. This correlates with website display quality validation scores deemed feasible by experts. Furthermore, website-based mathematics instruction benefits from clear sequences and series material presentation, adequate navigation, and highly feasible program management, ensuring optimal problem-solving website functionality for classroom mathematics instruction. Problem-solving as an intervention to enhance individual student learning motivation can be quantitatively analyzed using the independent samples t-test to compare mean differences between the experimental and control groups.

The validation results for website interface aspects—namely content clarity, ease of use, display quality, navigation, and program management—demonstrate a strong correlation with enhanced student cognitive problem-solving in learning mathematical sequences and series at vocational high schools (SMKs). The material is presented clearly, concisely, and in a structured manner. Students grasp abstract concepts such as general terms and partial sums more rapidly, thereby making analytical and deductive thinking processes more effective. The intuitive ease of use and navigation reduce cognitive load related to technical tools, allowing students to focus on mathematical problem-solving strategies and meticulously evaluate solutions (AlShaikh et al., 2024; Surbakti et al., 2024). High display quality (including graphical visualizations, neat mathematical notation, and interactive examples) facilitates mental representations of sequence and series concepts, strengthening knowledge transfer from symbolic to conceptual understanding (González-Campos et al., 2022; Mary Osei Fokuo et al., 2023). Furthermore, effective program management, such as module sequencing, automated feedback, and progress tracking, supports scaffolded and personalized learning, which can boost students' confidence and learning motivation.

Table 3. Research Data on Problem-Solving Skills

No	Grade Information	Control Class	Experimental Class
1	Minimum	54	72
2	Maximum	88	96
3	Average	76	82

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4	standard deviation	9,8	5,5

Table 1. Shows that the average learning outcome of students taught using Polya's step-by-step problem-solving strategy, which is 96, is better than the average learning outcome of students taught without using Polya's problem-solving strategy, which is 88. The mean problem-solving ability score for students in the experimental class was 82, exceeding the control class mean of 76. Additionally, the experimental class standard deviation (5.5) was lower than that of the control class (9.8), indicating greater uniformity in critical thinking abilities among experimental students. Therefore, the data demonstrate that the Mathematics Problem-Solving Website more effectively enhances student motivation compared to conventional instruction.

Hypothesis testing requires prerequisite examinations for final comparison of both groups. The One-Sample Kolmogorov-Smirnov Test yielded significance values of 0.200, both exceeding the 0.05 threshold. Therefore, the data exhibit normal distribution. The following presents the SPSS computation results: One-sample Kolmogorov-Smirnov normality testing revealed that data on the mathematics problem-solving website usage adhered to a normal distribution ($p = 0.200 > 0.05$). This satisfied the normality assumption for subsequent analyses, thereby enabling evaluation of the website-based mathematics learning intervention's impact on student motivation and academic outcomes. Utilizing the website for sequences and series mathematics proves effective as a learning tool (Akın, 2022). Website-based mathematics learning enhances student learning motivation, potentially yielding improved conceptual understanding and elevated academic performance (Nafiah et al., 2022; Tong et al., 2022).

The homogeneity test examined whether variances between experimental and control groups were equivalent, yielding a significance value of 0.516. Since this significance value exceeds 0.05, variances for both classes are declared homogeneous. The following presents the SPSS computation results:

Test of Homogeneity of Variances

Motivation

Levene Statistic	df1	df2	Sig.
.426	1	58	.516

Fig. 6. Results of normality test calculations

The results of the data analysis show that students' cognitive scores and enthusiasm to learn were significantly improved by using math problem-solving websites. The efficiency of instructional instruments is reflected in a normal data distribution, which is confirmed by normality testing with p-values greater than 0.05. The homogeneity of variance test p-value of 0.516, on the other hand, shows steady variation in student motivation and suggests that everyone benefits equally from using the website. Incorporating technology into math lessons promotes interactive problem-solving and builds stimulating learning settings that raise student interest. Pupils were more motivated to learn mathematics and take on challenges, which eventually helped them perform better academically (Lishchynska et al., 2023; Wheeler, & Cabigas, 2024). Web-based tool integration in math education offers flexible, adaptive methods that encourage self-directed learning while preserving the essential support for cognitive growth (Muhammad et al., 2025).

Independent Samples Test

		Levene's Test for Equality of Variances		t-test for Equality of Means						
		F	Sig.	T	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower	Upper
Motivasi	Equal variances assumed	.426	.516	5.506	58	.000	6.767	1.229	4.306	9.227
	Equal variances not assumed			5.506	57.347	.000	6.767	1.229	4.306	9.227

Fig. 7. Results of hypothesis test calculations

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Independent samples t-test analysis reveals significant differences between experimental and control classes in mathematics learning on sequences and series material. The significance value (Sig. 2-tailed) of 0.000 (< 0.05) indicates that website-based learning through problem-solving approaches substantially enhances student abilities. The calculated t-value of 5.506 with a mean difference of 6.767 demonstrates superior achievement in the experimental class compared to the control group.

These findings suggest that systematic problem-solving steps (understanding the problem, planning solutions, implementing plans, and evaluating outcomes) integrated within website-based media foster more structured and analytical student thinking. This approach elevates cognitive abilities as students progress beyond mere memorization of sequence/series concepts to practical problem-solving applications.

Website-based instruction delivers more interactive and engaging learning experiences, thereby enhancing student motivation. Elevated motivation directly contributes to improved learning outcomes through increased student activity, engagement, and interest in solving assigned problems (Andrić et al., 2026; Singh et al., 2022).

Hypothesis testing outcomes demonstrate significant differences between experimental and control classes. These results confirm web-based learning effectiveness in enhancing students' cognitive abilities, motivation, and academic performance. Validation was conducted by experts assessing material content, instructional design, language clarity, visual presentation, and website functionality. Validation results categorized as "valid" or "highly valid" affirm that the developed website meets feasibility standards as instructional media while optimally supporting problem-solving processes.

Website-based mathematics instruction validity encompasses multiple stages. The first stage presents contextual problems. Subsequent stages involve the Polya method application for problem formulation, strategy development, implementation, and evaluation—logically aligned with sequences and series material characteristics (Chacón-Castro et al., 2023; Gopinath & Lertlit, 2017). Furthermore, validation of visual appeal, interactivity, and usability aspects creates engaging learning experiences that enhance SMK student motivation and learning outcomes.

Correlations

		CO	EK
CO	Pearson Correlation	1	.490**
	Sig. (2-tailed)		.006
	N	30	30
EK	Pearson Correlation	.490**	1
	Sig. (2-tailed)	.006	
	N	30	30

**. Correlation is significant at the 0.01 level (2-tailed).

Fig. 8. Correlation test results

Correlation analysis in the experimental class yielded a correlation coefficient of 0.490 with a significance value (Sig. 2-tailed) of 0.006 (< 0.01). This demonstrates a positive and significant relationship between problem-solving scores (variable X) and learning motivation scores (variable Y). The correlation coefficient of 0.490 falls within the moderate category. Higher student problem-solving abilities correspond with increased learning motivation.

Scientifically, this relationship occurs because problem-solving abilities in mathematics instruction on sequences and series require students to navigate systematic thinking stages: understanding problems, planning strategies, implementing solutions, and evaluating outcomes. Successful execution generates achievement experiences that enhance student confidence and learning satisfaction. These conditions directly elevate learning motivation.

The correlation analysis results indicate that problem-solving in learning sequences and series through the website platform exhibits a positive and significant relationship with students' cognitive

scores, as well as motivation dimensions and learning outcomes (W. Li et al., 2023). Scientifically, this positive correlation suggests that increased intensity and quality of student engagement in web-based problem-solving activities (e.g., interactive exercises, visualizations of sequence terms and series sums, and real-time feedback) (S. Li et al., 2025)is associated with elevated cognitive scores reflecting conceptual mastery, reasoning ability, and procedural skills (Sajidin, 2026; Wang et al., 2026). Furthermore, website-based interventions are consistently linked to enhanced intrinsic motivation including self-confidence, learning interest, and perseverance which in turn mediates positive effects on final learning outcomes for sequence and series topics. These findings align with cognitive and motivational learning theories, which posit that interactive and structured learning tools reduce cognitive load, strengthen mental representations of concepts, and boost self-efficacy, thereby empirically improving academic performance (De Witte et al., 2026; Gkintoni et al., 2025).

4. CONCLUSION

The research results indicate the integration of Polya's strategy into website-based learning is effective in enhancing students' motivation to learn about sequences and series, while also improving their cognitive achievements and problem-solving skills. This is demonstrated by the higher average learning outcomes in the experimental class compared to the control class, namely 96 versus 88, with a standard deviation of 5.5 in the experimental class and 9.8 in the control class, indicating that the distribution of learning outcomes in the experimental class is more homogeneous. Since the standard score of the experimental class is lower than that of the control class, the distribution of data in the control class is more homogeneous than in the experimental class.

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An Integer Linear Programming Model for Diagnosing Unmastered Mathematical Topics Based on Bloom's Cognitive Domains

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ABSTRACT

This study aims to develop an Integer Linear Programming (ILP)-based mathematical model to identify and map unmastered mathematics topics among senior high school students based on Bloom's cognitive domains, namely Knowledge (C1), Comprehension (C2), and Application (C3). The study employed a quantitative approach using test data obtained from a 48-item instrument covering 16 mathematical subtopics, administered to 147 twelfth-grade students in the Natural Science program. The data were analyzed using LINDO 6.1 software to generate a detailed profile of student mastery across subtopics and cognitive domains. The results indicate that student mastery was relatively higher in the Knowledge (C1) domain, with eight subtopics meeting the mastery criteria. In comparison, six subtopics were achieved in the Comprehension (C2) domain and five subtopics in the Application (C3) domain. Of the total 48 test items, only 19 items (39.6%) were classified as mastered, while 29 items (60.4%) were not mastered. Notably, the Equations and Inequalities (X2) subtopic was not mastered in any of the three cognitive domains, indicating a critical area requiring focused intervention.These findings highlight the need for instructional strategies that emphasize not only factual knowledge but also deeper conceptual understanding and contextual application. The ILP-based model demonstrated its effectiveness as a diagnostic tool by providing a structured and objective identification of students' learning deficiencies. Consequently, the resulting mastery map can serve as a valuable reference for teachers in designing targeted remedial programs. Furthermore, the proposed model has the potential to be replicated in other educational settings as a tool for continuous monitoring and improvement of student learning outcomes.

