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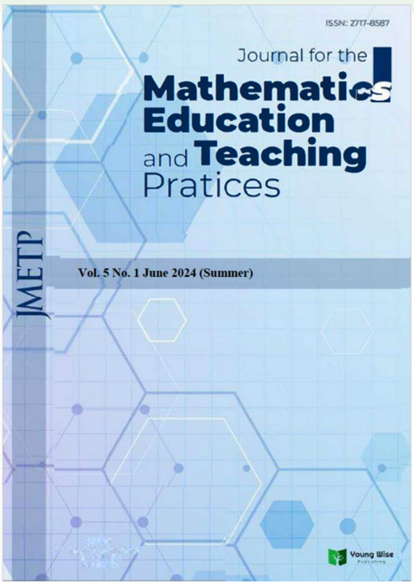

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Research Article

A study about mental calculation strategies with natural numbers in elementary school students using the broken calculator

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Abstract

This article reports a study about mental calculation in a group of elementary school students. Mental arithmetic, nowadays, is recognized as a subject of interest by several authors and educational systems. The latter have tried to design programs to develop it according to the flexibility of strategies, mathematical concepts, properties of the number system, and number sense. Several authors point out that tasks or activities should be incorporated with the intention of attending to this priority and not under a memoristic or strict teaching. In this sense, this qualitative research aimed to explore and describe the processes, strategies, operations, and skills (Rathgeb-Schnierer and Green 2019) used by six students studding sixth grade primary school in Puebla, Mexico. These students were 11 years old at the time they used the Broken Calculator application as a milieu to solve tasks; and it is shown that different strategies are developed when faced with the same tasks: some are predominant, others with a simple level of complexity, and how different calculation trains are elaborated according to the mastery of the strategies.

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Introduction

This exploratory study addresses mental arithmetic strategies using an app. It aims to analyze and describe the skills of sixth grade students when they confront tasks with the help of the *Broken Calculator* app. In this framework, six elementary school students were interviewed with the intention of recognizing the mental calculation strategies they have as well as their acquired knowledge.

Given the interest in the development of mental calculation skills, several teachers evidenced attempts to promote it in their classrooms as a personal decision, but which may be restricted by the conditions of the institutional environment (Weiss et al., 2019), the lack of knowledge of strategies (Mochón & Vázquez, 1995) and the use of inflexible rules (Lemonidis & Kaifa, 2014).

Mental arithmetic has been an important element in the training of basic education students. Such is the priority, that the *Secretaría de Educación Pública* [Ministry of Public Education] in Mexico (SEP, 2017) established as main purpose to use in a flexible way estimation, mental calculation and written calculation in operations with natural, fractional and decimal numbers. In those purposes, three important elements to achieve within the classroom are

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mentioned: estimation, written calculation (algorithmic calculation) and mental calculation (Jurić & Pjanić, 2023; Mochón & Vázquez, 1995).

Literature review

During the last decades, the importance of mental calculation has been recognized and like a necessity to include it in the mathematics curricula (Lemonidis, 2016). Since the 1980s, Hope (1987) mentioned that mental arithmetic should be part of the curriculum, as it promotes greater understanding of the structure of numbers and knowledge of number sense (Lemonidis & Kaiafa, 2014). However, this skill is rarely exploited, because it is not as evident as sports skills. For his part, Gómez (2005) argued that for the nineteenth century, the aim was to train versed calculators with a mastery of methods in the face of different situations. In the case of England, The Programme of National Numeracy Strategy in Primary Education was introduced in 1999. In 2000, the USA classified pencil and paper algorithms as a content that should be given less emphasis. By 1993 in Mexico, the SEP mentioned as a purpose in primary education to use mathematics as an instrument, both to solve problems and to estimate results, and even made recommendations to promote estimation calculation (SEP, 1993). It was at the secondary level where calculus estimation was proposed as a support for the study of whole numbers and decimals; however, there is no systematic and continuous practice (Cortés et al., 2004).

This analysis is closely related to the findings of Mochón and Vázquez (1995), who consider that students need active instruction in mental calculation and estimative calculus, since they have been neglected in the teaching of mathematics in Mexico. Similarly, Cortés et al. (2014) identified that few books in secondary education include this topic, have little didactic material and focus on estimation, also understood as approximation. Estimative calculus (or estimation) is that which does not seek to give exact answers to a problem, but rather its purpose is to give an answer close to the correct result of a problem (Mochón & Vázquez, 1995). Also, these students have knowledge of how place value is affected by arithmetic operations, the mathematical structure of the problem is adjusted and reformulated (Flores et al., 1990).