Keywords: Mathematical Model, Integer Linear Programming, Proficiency Mapping, Cognitive Domains, Bloom's Taxonomy, Senior High School Mathematics

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1. INTRODUCTION

Education serves as the foundation for a nation's development and is a crucial indicator of its civilizational progress (KEMENRISTEKDIKTI, 2020). In this context, the quality of mathematics education at the Senior High School (SMA) level holds strategic importance, not only as a compulsory subject in the national curriculum but also as a vehicle for developing higher-order thinking skills such as logical, analytical, critical, and creative thinking (Anderson, et al., 1994). These skills are essential for confronting 21st-century challenges in science, technology, and the knowledge-based economy.

However, various national and international studies indicate that the mathematics learning outcomes of Indonesian students remain suboptimal. Reports from the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS) consistently rank Indonesia below the average of participating countries in mathematical and scientific literacy (OECD, 2014; Wulandari, et al., 2015). These results point to a serious deficiency in content mastery, which, if not accurately identified and addressed, could result in low competency levels for future generations.

One strategy to address this issue is through student proficiency mapping. This mapping not only identifies mastered and unmastered topics but also serves as a diagnostic tool to help teachers design more targeted learning strategies (Tambunan, 2016). In educational theory, Bloom's Taxonomy has long been a primary framework for classifying learning objectives based on cognitive domains: Knowledge (C1), Comprehension (C2), and Application (C3) (Bloom, 1956). This classification enables a deeper analysis of learning achievements, allowing teachers to move beyond final scores and understand the depth of students' conceptual mastery.

In the context of diagnosing students' cognitive abilities, several empirical studies have emphasized the importance of analyzing prerequisite knowledge, learning duration, and task completion behavior in understanding students' mathematical achievement. Research also shows that students' success in solving mathematical problems is strongly influenced by their prior knowledge and cognitive readiness (Magdalena, et al., 2025; Manurung, et al., 2023). Moreover, higher-order thinking skills (HOTS), which correspond to higher levels in Bloom's taxonomy, play a crucial role in determining students' ability to analyze, evaluate, and apply mathematical concepts in various contexts. Learning approaches that emphasize HOTS and cognitive engagement have been shown to significantly improve students' conceptual understanding and problem-solving abilities (Subaini, et al., 2022; Magdalena, et al., 2025).

Despite these developments, a significant challenge in practice lies in transforming test data into accurate and actionable diagnostic information. Teachers often focus solely on final scores without conducting an in-depth analysis of error patterns or students' conceptual weaknesses (Dantzig, et al., 1997). As a result, the identification of unmastered topics is often incomplete and less effective for guiding instructional decisions. Therefore, a data-driven approach capable of processing information quantitatively and systematically is required.

In this regard, mathematical optimization provides a promising solution. One relevant approach is the use of integer programming models, which have proven effective in solving various complex problems in education, such as student project allocation (Anwar, et al., 2003), course scheduling (Daskalaki, et al., 2004), and test item evaluation based on cognitive domains (Junoh, et al., 2011; Sitepu, et al., 2017). Furthermore, previous studies have demonstrated that integer optimization models are flexible and powerful tools for solving complex decision-making problems, including educational planning and resource allocation (Sitepu, et al., 2017; Irvan, et al., 2008). Foundational works on integer stochastic programming and optimization modeling also provide strong theoretical support for the development of ILP-based diagnostic models, enabling structured and objective analysis of complex educational data under multiple variables and constraints (Irvan, et al., 2025; Azis, et al., 2026).

At the same time, developments in educational technology further highlight the importance of data-driven diagnostic approaches. Concepts such as Intelligent Tutoring Systems (ITS) and learning analytics have utilized student proficiency mapping to provide adaptive learning and content personalization (Siemens, 2013). Cognitive Diagnosis Models (CDM) are also widely used to identify specific student weaknesses in particular topics (Minn, 2021; Shen, et al., 2023). However, these approaches are generally probabilistic and may have limitations in incorporating optimization constraints simultaneously, indicating the need for alternative methods that can produce more optimal and interpretable diagnostic results.

Recent research further underscores the urgency of implementing accurate diagnostic mapping. For instance, a 2025 study reported that only 34% of students could demonstrate adequate visual representations, and only 15% were able to perform mathematical interpretations in linear programming topics (Muharani, et al., 2025). This finding indicates that student weaknesses are not uniformly distributed but are concentrated in specific subtopics requiring targeted intervention. Other studies also highlight that instructional strategies such as Problem-Based Learning (PBL) and mind mapping can improve students' higher-order thinking and problem-solving abilities (Firdaus, et al., 2023; Nature, 2025; Guo, et al., 2024), while the integration of generative artificial intelligence has shown potential in enhancing learning outcomes and self-efficacy. Nevertheless, these approaches primarily focus on instructional improvement rather than systematically identifying unmastered topics through optimization-based analysis.

Against this backdrop, this research develops an Integer Linear Programming (ILP)-based mathematical model to diagnose and map unmastered mathematics topics among senior high school students based on cognitive domains (C1, C2, C3). The research data, comprising 48 test items across 16 subtopics, are analyzed using LINDO 6.1 software to generate an optimal and detailed student proficiency map. The findings are expected to provide a strong analytical foundation for teachers and educational policymakers in designing more effective remedial and enrichment programs based on valid and data-driven decision-making.

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2. RESEARCH METHOD

A. Research Design

This study employs a quantitative approach with an integer programming-based mathematical modeling method. This approach was selected for its ability to systematically process student test data and provide an accurate cognitive proficiency map (Tambunan, 2016; Dantzig, et al., 1997). The research is descriptive-analytical in nature, aiming to map the unmastered mathematics topics among senior high school students across three cognitive domains: Knowledge (C1), Comprehension (C2), and Application (C3) (Bloom, 1956).

B. Subjects and Research Location

The subjects of this study were 147 twelfth-grade students from the Natural Science program at a public senior high school in Medan City during the 2024/2025 academic year. The subjects were selected using a purposive sampling technique, with the consideration that these students had already studied all the tested topics. The research was conducted within the school environment over a two-week period, encompassing the testing and data processing stages.

C. Research Instrument

The instrument used was an objective test consisting of 48 items, developed based on 16 senior high school mathematics subtopics and aligned with the national examination framework (KEMENDIKBUD, 2024; BSNP, 2024). Each subtopic was represented by three test items, each corresponding to the C1, C2, and C3 cognitive domains of Bloom's Taxonomy (Anderson, 1994). The test items were validated by three mathematics education experts to ensure content validity, while reliability was tested using Cronbach's Alpha coefficient (Nunnally, et al., 1994).

D. Research Procedure

The research was carried out in three main stages:

a. Preparation Stage
   1. Determining the topics and subtopics to be tested based on the curriculum and an analysis of core competencies.
   2. Developing and validating test items according to the cognitive domains.
   3. Preparing a mapping table format linking subtopics to cognitive domains.

b. Data Collection Stage
   1. Administering a written test to the students with a duration of 120 minutes.
   2. Collecting student answer sheets and performing scoring.
   3. Calculating the number of students who answered each test item correctly.

c. Data Analysis Stage with the Mathematical Model

   This stage aimed to identify and map unmastered mathematics topics systematically using an Integer Linear Programming (ILP)-based mathematical model. The analysis was conducted through the following steps:

   1. Model Formulation

      The mathematical model was formulated by adapting the notation from (Anwar, et al., 2003). The objective function was to maximize the number of test items mastered by students based on subtopic and cognitive domain. The model was formulated as follows:

$$\text{Maximize } Z = \sum_{i=1}^{p} \sum_{j=1}^{q} X_{ij}$$

      Subject to:

$$\sum_{j=1}^{q} X_{ij} \leq 1, \quad \forall i = 1, 2, ..., p$$

$$\sum_{i=1}^{p} X_{ij} \leq b_j, \quad \forall j = 1, 2, ..., q$$

$$X_{ij} \in \{0, 1\}$$

      Keterangan:

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Z = Objective function (maximum number of mastered test items)
X_{ij} = Binary variable (1 if the item for Subtopic-I and Domain-j is mastered, 0 otherwise)
p = Number of subtopics (16 subtopics)
q = Number of cognitive domains (3 domains: C1, C2, C3)
b_j = Maximum limit of items for domain-j according to the test distribution.

2. Mastery Criteria
   A test item was declared "mastered" if the percentage of students answering it correctly met or exceeded the predetermined Minimum Completion Criteria. If it did not meet this threshold, the item was categorized as "not mastered."
3. Model Optimization
   The ILP model was solved using LINDO 6.1 software to obtain the optimal solution for the Z objective function. This solution indicates the combination of test items and cognitive domains that students have truly mastered.
4. Proficiency Mapping
   The model output, comprising lists of mastered and unmastered items, was mapped onto a cognitive domain proficiency map for each subtopic. The data were visualized in tables and graphs to facilitate the identification of specific student weakness areas by teachers.
5. Data Analysis Technique
   Data were analyzed using LINDO 6.1 software to solve the ILP model. The model output consisted of lists of mastered and unmastered test items. These results were then visualized in a proficiency map showing the distribution of mastery for each cognitive domain across all subtopics.
6. Validity and Reliability of Analysis
   To ensure the validity of the findings:
   a. Construct validity was established through the alignment of the model with the research objectives and Bloom's Taxonomy theory (Anderson, 1994).
   b. The reliability of the analysis was strengthened by re-testing the model on a subset of data (cross-validation).
   c. Data triangulation was performed by comparing the model's results with evaluations from the subject teacher.