Within a study of teaching practice in Mexico, conducted by Weiss et al., (2019) in specific subjects, they observed that, for the case of mathematics, teachers allocate enough time to the exercise of algorithms and mental calculation in fourth and fifth grade; as it is recognized that formal education is decisive in arithmetic development and mental calculation (Jurić & Pjanić, 2023). It was also found that the problems posed were almost always isolated and for the purpose of applying knowledge already taught, despite the fact that authors such as Jurić and Pjanić (2023) indicate that the teaching of mental arithmetic should be carefully planned, since number sense is not developed by repeating algorithms (Yang et al., 2008).

Similarly, it was observed that little space is allotted for students to develop procedures autonomously. The teaching of mental arithmetic is minimal and little mentioned in the study program. Contrary, Gómez (2005) argues that mental arithmetic was taught, but not with such importance, and therefore there was no adequate approach or resources. Relationships with flexibility were unknown, nor with other mathematical knowledge and concepts that some studies already investigated (Barrera et al., 2018; Rathgeb-Schnierer and Green, 2019; Threlfall, 2009;).

Mental calculation is considered an indispensable segment of mathematical skills, important in and out of school (Juric & Pjanic, 2023), but erroneously executed in the classroom. Mochón and Vázquez (2005) mention that some exercises were taken as erroneous models and led to the idea that mental arithmetic were rules to be memorized as if they were shortcuts. Gómez (2005) argues the need for alternative calculation methods, since they are based on the properties of operations and the principles of the base ten numbering system, with the intention of obtaining exact results.

Mochón and Vázquez (1995) have defined mental calculation as a series of mental procedures that a person performs without the aid of paper and pencil, and that allow to obtain the exact answer to simple arithmetic problems. The original data of the problem are decomposed or replaced by others with which the subject works more comfortably to obtain the answer.

Theoretical Framework

Some common characteristics exist within the definitions of mental arithmetic. The most important ones deal with how it should serve to give exact answers, it makes use of decomposition strategies and the management of properties of the decimal number system in a cognitive way (Gómez, 2005; Mochón & Vázquez, 1995).

For his part, Lemonidis (2016) states that:

> *Mental calculation is calculation done mentally and using strategies. It produces a precise answer. Usually, it takes place without the use of external media such as paper and pencil, although it can be done with a paper and pencil, to make "jottings" that support the memory (p. 7)*

On the other side, written calculus is also known as algorithmic calculus and the following is mentioned: The distinction between algorithmic calculation and mental calculation does not consist in the fact that the former is written and the latter does not support the use of pencil and paper. Algorithmic calculus always uses the same technique for a given operation, whatever the numbers. On the other hand, when a mental calculation task is proposed, no single way of proceeding is expected (Ministry of Education, 2006).

Other authors such as Alsina (2007) and Rathgeb-Schnierer and Green (2019) recognize that children who have fewer memory resources have lower performance in calculation tasks and that one should not opt for repetition or mindless practice. They consider that understanding that changes and adapts to be used in problem solving should be preferred, in relation to connections between concepts, ideas, processes (Barrera-Mora et al., 2018) and easily remembered approaches (Threlfall, 2009). The above implies that a better choice of the appropriate strategy involves skills such as counting, mastery of tables, numerical combinations, offsets, and decompositions (Valencia, 2013).

Mental calculation, moreover, must be holistic, since the person maintains the identity of being whole numbers, even if decomposition is performed on them (Mochón & Vázquez, 1995). It is not fixed like the algorithm, but progressive (Threlfall, 2009) and, at the same time, it is variable since the problem can be solved in many correct ways. That is, mental calculation is flexible (Rathgeb-Schnierer & Green, 2019; Threlfall, 2002) since a single individual can use different strategies to solve problems, same that, together with memory, students begin from their early years, becoming more flexible and expanding in relation to knowledge and experiences (López, 2014). It is also constructive since the final result is built through partial results according to the chosen strategy. These should be mentioned in the classroom so that students understand that a question has several ways to be answered (Jurić & Pjanić, 2023; Mochón & Vázquez, 1995).

Rathgeb-Schnierer and Green (2019) and Threlfall (2002) assert that flexibility emphasizes deep conceptual development of numbers, operations, their relationships, and strategic means, should not be conveyed through methods for learning. They argue that teaching, from a flexible model, should emphasize from personal knowledge to the context of particular calculations, being analytical, from the perspective of students with operations and strategies at different levels of complexity (Carvalho & Rodrigues, 2021) and gradually expanding the range of numbers for problem solving, (Abd Algani et al., 2021). Rathgeb-Schnierer and Green (2017) conclude that there is consensus that mental calculation should be flexible, with two main characteristics: knowing different forms of solution and having the ability to adapt them appropriately to solve a problem optimally (Hickendorff, 2022).

Based on the characteristics mentioned about mental calculation and other research where the strategies developed by a student have been explored, as well as the favorable results of the Broken Calculator app (Rodríguez & Juárez, 2019; Sánchez et al., 2020), the interest was born to learn more about the development of strategies in this context and the implications of the application with different tasks and to use the calculator in a non-conventional way, taking as a reference the work of Goupil (2012). In addition, to make a technological environment that promotes students' concentration (Eleftheriadi et al., 2021) interacting with the calculator as a premeditated obstacle (also known as *milieu*) by the teacher (D'Amore and Fandiño-Pinilla, 2002).

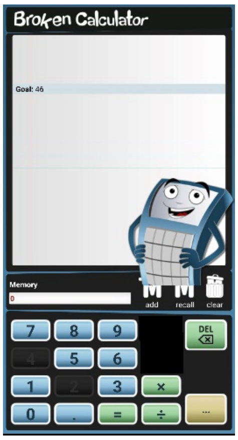

Figure 1. Image of broken calculator.

Method

Research Model

This research considered the challenges proposed previously for the development of mental calculation, so it introduced the Broken Calculator application, which in turn served as a *milieu*. Thus, the proposed technological environment challenged students to solve tasks as an a-didactic situation (D'Amore & Fandiño, 2002). Under the qualitative and **multiple case study approach** with **descriptive-exploratory** scope, the research question was resolved:

What strategies and skills of mental calculation are developed in elementary school students with the use of the decomposed calculator?

The research work has a phenomenological approach (Hernández et al., 2014). This approach explores, describes, and understands the processes of knowledge acquisition of the subjects. Making use of the classification proposed by Lemonidis, this helped us to discover the elements in common. Based on this question, the aim of the present study was to analyze the mental calculation strategies performed by sixth grade students with the basic operations of natural numbers using the Broken Calculator.

Participants

The subjects who participated in the study were three boys and three girls from an elementary school in Puebla City, Mexico. The age of the students was 11 years old. The students were selected by the teacher of the group according to their previous evaluations; three female students: one with high, medium, and low performance, three male students: with high, medium, and low performance.

Instrument and Data Collection

The instrument used to collect the information was a semi-structured interview. In it, the importance of the research question was considered as a real doubt that falls in the scientific field; also, under the natural observation of the events and the students (Schettini & Cortazzo, 2016), as a natural way to approach the case studies and that they could describe their mental calculation strategies.

The semi-structured interview allowed us to know, through the students' words, the processes they used, as well as to point out situations that could not be evaluated through writing, in order to describe situations that they considered important (Sánchez, 2013).

Classification

Table 1 is based on research literature gathered by Lemonidis (2016). He considers it third level because it is targeted for children who retrieve known numerical facts and mentally process them to compute another fact.