3. RESULTS AND DISCUSSION

A. Results

Based on the analysis of test results from 147 twelfth-grade Natural Science students using an Integer Linear Programming (ILP) model in LINDO 6.1 software, a mathematics topic mastery map was obtained, covering 16 subtopics and three cognitive domains (C1 = Knowledge, C2 = Comprehension, C3 = Application).

The optimization results indicate that:

a. 19 test items (39.6%) were declared mastered by students (decision variable value $X_{ij} = 1$)
b. 29 test items (60.4%) were declared not mastered by students (decision variable value $X_{ij} = 0$)

The distribution of mastery per cognitive domain is:

a. a. C1 (Knowledge): 8 subtopics.
b. b. C2 (Comprehension): 6 subtopics.
c. c. C3 (Application): 5 subtopics.

Table 1. Student Mathematics Topic Mastery Map Based on Cognitive Domains

No	Subtopic	Code	C1 (Knowledge)	C2 (Comprehension)	C3 (Application)	Mastery Description
1	Exponents and Logarithms	X1	1	0	1	Partially Mastered (C1 & C3)

2	Equations and Inequalities	X2	0	0	0	Not Mastered
3	Linear Programming	X3	1	1	0	Partially Mastered (C1 & C2)
4	Quadratic Equations & Functions	X4	1	0	0	Partially Mastered (C1)
5	Trigonometry	X5	0	1	0	Partially Mastered (C2)
6	Mathematical Logic	X6	0	1	0	Partially Mastered (C2)
7	Statistics and Probability	X7	0	1	0	Partially Mastered (C2)
8	Polynomials	X8	0	0	1	Partially Mastered (C3)
9	Inverse & Composite Functions	X9	0	0	1	Partially Mastered (C3)
10	Sequences and Series	X10	1	0	0	Partially Mastered (C1)
11	Matrices	X11	1	0	1	Partially Mastered (C1 & C3)
12	Vectors	X12	1	0	0	Partially Mastered (C1)
13	Transformations	X13	0	1	0	Partially Mastered (C2)
14	Three-Dimensional Geometry	X14	1	1	0	Partially Mastered (C1 & C2)
15	Limits	X15	0	0	1	Partially Mastered (C3)
16	Derivatives and Integrals	X16	1	0	0	Partially Mastered (C1)

Student mastery was generally higher in the Knowledge (C1) domain compared to the other two domains. Several subtopics showed mastery in more than one domain, such as Exponents and Logarithms (X1), Matrices (X11), and Three-Dimensional Geometry (X14). Conversely, the Equations and Inequalities (X2) subtopic was not mastered at all across all three cognitive domains, indicating a need for priority intervention. Furthermore, some subtopics were mastered in only one specific domain, for instance, Trigonometry (X5) only in C2, Limits (X15) only in C3, and Transformations (X13) only in C2. This signifies the existence of specific competency gaps at the level of conceptual comprehension and application.

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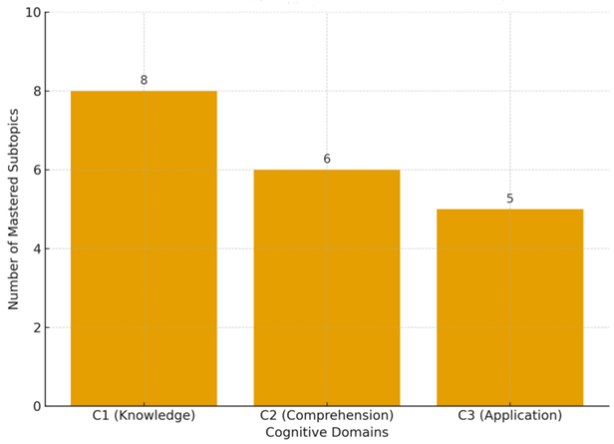

Fig. 1. Distribution of Mastery per Cognitive Domain

Figure 1 shows that the number of subtopics mastered by students decreases from C1 (Knowledge) to C2 (Comprehension) and is lowest in C3 (Application). This indicates that instruction has been more successful at the level of mastering basic facts and procedures compared to the ability to comprehend and apply concepts.

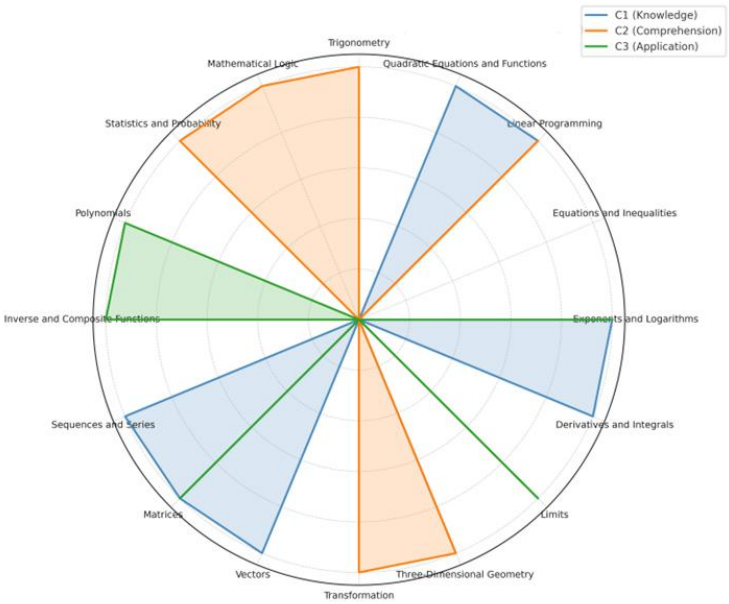

Fig. 2. Mathematics Topic Mastery Map per Subtopic and Cognitive Domain

Figure 2 provides a visualization of student mastery patterns for each subtopic across all three cognitive domains simultaneously. It is evident that several subtopics have a balanced mastery distribution across two domains, while most others excel in only one specific domain. This graph reinforces the identified weaknesses in the Comprehension and Application domains that need to be the focus of improvement.

B. Discussion

The results of this study indicate that senior high school students' mastery of mathematics topics across the three cognitive domains, namely Knowledge (C1), Comprehension (C2), and Application (C3), remains uneven. Among these domains, Knowledge (C1) is relatively better mastered, with eight subtopics meeting the established mastery criteria. This finding is consistent with previous studies suggesting that mathematics instruction in schools tends to emphasize the memorization of facts,

definitions, and procedural knowledge rather than deeper conceptual understanding (Anderson, 1994; Bloom, 1956; Firdaus, 2023).

However, despite the relatively satisfactory performance in C1, the lower achievement observed in the Comprehension (C2) and Application (C3) domains indicates that students still face significant challenges in interpreting mathematical concepts and applying them in unfamiliar contexts (OECD, 2012; Manurung, 2023). This gap reflects a lack of depth in conceptual understanding, which is essential for meaningful learning and problem-solving.

These findings are further supported by prior research indicating that students' mathematical achievement is strongly influenced by prerequisite knowledge and learning duration, both of which are critical for mastering higher cognitive domains. Students with insufficient foundational understanding are more likely to encounter difficulties when dealing with tasks that require comprehension and application skills (Magdalena, et al., 2025; Manurung, et al., 2023).

The disparity in mastery is particularly evident in specific subtopics. For instance, Equations and Inequalities (X2) were not mastered across all three cognitive domains, indicating fundamental conceptual and procedural difficulties. This result aligns with study (Muharani, et al., 2025), which reported low levels of student performance in visual representation and mathematical interpretation in linear programming topics, areas closely related to equations and inequalities. Furthermore, the presence of subtopics mastered only in a single domain, such as Limits (X15), which is mastered solely in C3, suggests that some students are able to solve application-based problems without a solid understanding of the underlying concepts. This phenomenon may lead to superficial learning and potential misconceptions in the long term (Guo, et al., 2024).

From a pedagogical perspective, the low achievement in the Comprehension and Application domains may be attributed to instructional practices that insufficiently emphasize conceptual exploration and contextual application. The PISA report (OECD, 2012) confirms that Indonesian students tend to struggle with problems requiring higher-order reasoning and non-routine problem-solving. Therefore, instructional strategies that promote knowledge construction and active cognitive engagement are essential. Approaches such as Problem-Based Learning (PBL) (Firdaus, 2023) and the use of visual tools like mind mapping (Guo, et al., 2024; KEMENDIKBUD; 2024) have been shown to support the development of higher-order thinking skills (HOTS).

This condition is also consistent with studies highlighting the importance of critical thinking and HOTS in mathematics education. Students exposed to problem-based and HOTS-oriented learning environments tend to demonstrate stronger analytical and evaluative abilities, which are essential for mastering higher levels of Bloom's taxonomy (Subaini, et al., 2022; Magdalena, et al., 2025).

In addition to pedagogical implications, this study demonstrates that the application of an Integer Linear Programming (ILP)-based mathematical model is effective in quantitatively mapping students' learning deficiencies. Compared to conventional evaluation methods, this model provides a more detailed representation of the relationships between subtopics and cognitive domains. These findings are in line with previous research (Tambunan, 2016; Anwar, et al., 2003; Junoh, et al., 2012), which emphasizes the role of quantitative modeling in supporting data-driven decision-making in education, particularly in identifying learning gaps and determining remedial priorities.