Table 1. Strategies compiled by Lemonidis

Strategy	Description	Examples	
		Addition (38 + 25)	**Subtraction (63–25)**
Division strategy (1010)	It is called this because the numbers added or subtracted are split into multiples of ten and units. This strategy is sometimes called partitioning method.	38+25: 5+8=13 30+20=50, 63	63-25: 13-5=8, 50-20=30, 38
Stringing strategy (N10)	According to this method, we keep the first term stable, split the second term into units and tens, and add or subtract units and tens successively from the first term.	38+25: 38+5=43, 43+20=63	63-25: 63-5=58, 58-20=38 (Subtraction) or 63-25: 25+8=33, 33+30=63, 38 (Addition)
Bridging through multiples of 10 (A10)	It can be considered a subcategory of the stringing strategy. In this case, we keep the first term stable, and add or subtract parts of the second term to get to the nearest ten.	38+25: 38+2=40, 40+23=63	**Subtraction** 63-25: 63-3=60, 60-20=40, 40-2=38 **Addition** 63-25: 25+**5**= 30, 30 + **33** =63, 38
Holistic: Compensation (N10C)	It can be regarded as a stringing strategy (N10) that moves to the nearest ten.	38 +25: 40+25= 65, 65 – 2 =63	
Levelling	This strategy is based on the property of levelling, where what is added to one term is subtracted from the other to have the same result	6 + 8: 7 + 7 = 14	
Direct modelling	Students model the problem and count the total number of objects, the number of groups or the number of the objects in every group.	**Multiplication**: They count in the model the total number of objects.	**Division** They count in the model the number of groups (quotitive) or the number of objects in each group (partitive).
Counting (3er level)	Every form of count strategy, skip counting forwards or backwards, repeated addition or subtraction, doubling and halving strategies.	**Multiplication** 5 x 15: 15, 30, 45, 60 or 5 x 15: 2 x 15=30, 30 + 30 = 60, 60 + 15 = 75	**Division** 75÷5: 15, 30, 45, 60, 75 or 180÷4: 180÷2 = 90 90 ÷ 2 =45
Direct retrieval	They use a known multiplication or division fact or a derived fact.	**Multiplication** 8×11=88, 5×12=60	**Division** 120÷6=20 because 6÷20=120
Partitioning a number based on place value.	One number is partitioned based on the place value of the arithmetic system.	**Multiplication** 7 x 15= (7x5) +(7x10) = 35 + 70 = 105	
Mental image of pen and paper algorithm	Children think and mentally perform the method of the standard written algorithm.		
Hybrid	Combine strategies from two or three basic groups of strategies to calculate multiplication tables. For example, this might be direct retrieval + counting all, or another such combination.		

Note: Strategies compiled by Lemonidis from the third level with examples and at the end is included the Hybrid strategy that belongs to strategies for multiplication table calculation, also mentioned by the same author.

Results

Task 1

In this first task, (see table 2) it was observed that, despite being buttons of a calculator, they had some inconveniences when writing the numbers they thought; some wrote in their attempts the number "1 + 1" and in subsequent movements they omitted the sign and wrote figures such as 111, 1111, etc. However, they had no problems in deducing the operation of the "DEL" key to erase some digits. The above could be due to the students' familiarity with the use of smartphones and not so with calculators.

In this first task the students had an attitude of testing and exploring the application. We could observe that such an attitude is favorably related to the functioning of *milieu*, since the researcher did not give recommendations to the students on how to solve the tasks and they remained interested, trying to correct their mistakes. In some cases, and later tasks, we could observe a tendency to change the strategies used to reduce the number of steps, this happened by students' initiative, which explains Valencia (2013) that mental calculation seeks to work comfortably with initial data that are easier to calculate. In the case of student **E3**, he mixed two strategies, also with the idea of avoiding the repeated addition of 7 times "+1" for this reason, he preferred to use three subtractions starting from 60. On the other hand, student **E1** changed strategy and reduced the number of steps performed, besides that in this first activity there was greater use of the division strategy (1010).

Table 2. Task 1: Set 57, with active keys 1, 0, +,-, =.

Student	Strategy used	Description
E1	*Started with division strategy (1010), changed to holistic strategy: Leveling*	2 attempts: 10 + 10 + 10 + 11 +11 +11 = 66, on the second attempt she changed the quantities 11 + 11 + 11 + 11 + 11 + 1 +1 = 57
E2	*Division strategy (1010)*	Two attempts: 10 + 10 +10 + 10 +10 + 1 + 1 + 1+ 1 +1 +1 +1 = 57
E3	*Division strategy (1010) and Estimation* (Mochón & Vázquez, 1995)	He made two attempts, in the first one he made a mistake and in the second one he approached the goal (the student mentioned going over the goal), then he subtracted: 10 + 10 + 10 + 10 + 10 + 10 – 1 – 1 – 1=57
E4	*Division strategy (1010)*	She made several attempts, also using decimals. Then corrected using: 10 + 10 + 10 + 10 +10 + 1 + 1 + 1 + 1 + 1 + 1 + 1
E5	*Holistic: Compensation (N10C)*	On his last attempt he placed 10 + 10 + 10 + 10 + 10 + 10 – 1 – 1 – 1, he said that "it's less steps". I plan to subtract to get there faster
E6	*Division strategy (1010)*	She made two attempts, in the last one he placed: 10 + 10 + 10 + 10 + 10 + 1 + 1 + 1 + 1 + 1 + 1 +1

Task 2

The first student mentioned in the interview that she used mental calculation and that for her it means "a way to do faster without writing operations", to know that the result sought was 60, but she already knew the table of 12, so she quickly placed in the broken calculator "12x5 ="; the student **E2**, found the result doing a multiplication x10 that she already knows and then added the result of 5 x 2 = 10, so she would put together both factors (10 and 2) to press "5 x 12 =".

The case of student **E3** stands out, since he performed the addition operation quickly, and when trying to describe it he mentioned that he only added it by imagining the operation, but in the calculator he placed a multiplication with the figures provided as an indication of the clause of the didactic contract to use as operators the numerical data present (D'Amore, 2021), when trying to specifically use "45 and 15". In turn, he used "- 99", since he could not place "- 100" because he did not have the digit "0" to approach the goal and until the last step he stopped to count with fingers the difference between the number he had and the goal as a reformulation of his estimate (Flores et al., 1990), he ended up rightly placing "- 21", but this counting strategy Lemonidis categorizes it in a lower level (2nd). In the case of student **E4**, mastery of the counting strategy was observed, since he mentally verified that the repeated sum of 15 gave 60, in order to place "15 x 4 = 60".

In the cases of students **E5** and **E6**, their strategies are not directly classified in the categories proposed by Lemonidis, nor do they fall into the counting classification, but they represent an ingenious alternative to solve the task, which demonstrates flexibility of operations and adaptability (Rathgeb-Schnierer & Green, 2019); on the other hand, their cases are particular because, in contrast to the group, they did not consider multiplication as the first option.

Table 3. Task 2: Enter 45 + 15, without the 0, +, keys

Student	Strategy used	Description
E1	*Bridging through multiples of 10 (A10)* and *multiplication: direct recovery.*	First, she mentally solved 45 + 5 = 50; 50 + 10 = 60, when she had the answer, she used keys "12 x 5", because she said she knew the table.
E2	*Partitioning a number based on place value*	(5 x 10) + (5 x 2) = 50 + 10 = 60, recovered the factors and wrote 5 x 12 =60
E3	*Mental image of pen and paper algorithm* *Estimation* and *Counting with fingers (2nd level).*	He said out loud that the answer is 60; however, to write it on the broken calculator he estimated 45 x 15 =675 and subsequently subtracted -99 several times, until he was as close to 60 as possible. In the last step, before pressing, he counted with his fingers to be sure. that 81 – 21 = 60.
E4	*Division Strategy (1010)* *Estimation* *Estimation and counting (3rd level)*	She wrote 45 x, then changed to 15 x. She quickly solved the operation = 60 and described it as 40 + 10 + 5 + 5. She wrote 45 x, then changed to 15 x. She said that he checked on the calculator that 15 x 4 = 60. Under the counting category this means: 15 x 4: 15, 30, 45, 60.
E5	They are not categorized.	Finding the answer 60, she described it as 5 + 5 = 10, and transformed the tens according to their place value 40 is 4 tens, 10 ones is 1 one, so 4 + 1 + 1 = 6 tens, and 6 tens is 60. Subtraction of units: 69 – 1 = 68 68 – 8 = 60. The student made two subtractions since by mistake he had written -1, so he subtracted – 8 to reach the goal.
E6	*Division Strategy (1010)*	The task answer was mentioned correctly and asked to describe how she found the answer, she mentioned a decomposition 45 + 5 = 50, 50 + 10 = 60 Subtraction of units: 61 – 1 = 60

Task 3

In this task, the + sign was omitted, since in the pilot it was the operation that predominated and did not meet the objective of the research. For this task, there was a greater tendency to use estimation since the *Broken Calculator* allows approaching from a higher or lower number to the goal, and a tendency to use multiplication since the "+" sign is not present.

Student **E1** had a more complex response than the rest on moving between categories of strategies and using them accurately and demonstrating certainty in their execution. For his part, student **E2** demonstrated mastery of the Direct modeling strategy by making a quick count of the times that "5 + 5 + ... are 90", and then converting it into a product just as student **E6** did (45 x 2).