From a methodological standpoint, the use of ILP in this study is supported by optimization-based research demonstrating that mathematical programming models are capable of handling complex datasets and generating optimal solutions for decision-making problems. Such models have been widely applied in scheduling, allocation, and planning contexts, and their application in diagnosing students' learning gaps represents a significant extension in the field of educational research (Sitepu, et al., 2017; Irvan, et al., 2008; Irvan, et al., 2025; Azis, et al., 2026).

Practically, the resulting mastery map provides valuable insights for teachers in designing targeted remedial interventions. For example, for subtopics with low achievement in C2, instructional efforts can focus on conceptual discussions, guided explanations, and interpretation exercises. Meanwhile, for weaknesses in C3, students should be provided with more application-oriented tasks, contextual problems, and case-based learning activities to strengthen their problem-solving abilities.

Therefore, the findings of this study not only reveal students' competency gaps but also contribute methodologically by offering a replicable ILP-based diagnostic model. This model can serve as a

sustainable tool for monitoring students' mastery of mathematical topics over time, while also providing a robust foundation for developing more effective and data-driven instructional strategies.

4. CONCLUSION

This study developed and applied an Integer Linear Programming (ILP)-based mathematical model to identify and map unmastered mathematics topics among senior high school students based on Bloom's cognitive domains, namely Knowledge (C1), Comprehension (C2), and Application (C3). The model was implemented using data from a 48-item test covering 16 subtopics, administered to 147 twelfth-grade Natural Science students, and analyzed using LINDO 6.1 software to generate a measurable mastery profile.

The results indicate that students' mastery was highest in the Knowledge (C1) domain, with eight subtopics meeting the mastery criteria. In contrast, only six subtopics were mastered in the Comprehension (C2) domain and five subtopics in the Application (C3) domain. Overall, 19 test items (39.6%) were classified as mastered, while the remaining 29 items (60.4%) were not mastered. Notably, the Equations and Inequalities (X2) subtopic was not mastered in any of the three domains, indicating a critical area requiring targeted intervention.

The findings further suggest that the disparity in mastery across cognitive domains reflects the need to shift instructional practices from an emphasis on memorization and procedural skills toward strengthening conceptual understanding and contextual application. The ILP-based model demonstrated its effectiveness in producing a detailed and structured mapping of students' learning deficiencies, thereby supporting more precise identification of problematic subtopics.

Therefore, this study contributes both practically and methodologically. From a practical perspective, the generated mastery map can assist teachers in prioritizing topics and cognitive domains that require reinforcement. From a methodological perspective, the proposed ILP-based model offers a systematic and replicable approach that can be applied in other educational settings for continuous monitoring and improvement of students' learning outcomes.

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Transformative Curriculum in Indonesian Higher Education: An Integrative Framework for Realizing University 4.0

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ABSTRACT

The transformation of higher education toward the University 4.0 paradigm demands fundamental changes in curriculum design that transcend conventional knowledge transmission. This article aims to analyze the components of transformative curriculum as an integrative learning framework in Indonesian higher education, encompassing learning orientation, learning materials, learning methods, and learning evaluation. The study employed a literature review method with a conceptual analysis approach applied to the Guide to Transformative Pedagogy for Lecturers (Ministry of Higher Education, Science and Technology, 2025), synthesized with Mezirow's transformative learning theory, Freire's critical pedagogy, and Ki Hadjar Dewantara's educational philosophy. The findings reveal that transformative curriculum comprises four interrelated components. Learning orientation focuses on developing critical consciousness through three levels of reflection: content reflection, process reflection, and premise reflection. Learning materials integrate three main pillars—inclusivity, sustainability, and social justice and anti-racism—contextualized within societal realities. Learning methods include the case-method, reflective discussion, simulation, project-based learning, and narrative inquiry, all of which emphasize the dialectic between reflection and action. Learning evaluation is qualitative, reflective, participatory, and narrative in nature, prioritizing the process of perspective transformation through reflective journals, transformative portfolios, action projects, and self- and peer-evaluation. Transformative curriculum provides an operational framework for higher education institutions to realize meaningful learning with social impact, aligned with the Impactful Higher Education (DIKTISAINTEK Berdampak) policy and the Sustainable Development Goals.

Keywords: transformative curriculum; higher education; reflective learning; critical consciousness; agent of change

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1. INTRODUCTION

The Fourth Industrial Revolution has fundamentally reshaped the structure of human life, including the domain of education. Since the World Economic Forum released the report "New Vision for Education: Unlocking the Potential of Technology" in 2015, the orientation of education has undergone a significant shift. Learners are now required to possess a set of competencies known as twenty-first-century skills, which encompass foundational literacies for everyday tasks, competencies for addressing complex challenges, and character qualities together with the capacity to adapt to environmental change (World Economic Forum, 2015). Accordingly, the orientation of education no longer emphasizes cognitive ability alone; it further requires learners to engage with real problems in society.

Parallel to the demand for twenty-first-century skills, the Sustainable Development Goals (SDGs) have emerged as a global agenda emphasizing the role of individuals as agents in transforming world society toward inclusive economic growth, ecological sustainability, and social harmony (United Nations, 2015). Bates (2019) argues that education plays a central role in cultivating individual and collective ethical awareness, which is actualized through dialogic learning with the physical and social environment. Education is no longer merely a matter of cognitive, affective, and psychomotor development; rather, it constitutes an endeavor to transform knowledge and skills in order to address tangible problems in society.

In response to these dynamics, in 2025 the Ministry of Higher Education, Science and Technology (hereafter, the Ministry) launched the Impactful Higher Education (Diktisaintek Berdampak) program, which positions higher education as a center for concrete solutions for society, moving beyond its

conventional roles of teaching and research (Ministry of Higher Education, Science and Technology [Kemdiktisaintek], 2025). This paradigm aligns with the concept of University 4.0, which emphasizes the adaptation of new technologies and methodologies to support students' twenty-first-century competencies in confronting present and future challenges (Acuñar, 2024; Chernaya et al., 2023). The transformation toward University 4.0 is not merely about encouraging universities to adopt technology; it requires higher education institutions to become genuine solutions for the diverse challenges and real problems faced by society.

Within the domain of teaching and learning, this paradigmatic transformation can be actualized through the implementation of transformative pedagogy. UNESCO (2017, 2022) defines transformative pedagogy as a student-centered learning approach aimed at cultivating critical and reflective thinking that contributes to local and global society. Meyers (2008) further notes that transformative pedagogy entails innovative learning processes along with the active and collaborative participation of students, which ultimately fosters the development of their personal potential. Such an approach requires a curriculum specifically designed to support these transformative aims.

According to Clifford and Montgomery (2015), transformative curriculum refers to learning and teaching that seeks to empower individuals and communities by building connections, promoting social change, and expanding intellectual understanding of the world and of the self. Kandiko Howson and Kingsbury (2023) extend the notion of curriculum to encompass objectives, content, alignment, scale, learning activities, assessment, physical environments, and learning collaborators as a comprehensive conceptual framework. Transformative curriculum is therefore not merely an administrative document listing courses; rather, it constitutes a holistic framework that directs the entire educational process toward shaping students as agents of change.

Although the concept of transformative curriculum has been extensively examined in the international literature, its implementation in the Indonesian higher education context still requires a more systematic and operational conceptual framework. This gap is problematic because lecturers and higher education practitioners need more concrete guidance to design and implement transformative curricula. Against this background, the present article aims to analyze the components of transformative curriculum in higher education with a focus on four main dimensions: learning orientation, learning materials, learning methods, and learning evaluation. The study is expected to offer a comprehensive and applicable conceptual framework for curriculum development that supports the formation of students as agents of change.

2. RESEARCH METHOD

This article employs a literature review method with a conceptual analysis approach to examine the components of transformative curriculum in the context of higher education. This approach was selected because it aligns with the study's purpose of synthesizing multiple theoretical perspectives in order to generate a coherent and operational conceptual framework.

The primary data source for this study is the Guide to Transformative Pedagogy for Lecturers (Panduan Pedagogi Transformatif untuk Dosen), published in 2025 by the Directorate of Transformative Learning Strategy and Systems, Directorate General of Science and Technology, Ministry of Higher Education, Science and Technology. This document was chosen as the principal reference because it constitutes the official guideline developed to support the implementation of transformative curriculum in Indonesian higher education. In addition, the study draws upon the theoretical literature that forms the conceptual foundation of transformative curriculum, including Jack Mezirow's transformative learning theory, Paulo Freire's critical pedagogy, Lev Vygotsky's social constructivism, and the educational philosophy of Ki Hadjar Dewantara.

Data analysis was conducted in three stages. The first stage involved identifying key concepts related to transformative curriculum from the reference sources. The second stage entailed classifying these concepts into four thematic categories corresponding to the curriculum components: learning orientation, learning materials, learning methods, and learning evaluation. The third stage consisted of a conceptual synthesis that integrated the various theoretical perspectives to produce a coherent and applicable transformative curriculum framework for Indonesian higher education.

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3. RESULTS AND DISCUSSION

A. Theoretical Foundations of Transformative Curriculum

Before elaborating on the components of transformative curriculum, it is necessary to understand the theoretical foundations that shape this paradigm. Murphy (2008) argues that pedagogy is the process of interaction among teacher, student, learning environment, and learning task. In this view, pedagogy is not merely a matter of knowledge transfer; it further involves social interaction among various actors and the social environment in which they operate. Alexander (2008) adds that pedagogy differs from teaching: teaching is limited to an action, whereas pedagogy encompasses the discourse that educators must engage in when carrying out teaching actions. Pedagogy, therefore, is not only about classroom activities but is also connected to educational, social, and even political discourses in society.