Table 4. Task 3: Place 90 without using 9, 0 or +

Student	Strategies used	Description
E1	*Hybrid*	12-3= 9, (Subtraction) 9 x 5 = 45. 45 x 2 = 90 (Direct recovery)
E2	*Direct modeling*	Mentally he verified that 5 + 5 + 5...+ 5 = 90 Then he counted that 5 is repeated 18 times, so 5 x 18 = 90 His process was fast, he demonstrated efficiency.
E3	*Estimation* (Mochón & Vázquez, 1995) and *counting*.	Start by placing 12 x 12= 144 as a way to go over the target amount and then use subtraction to get closer. 12 x 12 = 144, 144 – 21 = 123, 123 – 21 = 102, 102 – 12 = 90
E4	*Estimation* and *counting*	She made several movements, in which estimation through multiplication predominated: 4 x 6, 4 x 7, 28 x 5, 24 x 3, 44.5 x 2. Finally, she placed 45 x 2 = 90. She explains that this she did it because 45 + 45 = 90.
E5	*Estimation*	He wrote a number higher than the target so he could use the "-" button; he then subtracted 111-11 = 100. He noted his mistake and corrected his second attempt to 111 – 21 = 90.
E6	*Counting*	In a single movement she wrote 45 x 2 =90. She explains that she did it because she mentally added 45 + 45 = 90.

Task 4

This task was not solved by all five students; however, those who had made an estimate in the previous tasks were more creative and exploratory than those who had not; their opinions about the task varied, but they agreed that there is a way to solve the challenge, they just could not find a way to do it. **E1**, planned a strategy that was accurate and demonstrated the use of two strategies to solve the task.

Table 5. Task 4: 46 without numbers 4, 2, +, -.

Student	Strategies used	Description
E1	*Division strategy* (1010) and *Direct recovery*.	On her first attempt, she wanted to add, but changed her strategy as she did not have +. Then she mentally added 40 + 40 + 40 + 6 + 6 + 6 = 138 138 ÷ 3 = 46 (justify her answer because 46 x 3 = 138).
E2	*They were estimation attempts with different quantities	Tried several multiplications with natural numbers, but did not achieve the result
E3		He tried various ways but did not achieve the result; He believes that this is because he "doesn't know much about mathematics" but that there is a result.
E4		She tried to multiply with the 5's table and add. Then with other factors, but none of them give him the answer. She chose to use decimals in different ways. The closest attempt he had was 5.1 x 9 = 45.9 (She said he would be one number short).
E5	**They planned a strategy to divide exactly but didn't find an answer.	He tried to place 90 between 2, resulting in 45, but he couldn't try 92 ÷ 2 because the 2 was broken. He said "I don't have a number to get 46"
E6		She pressed 92, but she saw that she didn't have the number 2 to divide. Then she pressed "158 ÷", however, she did not press anything else, she hesitated, she erased her progress to start over and she no longer knew what to do. In the interview she said that the task became complicated, and she kept thinking of a number to multiply or divide that would result in 46.

Discussion and Conclusion

The broken calculator study revealed that, within a group, we can find a diversity of strategies employed, and cases of students who efficiently employ more than one strategy for task resolution. For Lemonidis (2016) this is an indication of greater mastery and skill. Cases were also found that employed counting strategies and that, while not considered mental calculation, these students were able to perform better with the broken calculator as a *milieu* and with an exploratory attitude of the appeal.

The Broken Calculator application meets the characteristics of challenging students to provide answers with the resources on the screen. For the student, this environment proved to be more attractive, in which different strategies could be manifested and in which they acted autonomously, as the task seemed to be affordable to solve despite their failed attempts (Yang et al., 2008). The use of milieu, for mental calculation, is consistent with the recommendation of Yang et al., (2008) and Gomez (2005), who argue that mental calculation cannot be developed with the repetition of algorithms, as it requires adaptability from the students.

This study showed that students had the opportunity to create their own train of calculations corresponding to their level of numerical knowledge and operations (Carvalho & Rodrigues, 2021), and tended to rely on the operations they mastered and at the same time felt self-confident to solve more complex tasks as they interacted with the environment and exercised their working memory (Lopez, 2014). Also, despite the errors found, some students mentioned accepting that there was an answer, but they did not know what it was.