The roots of transformative curriculum can be traced to Jack Mezirow's concept of perspective transformation, first articulated in 1978. Mezirow explicitly argued that perspective transformation is a vital aspect of adult development. Transformation is defined as a reorganization of one's perspective in viewing the self and one's environment, which in turn determines attitudes, value judgments, and actions (Mezirow, 1978). This perspective is shaped by social and cultural contexts, yet it can be altered through a process of critical consciousness that typically begins with a life dilemma that cannot be resolved merely by adding information. Mezirow (2018) subsequently defined transformative learning as the process by which an individual transforms old mindsets, habits, or perspectives through communicative processes toward a more inclusive, open, and reflective paradigm.

Mezirow's ideas are enriched by Paulo Freire's thinking on critical pedagogy. According to Freire (2000), education is a tool for cultivating learners' critical consciousness in order to transform the various problems present in society. Educators must facilitate learners in identifying concrete problems, recognizing their causes, and taking action to resolve them. Freire emphasizes the importance of education as praxis—that is, a process of action and reflection aimed at realizing social transformation. Education as social praxis constitutes a process of knowledge formation that encourages learners to recognize real problems and formulate transformative actions as solutions to those problems.

The ideas of Ki Hadjar Dewantara also make a significant contribution to shaping the paradigm of transformative curriculum. Dewantara (2011) asserts that education must maintain relevance to the "spirit of the age" (rokh zaman), which serves as the foundational principle guiding the practice of education across historical periods. From this perspective, contemporary education must be aligned with the demands of twenty-first-century competencies and with multidimensional contemporary issues. Ki Hadjar's concept of Tut Wuri Handayani is likewise relevant to transformative curriculum: the educator attends to learners by granting them the freedom to move in accordance with their will and potential, while the educator functions as an encourager and facilitator (Sugiyanto et al., 2022).

Drawing upon the synthesis of these theoretical perspectives, transformative curriculum is defined as a student-centered pedagogical framework that cultivates critical thinking and reflective awareness through processes of perspective transformation focused on action to resolve real problems at both local and global levels of society. This definition implies four main components of transformative curriculum, which are elaborated in the following sections.

B. Learning Orientation in Transformative Curriculum

Learning orientation is a fundamental component that determines the direction and focus of the entire learning process in a transformative curriculum. In contrast to conventional curricula, which are oriented toward knowledge transmission, transformative curriculum is oriented toward the development of critical consciousness and the transformation of students' perspectives.

The principal aim of transformative learning is to effect a deep change in the ways learners think, see, and become aware. This approach emphasizes not only the acquisition of knowledge but also the transformation of perspectives that can reshape individuals' values, beliefs, and actions. Mezirow (2009) explains that the key processes of transformative learning are critical reflection, dialogue, and experience-based learning. Learners examine their assumptions, identify distortions in their thinking, and construct new understandings that are more inclusive and reflective.

Critical reflection within transformative curriculum unfolds across three interrelated levels. The first level, content reflection, concerns the evaluation of the content of personal experience: students are invited to question what they perceive and understand from an experience or piece of information.

The second level, process reflection, seeks to critically examine thinking strategies and ways of doing things; at this level, students analyze how they arrived at a particular understanding and what methods they employed in their thinking. The third level, premise reflection, scrutinizes the underlying assumptions that have hitherto shaped a person's worldview. This level is the deepest, as it makes possible the transformation of perspective—namely, fundamental changes in one's views about the world, the self, and the practices of life (Mezirow, 2009).

Transformative learning orientation also emphasizes the importance of life experience and societal discourse as sources of learning. Through discussion among learners, an exchange of experiences and perspectives occurs that can accelerate personal and social transformation. This process becomes the starting point for a profound shift in perspective, in which students experience an "aha" moment that helps them attain a new level of awareness and forge new connections. At that moment, students begin to accept new viewpoints, broaden their modes of thinking, and undergo perspective transformation.

A practical implication of this learning orientation is the shift in the role of lecturers from sources of knowledge to facilitators. Consistent with Vygotsky's social constructivism and Ki Hadjar Dewantara's concept of Tut Wuri Handayani, lecturers must be able to serve as scaffolders who accompany students in the early phase of learning and, at more advanced stages, give way to student learning autonomy (Aubrey & Riley, 2022). Lecturers are no longer the sole source of knowledge; rather, they focus on fostering a conducive learning environment so that students' cognitive, affective, and psychomotor potentials may develop optimally.

C. Learning Materials in Transformative Curriculum

Learning materials in transformative curriculum cannot be understood merely as a list of topics or content that students must master. More fundamentally, learning materials must be conceived as a medium for cultivating critical consciousness and encouraging the transformation of perspective. Transformative curriculum integrates three main pillars in the development of learning materials: inclusivity, sustainability, and social justice together with anti-racism.

a. Pillar of Inclusivity.

Inclusivity in education demands a paradigm that views individual differences not as problems to be rectified but as opportunities to democratize learning. The development of a transformative curriculum focuses on the exploration of global diversity to realize an inclusive environment. The implementation of the inclusivity pillar encompasses several strategies. First, the use of content warnings for sensitive or controversial topics to give students the opportunity to prepare themselves emotionally and mentally and to make informed decisions about their engagement with such content. Second, the use of language that is comprehensible to all students in the preparation of the Semester Learning Plan (Rencana Pembelajaran Semester, RPS), as well as in the delivery and evaluation of instruction.

b. Pillar of Sustainability.

The content of transformative curriculum must include the pillar of sustainability relevant to the SDGs agenda. Five aspects should be integrated into learning materials. The first aspect is the issue of climate change, encompassing discussions of its causes, impacts, and responses. The second aspect is ecological disaster, addressing the emotional and psychological distress experienced by individuals or communities confronted with loss, degradation, or disruption of ecosystems and the natural environment. The third aspect is local wisdom, which integrates the collective wisdom, practices, and perspectives of Indigenous communities regarding traditional ecological knowledge transmitted across generations. The fourth aspect is the SDGs, which equip students to address pressing issues such as poverty, inequality, environmental degradation, and peace. The fifth aspect is environmental justice, which integrates equitable practices in waste management and pollution sources across all communities.

c. Pillar of Social Justice and Anti-Racism.

The content of transformative curriculum should explore diverse global perspectives and cultivate a broad understanding across scholarly fields in order to address social injustice and to promote social change. The implementation of this pillar encompasses three dimensions. The first dimension conceives of the curriculum as a bridge connecting students to society through the integration of community empowerment, advocacy, and solidarity, thereby linking theory with factual conditions. The

second dimension is contextualization in students' everyday lives, which explores their identities, values, and experiences, particularly in relation to equity, diversity, and inclusivity. The third dimension is the use of asset-based language—communication that focuses on emphasizing and appreciating the strengths, capacities, and positive qualities of individuals, groups, or communities.

These three pillars must be grounded in the actual realities of society. Freire (2000) asserts that meaningful education is education that begins from the social, cultural, and economic realities in which learners are situated. Real-world issues relating to the economy, the environment, education, human rights, and other concerns must serve as instructional material and as objects of discussion. Learning, accordingly, does not take place in a space isolated from its social context; rather, it engages directly with the concrete problems of life.

D. Learning Methods in Transformative Curriculum

Learning methods in transformative curriculum are not merely instructional techniques; they are manifestations of the orientation and values that underlie the curriculum itself. Learning methods must be student-centered, contextual, and relevant to societal problems. More importantly, learning methods must integrate reflection and action as a unified pedagogical praxis.

The learning process in transformative curriculum proceeds through horizontal dialogue between lecturers and students. Learning is not a one-way process in which lecturers transmit knowledge to students; rather, it is dialogic, with students positioned as knowledgeable subjects who contribute actively to the learning process. Learning is understood as a shared process, not as the bestowal of knowledge from those who "know" to those who "do not know" (Freire, 2000).

Based on a synthesis of the literature and the Guide to Transformative Pedagogy, five learning methods are particularly relevant to transformative curriculum.

a. Case-Method.

Merseth (1994) defines the case-method as a discussion-based method that employs real or simulated situations to foster critical thinking, analysis, and problem-solving skills. Three essential elements of this method are: reality-based cases that enable students to explore and analyze problems in authentic settings; an emphasis on careful research and study; and encouragement for users to develop multiple perspectives. The case-method is effective for triggering a "disorienting dilemma" in transformative learning, in which students perceive the gap between actual and ideal conditions through the cases being examined. In the context of teacher education institutions (Lembaga Pendidikan Tenaga Kependidikan, LPTK), cases may function as exemplars, as opportunities to practice analysis, and as stimuli for personal reflection.

b. Reflective Discussion.

Taylor (2007) defines reflective discussion as a discussion that encourages learners to critically examine their experiences, beliefs, and assumptions through in-depth dialogue aimed at exploring experience, values, assumptions, and beliefs. Its purpose is to develop new understandings that are more inclusive and transformative. In the context of transformative learning, reflective discussion is central to the process of perspective change because it encourages students not merely to receive information passively but actively to reflect on the meaning underlying the experiences or materials they study. Reflective discussion may be conducted individually through reflective journal writing or collectively through intersubjective dialogue using techniques such as learning circles or Socratic dialogue to enhance the participation of each individual.

c. Simulation and Role Playing.

Santos (2018) explains that the simulation method allows students to experience real situations or specific scenarios virtually or through role-play. Through simulation, students can experiment and directly observe the consequences of decisions made in a given situation without real-world risk, thereby deepening their understanding of subject matter. This method is effective for cultivating empathy, as students place themselves in the position of others within particular social contexts, which helps them appreciate the diversity of perspectives. Beyond deepening academic knowledge, simulation also fosters critical thinking, cooperation, and problem-solving skills.

d. Project-Based Learning.

Thomas (2000) explains that project-based learning engages students in research or development activities that require them to plan, implement, and evaluate projects related to the subject matter. This

method is consistent with transformative learning because it focuses not only on theoretical knowledge but also encourages students to apply what they have learned in real contexts. Collaborative projects that address social, environmental, or cultural issues promote contextual and transformative learning while also shaping attitudes and values that support social change.

e. Narrative Inquiry.

Clandinin and Connelly (2000) explain that narrative inquiry is a learning method focused on the collection and analysis of individual stories or narratives in order to understand experiences, meanings, and specific phenomena within educational contexts. By employing stories as a tool for learning, students are invited to share personal experiences related to the topic under study and to construct deeper understandings through collective reflection on those narratives. This method contributes to transformative learning because students not only acquire new knowledge but also reflect upon and construct new understandings of themselves and of their relationships with others within the broader social context.

These five methods share a common thread: an emphasis on the dialectic between reflection and action. Transformative curriculum invites students not only to think critically but also to act in order to reshape reality. As Freire (2000) asserts, education as praxis is a process of action and reflection aimed at the realization of social transformation.

E. Learning Evaluation in Transformative Curriculum

Learning evaluation in transformative curriculum requires a fundamental paradigmatic shift from conventional models of evaluation. Whereas conventional evaluation focuses on measuring mastery of content through instruments such as written examinations, evaluation in transformative curriculum focuses on processes of critical thinking, changes in attitudes and perspectives, and students' concrete actions. What is assessed, therefore, is not merely knowledge but the transformation that students experience and manifest.

The aims of transformative learning evaluation encompass four aspects. First, to assess whether students have undergone perspective transformation as a result of the learning process. Second, to examine the extent to which students are able to critically reflect on their own experiences and assumptions. Third, to measure students' engagement in real-world actions that are ethically and critically reflective. Fourth, to monitor the learning process as a whole—not only the final outcome—because processes of reflection and dialogue are as important as the final products of learning.

Evaluation in transformative curriculum is qualitative, reflective, participatory, and narrative in nature. These characteristics differ fundamentally from the quantitative-objective evaluations commonly employed in conventional curricula. Six forms of evaluation instruments are relevant to transformative curriculum.

1. Reflective Journal.

Students maintain a journal that documents their thinking processes, emotions, changing assumptions, and the impact of learning experiences. Reflective journals enable longitudinal and personal documentation of perspective transformation processes.

2. Narrative of Self-Transformation.

Students compose a narrative describing how their understanding changed throughout the learning process. Such narratives offer a holistic portrait of the student's transformative journey from a first-person perspective.

3. Transformative Portfolio.

A portfolio is a collection of learning artifacts, such as journals, videos, action photographs, and discussion notes, that serve as evidence of change. Portfolios enable comprehensive, evidence-based evaluation of the learning process.

4. Action Project.

An action project is a concrete activity grounded in students' critical reflection on societal problems. Evaluation of an action project assesses not only outcomes but also students' planning, implementation, and reflection processes.

5. Self- and Peer-Evaluation.

Students assess their own process and contribution as well as those of their peers in the learning process. This form of evaluation fosters the development of metacognitive skills and collective responsibility in learning.

6. Critical Dialogue and Debate.

Students demonstrate their capacity to engage in critical dialogue and debate as an indicator of the development of critical thinking and argumentation skills.

In the conduct of evaluation, lecturers must employ rubrics oriented toward reflection and student development, rather than criteria based on right-or-wrong answers or rote memorization. Evaluation must be carried out continuously throughout the learning process (formative assessment), not merely at the end of the semester (summative assessment). This approach aligns with the principles of transformative learning, which emphasize the gradual and continuous transformation of perspective.

F. Synthesis: An Integrative Framework of Transformative Curriculum

The four components of transformative curriculum elaborated above constitute an integrated and mutually reinforcing system. A learning orientation focused on perspective transformation through critical reflection determines the character of learning materials that are contextual and oriented toward inclusivity, sustainability, and social justice. These materials are delivered through methods that emphasize the dialectic of reflection and action—namely, the case-method, reflective discussion, simulation, project-based learning, and narrative inquiry. Learning evaluation that is qualitative, reflective, participatory, and narrative serves as the feedback mechanism that ensures the attainment of the transformative learning orientation.

This integrative framework implies four paradigmatic shifts in the conduct of higher education. First, a shift from a learning orientation centered on knowledge transfer to one focused on the formation of critical consciousness and the transformation of perspective. Second, a shift from learning materials isolated from their social context to materials that are contextual and oriented toward inclusivity, sustainability, and social justice. Third, a shift from passive, one-way learning methods to participatory, dialogic, and reflective methods. Fourth, a shift from evaluation that is summative and cognitive to evaluation that is formative, transformative, and holistic.

The implementation of transformative curriculum is consistent with the eight key elements of transformative pedagogy identified in the literature: reflective awareness, critical thinking, social sensitivity, dialogue, collaboration, participation, adaptability to the changing times, and a leadership disposition (Enkhtur & Yamamoto, 2017; Hoggan & Kloubert, 2020; Mezirow, 2009; UNESCO, 2022). Transformative curriculum thus serves as a vehicle for developing all of these elements in an integrated manner, with the ultimate aim of shaping students as agents of change who are able to contribute to social transformation and to the attainment of the Sustainable Development Goals.

4. CONCLUSION

Transformative curriculum constitutes an essential integrative framework for realizing the University 4.0 paradigm and the Impactful Higher Education (Diktisaintek Berdampak) policy in Indonesian higher education. On the basis of the conceptual study conducted here, it can be concluded that transformative curriculum comprises four components that are mutually integrated and mutually reinforcing.

Learning orientation in transformative curriculum centers on the formation of critical consciousness and the transformation of students' perspectives through three levels of reflection: content reflection, process reflection, and premise reflection. This orientation requires a shift in the role of the lecturer from source of knowledge to facilitator, thereby enabling students not only to know "what" but also to question "why" and "how to improve it."

Learning materials in transformative curriculum integrate three fundamental pillars: inclusivity, which regards difference as an opportunity to democratize learning; sustainability, which encompasses climate change, ecological disaster, local wisdom, the SDGs, and environmental justice; and social justice together with anti-racism, which bridges students and society through community empowerment and advocacy. These three pillars must be rooted in the social, cultural, and economic realities of students.

Learning methods in transformative curriculum include the case-method, reflective discussion, simulation, project-based learning, and narrative inquiry, all of which emphasize the dialectic between reflection and action. These methods are implemented through horizontal dialogue between lecturers and students, positioning students as active subjects who contribute to the learning process.

Learning evaluation in transformative curriculum is qualitative, reflective, participatory, and narrative, and focuses on the process of student perspective transformation. Evaluation instruments include reflective journals, narratives of self-transformation, transformative portfolios, action projects, self- and peer-evaluation, and critical dialogue and debate, which are conducted continuously throughout the learning process.

The synthesis of these four components yields a conceptual framework of transformative curriculum with the potential to support the formation of students as agents of change who contribute to social transformation and to the attainment of the Sustainable Development Goals. This study recommends further empirical research to test the effectiveness of implementing transformative curriculum across diverse study program contexts. Valid and reliable evaluation instruments are also needed to measure students' perspective transformation, along with systematic lecturer training models to build the competencies required to design and implement transformative curriculum.

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Investigation-Based Scientific Collaborative (IBSC) Learning Model to Foster Students' Communication and Collaboration Skills

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ABSTRACT

The development of communication and collaboration skills constitutes a critical demand in 21st-century learning. However, classroom practices remain predominantly teacher-centered, limiting students' opportunities to actively engage in scientific investigation and collaborative work. This study aims to examine the effectiveness of the Investigation-Based Scientific Collaborative (IBSC) learning model in enhancing students' communication and collaboration skills.

This research employed a quasi-experimental design involving students as research participants. The experimental group received instruction using the IBSC model, while the control group was taught using conventional methods. Data were collected through assessment instruments measuring communication and collaboration skills, observation sheets, and supporting documentation. Data analysis was conducted using descriptive and inferential statistics to determine differences between the two groups.

The findings indicate that students taught using the IBSC model demonstrate significantly higher communication and collaboration skills compared to those taught through conventional learning. The IBSC model promotes active student engagement in investigative activities, scientific discussions, and collaborative problem-solving, thereby positively influencing their ability to communicate and work effectively in teams.

This study concludes that the Investigation-Based Scientific Collaborative (IBSC) learning model is effective as an alternative instructional approach for developing students' communication and collaboration skills.

Keywords: model IBSC, keterampilan komunikasi, keterampilan kolaborasi, pembelajaran kolaboratif, keterampilan abad ke-21

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1. INTRODUCTION

Science learning in the 21st century no longer focuses solely on the mastery of concepts but also requires students to possess communication and collaboration skills as integral components of 21st-century competencies. Various international reports emphasize that scientific communication and teamwork are crucial aspects in solving science-based problems (OECD, 2019; UNESCO, 2023). In science learning, dialogic interaction and well-structured group work provide opportunities for students to construct conceptual understanding through processes of argumentation, discussion, and negotiation of meaning. Recent studies indicate that collaborative learning has a significant effect on improving students' scientific communication skills (Kurniawati & Farida, 2022; Wikanengsih & Rostikawati, 2024; Hidayat et al., 2023).

However, classroom practices are still predominantly teacher-centered, resulting in suboptimal development of scientific interactions among students. Empirical studies reveal that the implementation of collaborative learning without clear structure tends to fail in establishing effective positive interdependence (Gillies, 2020; Rahmawati et al., 2022). In addition, students' scientific communication skills, particularly in presenting evidence-based arguments, remain relatively low when not supported by systematic and well-directed instructional design (Llorente & Revuelta, 2023; Sánchez & Martínez, 2021).