In the development of the activity, the affirmation of Mochón & Vázquez (2005) was reaffirmed, who state that the subject works more comfortably with the decomposition of the original data of the problem when substituted and that they are also easy to remember (just like task 1 and 2). We could see this in the decrease in the number of steps performed in the tasks each time they made a new attempt.

However, the tasks were increasing in complexity, and this demanded the use of more memory resources, being the student **E1**, the one who solved the problems more easily, also showed more planning and use of more elaborate strategies. For their part in task 2, students **E5** and **E6** also gave an answer that does not fall into Lemonidis' classification, but which refer to the concept of flexibility and ability to adapt them adequately to solve a problem (Hickendorff, 2022; Rathgeb-Schinner & Green, 2017). These last concepts were not the objective of the research, but the students' answers remain as a background for future research that, under the vision of the didactics of mathematics, has interest in exploring these characteristics in depth.

Also, as future research, we can rescue the signs of estimation in relation to mental calculation, because although they are not the same, there is a close relationship. This research could be useful to study in the future the relationship between them or the change of strategies before the proposed *milieu* throughout many sessions or different school levels.

Finally, it is worth mentioning that in this work specific tasks were used due to time limitations, but more or different tasks could be used, since the possibilities for investigating characteristics of mental calculation and its development such as number sense, flexibility and adaptability are very broad, so we suggest to narrow the focus of interest for future research, because of the possibilities of the calculator and the students' processes are diverse.

Limitations of Study

Due to the nature of the study, it was conducted with students without considering as variables the time or number of attempts to solve each task. Therefore, some interviews were longer, which led to limiting the specific number of participants and tasks.

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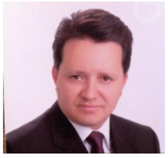

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Research Article

Constructing critical thinking module to teach math logic for vocational school student

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Abstract

Critical and logical thinkers are in high demand in the workforce. Vocational students need to possess this knowledge if they plan to work after graduation. Nevertheless, there aren't many Math Logic modules designed for students in vocational schools that have this ability. The goal of this research is to provide module that facilitating students at vocational schools to improve their critical thinking abilities. Utilizing 4-D Thiagarajan steps, this study using R&D method. Critical thinking ability tests, teacher and student answer questionnaires, and expert validation sheets are the instruments employed. Both quantitative and qualitative analysis was done on the data collected from the instruments. The data processing results demonstrate: 1) valid modules, as determined by validity test results from media, practitioners, and subject matter experts; 2) high-quality modules, as determined by student and teacher response results; and 3) useful modules, as determined by effectiveness test results in the classroom. The module can be utilized for instruction at vocational schools.

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Introduction

Students who study in vocational schools concentrated on skills that will be necessary in the labor market. One of those is critical thinking skill (Changwong et al., 2018). Mastering this skill is necessary to enable someone to understand, assess, evaluate, make judgments, and provide context for evidence (Selviana et al., 2016). This skill also related to student's career preparation (Baidowi et al., 2021).

Despite the necessity to think critically, multiple studies have found that vocational school students' critical thinking abilities remain low. At global scope, study from Deechai (2019) reported that Thai student still had low critical thinking skill degree. Meanwhile national studies found that vocational school learners in Boyolali saw low category in this skill (Ari et al., 2018). In line with this study, another research also revealed that the skill to think critically of students in one Semarang school remained low (Lestari et al., 2020). Meanwhile, Mataram's vocational school students who are predicted to be able to work after graduating also experienced low at this skill (Baidowi et al., 2021).

Critical thinking abilities will be taught in vocational school through instructional activities. These exercises include both theoretical and practical components (Eryandi & Nuryanto, 2020). Logic is one of the topics covered in

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vocational school mathematics classes. This content teaches learners how to develop logical conclusions . In everyday life, it is necessary to draw logical conclusions. This ability is essential to optimizing critical thinking abilities because being able to make logical conclusions is one indicator of critical thinking ability (Ennis, 1985).

Several studies have indicated that the outcomes of learning for vocational school students in Logic material are still low. Sawitri's research found that student at one of Cimahi's vocational schools still did not understand Logic content adequately (Sawitri, 2020). In two of the three measures examined, these students were classified as poor or extremely poor. Teachers have trouble expressing logical concepts to students, making logic material challenging (Septiani et al., 2022). Students struggle to determine the equivalence of compound sentences, the conclusion from two premises, and the truth value of compound phrases (Mirati, 2015).