The inquiry-based learning (IBL) approach has been proven effective in enhancing students' scientific literacy and scientific thinking skills (Amaditha et al., 2024; Diser Research, 2025; National Research Council, 2020). Furthermore, studies show that integrating investigative processes with collaboration in inquiry learning has a positive impact on students' scientific problem-solving abilities

(International Journal of Educational Research, 2022; Lee et al., 2021). Nevertheless, the implementation of inquiry without clearly structured collaboration may lead to unequal participation among group members.

From a social constructivist perspective, social interaction plays a fundamental role in knowledge construction (Suparno, 1997; Moreno, 2010; Vygotsky revisited studies, 2022). Therefore, a learning model is needed that explicitly integrates scientific investigation with structured collaboration. The Investigation-Based Scientific Collaborative (IBSC) model was developed to address this need through a learning syntax that combines investigation phases with sharing tasks and jumping tasks, thereby fostering academic empathy, collective responsibility, and productive scientific communication.

The development of the IBSC model adopts the Educational Design Research (EDR) approach, which is oriented toward producing learning models that are valid, practical, and effective (Plomp, 2013; Nieveen et al., 2007; McKenney & Reeves, 2021). This approach enables an iterative process involving design, implementation, evaluation, and revision, resulting in a model that is not only theoretically grounded but also empirically validated. Accordingly, this study aims to develop an IBSC model that systematically and measurably enhances students' communication and collaboration skills in science learning. The novelty of this research lies in the integration of scientific investigation and structured collaboration within a single learning syntax specifically designed to develop both skills simultaneously, thereby offering an innovative alternative for strengthening competency-based science learning in the 21st century.

2. RESEARCH METHOD

A. Research Design

This study employs a Research and Development (R&D) design aimed at developing the Investigation-Based Scientific Collaborative (IBSC) learning model to foster students' communication and collaboration skills. The R&D approach was selected as the study not only examines the effectiveness of an intervention but also produces an educational product that meets the criteria of validity, practicality, and effectiveness (Borg & Gall, 2003; Sugiyono, 2012).

The development of the IBSC model follows the procedures of Borg and Gall (2003), modified to suit field conditions, comprising three main stages: (1) preliminary study, (2) product development, and (3) product testing. During the testing phase, a one-group pretest–posttest design was employed (Fraenkel & Wallen, 2012). This design was applied in both Trial I (limited trial) and Trial II (replication across three classes) to examine the improvement in students' communication and collaboration skills before and after the implementation of the IBSC model.

B. Research Procedure

The research procedure was carried out systematically following the development framework adapted from Borg and Gall (2003). The first stage was the preliminary study, which aimed to identify the need for model development through literature review, expert consultation, and field study (Suharsimi, 2006). The literature review was conducted to analyze theories and previous research related to communication and collaboration, while the field study aimed to obtain an empirical overview of Biology learning practices as well as students' communication and collaboration skills.

The second stage involved product development. Based on the identified problems, the researcher developed an initial draft (Prototype I) of the IBSC model along with its instructional tools, including syllabus, lesson plans, student worksheets, student textbooks, communication skills test instruments, collaboration skills observation sheets, student activity observation sheets, student response questionnaires, and model implementation observation sheets. The draft was validated by experts to assess both content and construct validity (Nieveen et al., 2007). Revisions were made based on expert feedback, resulting in Prototype II and Prototype III.

The third stage was product testing through Trial I and Trial II. Trial I was conducted on a limited basis using the O_1 X O_2 design. Following revisions, Trial II was carried out in three replication classes using the same design. The subjects in Trial II were ninth-grade students of MTs Negeri Rantauprapat and MTs Abu Hurairah Rantauprapat, selected purposively based on the heterogeneity of their academic abilities.

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C. Data Collection Techniques

Data were collected using multiple techniques in accordance with the research variables. The validity of the model and instructional tools was obtained through expert validation using validation sheets. The practicality of the model was assessed through observations of learning implementation, student activity observations, and interviews regarding instructional constraints. The effectiveness of the model was measured through communication skills tests, collaboration skills observations, and student response questionnaires. The tests were administered before (pretest) and after (posttest) the implementation of the IBSC model. Student response data were analyzed using descriptive quantitative methods by calculating the percentage of positive and negative responses.

A complete matrix of the research procedures, variables, data collection techniques, instruments, data types, and analysis techniques is presented in Table 1.

Table 1. Research Matrix

No.	Research Variables	Data Collection Techniques	Instruments	Type of Data	Data Analysis Techniques
1	IBSC model for fostering communication and collaboration skills	Expert validation	IBSC model validation sheet	Qualitative	Descriptive qualitative analysis
2	Quality of IBSC syllabus	Expert validation	Syllabus validation sheet	Qualitative	Descriptive qualitative analysis
3	Quality of IBSC lesson plans	Expert validation	IBSC lesson plan validation sheet	Qualitative	Descriptive qualitative analysis
4	Quality of IBSC student worksheets	Expert validation	IBSC worksheet validation sheet	Qualitative	Descriptive qualitative analysis
5	Quality of IBSC student textbook	Expert validation	IBSC textbook validation sheet	Qualitative	Descriptive qualitative analysis
6	Implementation of the IBSC model	Observation	IBSC implementation observation sheet	Qualitative (quantified)	Descriptive quantitative analysis
7	Student activities in IBSC model	Observation	IBSC student activity observation sheet	Qualitative (quantified)	Descriptive quantitative analysis
8	Constraints in implementing the IBSC model	Observation and interview	Observation notes and interview guidelines on implementation constraints	Qualitative	Descriptive qualitative analysis
9	Students' responses to IBSC model	Questionnaire	IBSC student response questionnaire	Qualitative (quantified)	Descriptive quantitative analysis
10	Communication skills	Test, product assessment, observation	Communication skills test, product assessment sheet, communication skills observation sheet	Quantitative and qualitative (quantified)	t-test, ANOVA, and descriptive quantitative analysis

11	Students' collaboration skills	Observation	Collaboration skills observation sheet (IBSC model)	Qualitative (quantified)	t-test, ANOVA, and descriptive quantitative analysis

D. Data Analysis Techniques

Data analysis was conducted to evaluate the validity, practicality, and effectiveness of the IBSC model. Content and construct validity were analyzed using the mode of expert judgment scores and the reliability coefficient measured by the percentage of agreement. An instrument was considered reliable if the reliability coefficient reached ≥ 75% (Borich, 1994).

The practicality of the model was analyzed using descriptive quantitative methods based on the percentage of learning implementation and student activities. The effectiveness of the model was examined through parametric statistical tests, including the t-test to determine differences in mean scores before and after the treatment, and ANOVA to assess the consistency of the model's effect across replication classes.

Overall, the research design and procedures adhere to systematic educational development research principles, involving expert validation, staged trials, and both quantitative and descriptive analyses to ensure the scientific validity of the findings.

3. RESULTS AND DISCUSSION

A. Results of IBSC Model Development

This study produced an instructional product in the form of the Investigation-Based Scientific Collaborative (IBSC) learning model, systematically designed to foster students' communication and collaboration skills in science learning. The model was developed in response to the demands of 21st-century education, which emphasize the integration of conceptual understanding with socio-cognitive skills. Conceptually, the development of the IBSC model is grounded in the principles of social constructivism, which position interaction as the primary means of knowledge construction (Suparno, 1997; Moreno, 2010; Rahmawati et al., 2022).

The IBSC model structure consists of five main phases: (1) motivation and problem orientation, (2) collaborative investigation through sharing tasks, (3) presentation of results, (4) collaborative investigation through jumping tasks, and (5) evaluation. Each phase is designed to promote active student engagement in the learning process, both individually and collaboratively. The sharing task phase serves as an initial stage of collaboration to build foundational understanding, while the jumping task phase provides more complex challenges to stimulate higher-order thinking and advanced collaboration. This design aligns with the principle of scaffolding in learning, where students are provided with gradual support to achieve higher levels of understanding (Sato, 2014; Vygotsky revisited studies, 2022).

The development of the IBSC model also integrates the inquiry-based learning (IBL) approach, which emphasizes scientific investigation as the core of science instruction. Through activities such as observation, data collection, analysis, and conclusion drawing, students are trained to think scientifically and systematically. The integration of inquiry and collaboration has been shown to be effective in enhancing students' scientific literacy and problem-solving skills (Amaditha et al., 2024; National Research Council, 2020; Lee et al., 2021).

B. Validity of the Model and Instructional Materials

The validation results indicate that the IBSC model demonstrates both content validity and construct validity at a very high level. The reliability coefficient for all aspects reached 100%, thereby meeting the inter-observer agreement criterion of ≥ 75% (Borich, 1994). A summary of the construct validity of the IBSC model is presented in Table 2.

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Table 2. Construct Validity Results of the IBSC Model

No.	IBSC Model Category	Mean Validation Score	Validity Level	R (%)	Reliability
1	IBSC Model Structure	4.00	Very Valid	100%	Reliable
2	Theoretical and Empirical Support of the IBSC Model	4.00	Very Valid	100%	Reliable
3	Planning and Implementation of the IBSC Model	4.00	Very Valid	100%	Reliable
4	Learning Environment Management	4.00	Very Valid	100%	Reliable
5	Use of Evaluation Techniques	4.00	Very Valid	100%	Reliable
6	IBSC Model: A Final Reflection	4.00	Very Valid	100%	Reliable
	Mode of validity and reliability across all categories	—	Very Valid	100%	Reliable

The validity of the instructional materials (syllabus, lesson plans, and student worksheets) was also categorized as very valid, with a reliability coefficient of 100%. This indicates that the developed materials meet the criteria of theoretical soundness, syntactic consistency, linguistic appropriateness, and alignment with learning objectives. Conceptually, these findings support the view of Nieveen et al. (2007), which states that a development product is considered valid when it possesses a strong theoretical foundation and logical internal consistency. The high level of validity suggests that the IBSC model is appropriate for implementation testing in instructional settings.

C. Practicality of the IBSC Model

The practicality of the model was evaluated through the implementation of learning activities, student engagement, and constraints encountered during the instructional process. The observation results indicate that the implementation of the IBSC model syntax was categorized as very good in both Trial I and Trial II. Teachers were able to carry out each phase in accordance with the planned design, particularly in the collaborative investigation phase, which constitutes the core of the model.

Student activities showed increased participation in discussions, presentations, and group work. Interactions among group members became more balanced compared to conventional cooperative learning models. This suggests that the design of sharing tasks and jumping tasks effectively fosters positive interdependence.

These findings are consistent with collaborative learning theory, which posits that the success of group work depends on individual accountability and promotive interaction (Slavin, 2011; Suyatno, 2009). Therefore, the IBSC model is not only theoretically sound but also practical for classroom implementation.

D. Effectiveness of the IBSC Model

The effectiveness of the model was analyzed based on improvements in students' communication and collaboration skills using pretest–posttest results, t-tests, ANOVA, and N-gain analysis. The statistical results indicate a significant difference between pretest and posttest scores following the implementation of the IBSC model in both Trial I and Trial II. The increase in students' mean scores is presented in Figure 1.

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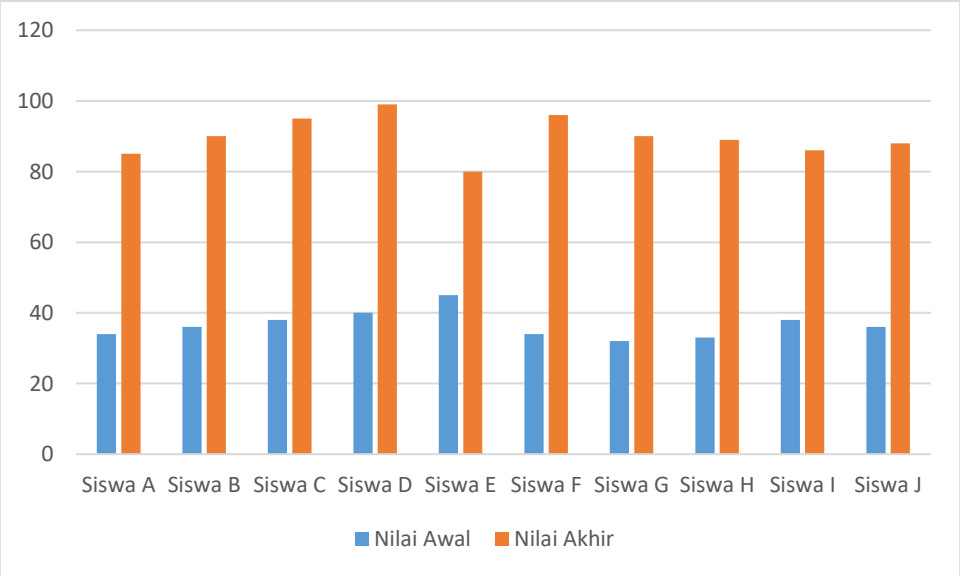

Fig. 1. Communication Skills Mastery Graph

The figure indicates moderate to high improvement categories, suggesting that the IBSC model is effective in enhancing students' communication skills. Furthermore, the ANOVA results across the three replication classes demonstrate that the IBSC model exerts a consistent effect on students' collaboration skills.

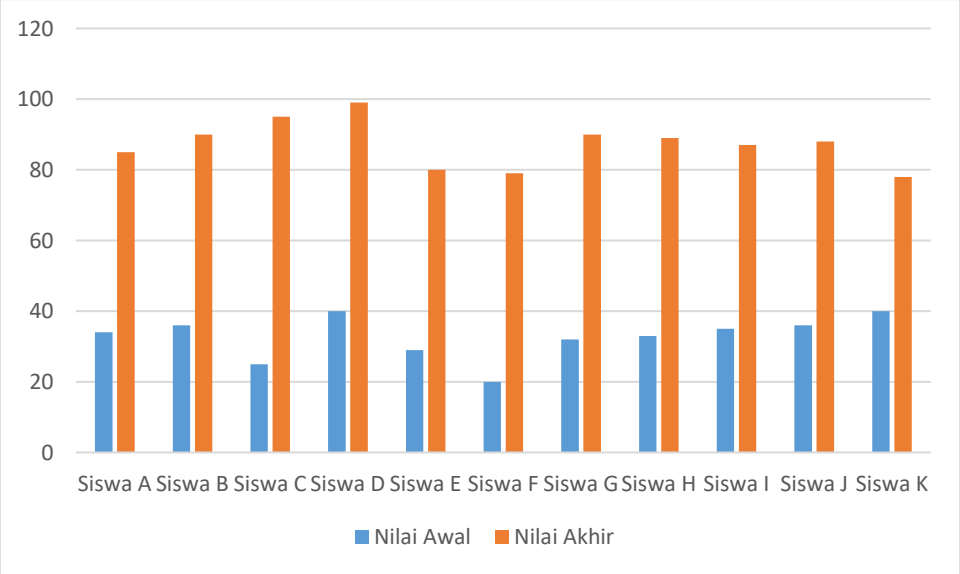

Fig. 2. Proportion of Students' Communication Skills Mastery at Pretest and Posttest in Replication Class I (Trial II)

Pedagogically, this improvement can be explained by the integration of scientific investigation and collaborative learning, which enables students to construct knowledge through dialogue and reflection. Scientific communication practices, facilitated through presentations and discussions, reinforce conceptual understanding (Wrench et al., 2009). Meanwhile, deliberately structured heterogeneous groupings support the development of academic empathy and shared responsibility.

E. Theoretical Discussion and Implications

The findings of this study indicate that the IBSC model not only meets the criteria of validity, practicality, and effectiveness, but also reinforces the social constructivist paradigm, which emphasizes the importance of interaction in the process of knowledge construction. Through investigative activities and collaborative discussions, students are actively engaged in constructing conceptual understanding both individually and collectively. This is consistent with the view that knowledge is constructed through social interaction and negotiation of meaning within learning contexts (Suparno, 1997; Moreno, 2010; Rahmawati et al., 2022).

More specifically, the integration of sharing tasks and jumping tasks within the IBSC model has been shown to effectively establish positive interdependence, which is central to collaborative learning. This structure enables students with diverse abilities to support one another and contribute to task completion. These findings are aligned with cooperative learning theory, which posits that successful group work depends on individual accountability, promotive interaction, and shared goals (Gillies, 2020; Slavin, 2011; Hidayat et al., 2023).

From the perspective of science education, the IBSC model also strengthens the effectiveness of the inquiry-based learning approach in enhancing scientific thinking skills and evidence-based communication. The integration of investigative processes with group discussions provides opportunities for students to develop scientific argumentation skills, interpret data, and present findings systematically. This is consistent with studies indicating that inquiry combined with collaboration enhances scientific literacy and problem-solving abilities (Amaditha et al., 2024; Llorente & Revuelta, 2023; National Research Council, 2020).

The practical implications of this study suggest that the IBSC model can serve as a strategic alternative for teachers in addressing the dominance of teacher-centered instruction. With its clear and structured syntax, the model facilitates more interactive, participatory, and skill-oriented learning aligned with 21st-century competencies. It also supports the creation of an inclusive learning environment in which each student has the opportunity to actively contribute within the group (Hidayat et al., 2023; Wikanengsih & Rostikawati, 2024).

Furthermore, from a curriculum development perspective, the IBSC model has the potential to be integrated into competency-based learning implementation, particularly in supporting the achievement of communication and collaboration skills as key targets of 21st-century education. This integration aligns with global recommendations emphasizing the importance of strengthening 21st-century skills within modern education systems (OECD, 2019; UNESCO, 2023).

In summary, the IBSC model not only provides empirical contributions to improving students' communication and collaboration skills, but also enriches the theoretical discourse in science education through the integration of scientific investigation and structured collaboration within a systematic and innovative instructional design.

4. CONCLUSION

This study aimed to develop an Investigation-Based Scientific Collaborative (IBSC) learning model that is valid, practical, and effective in fostering students' communication and collaboration skills. Based on the findings, the IBSC model was determined to be highly valid in terms of both content and construct, with a high level of reliability. The implementation of the learning syntax was categorized as very good during the trial stages, indicating that the model is practical for classroom application. In terms of effectiveness, the results of statistical tests revealed a significant improvement in students' communication and collaboration skills following the implementation of the IBSC model. Thus, the problems identified in the Introduction have been addressed, demonstrating that the IBSC model can serve as an innovative solution for enhancing communication and collaboration skills in science learning. In the future, the IBSC model has the potential to be further developed across different educational levels and subject areas, as well as integrated with educational technology to broaden its contribution to the development of 21st-century skills.

Furthermore, the findings of this study confirm that the integration of scientific inquiry and structured collaboration within the IBSC model not only improves communication and collaboration skills quantitatively but also enhances the quality of meaningful scientific interaction among students. The IBSC model creates a learning environment that promotes active participation, evidence-based idea

exchange, and collective responsibility in problem-solving processes. This indicates that the instructional design combining sharing tasks and jumping tasks plays a strategic role in fostering positive interdependence and productive scientific communication.

From a theoretical perspective, this study reinforces the relevance of the social constructivist approach in modern science education while contributing a more structured inquiry-based collaborative learning syntax. From a practical standpoint, the IBSC model provides implications for teachers in designing instruction that emphasizes not only learning outcomes but also the process of students' scientific interaction. Therefore, this model has the potential to serve as a pedagogical innovation that supports the effective and sustainable implementation of competency-based learning in the context of 21st-century education.

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