Teachers can integrate classroom mathematics questions with mathematics in everyday life to enable learning that is relevant to the workplace (Baidowi et al., 2023). Teaching learning based on real-life circumstances, according to Magwilang, is helpful in enhancing students' enthusiasm to study (Magwilang, 2016). Aside from that, contextual learning is able to facilitate students to improve their logical reasoning skills (Septiani et al., 2022)

Several previous studies investigated the development of textbooks for vocational school mathematics lessons aimed at improving critical thinking skills. STEM-based mathematics materials on arithmetic sequences and series have been developed by (Insani et al., 2021). Pertiwi et al. have also created specific teaching materials based on Matrix content (Pertiwi et al., 2021). However, limited researches have been conducted to generate module on math logic.

Reflecting the solutions provided and ongoing research, this study aims to developing a math module based on Logic for vocational school math teachers. This study will focus on the development of educational materials using the Merdeka curriculum as the new curriculum in Indonesia.

Method

Research Model

This study was categorized as development research using the model of 4-D, namely define, design, development, dissemination (Thiagarajan et al., 1974). The 4-D research steps were presented in Figure 1.

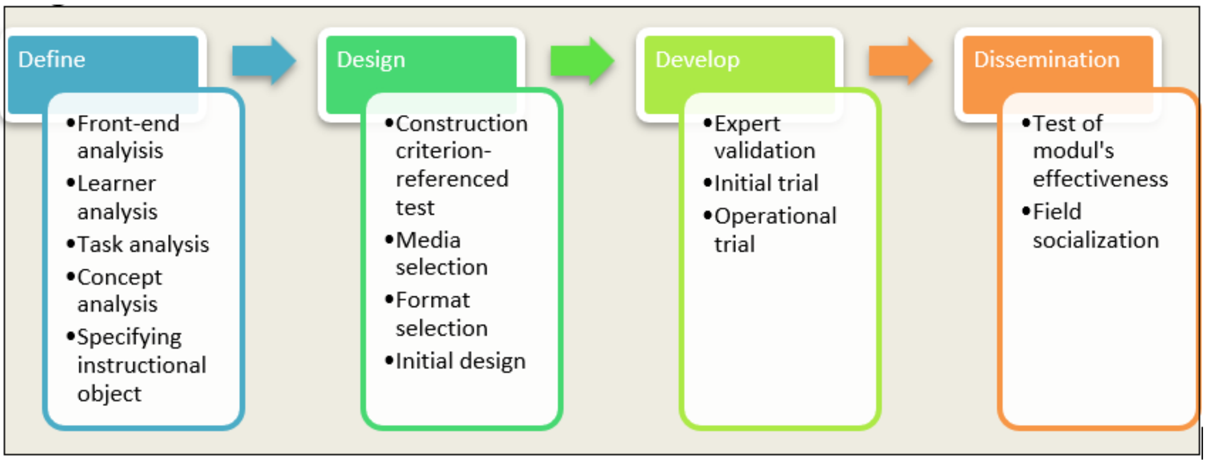


Figure 1. The Flowchart of The Research

Participants, Sampling and Data Analysis

Researchers analyzed the module's needs during the define stage by interviewing teachers at the school where the module would be tested, namely teacher of eleventh grade SMKN 4 Mataram, Indonesia, examining respondents who would use teaching materials, organizing the topic for discussion, and refining learning objectives into more practical goals.

During the design phase, researchers developed reference tests to evaluate the module's efficacy, selected the module delivery medium, decide on the ideal module format, and design the module. Expert validation is then conducted at the develop stage using practitioners, media experts, and material experts. Teachers at SMKN 4 Mataram, Indonesia, who will be using the module as a teaching tool were the practitioners, and math education lecturers serve as the media and material specialists.

The data obtained from expert validation was then added up and then averaged. Then, the average score was converted into categories as in Table 1 (Ratumanan & Laurens, 2016). The module can proceed to the dissemination stage if the module is at least in a valid category

Table 1. The validity of module

Interval's score	Category	Information
$1 \leq P \leq 1.75$	Very invalid	Can not be use
$1,75 \leq P \leq 2.75$	Invalid	Can be used but many revisions required
$2.75 \leq P \leq 3.25$	Valid	Can be used but with several revisions
$3.25 \leq P \leq 4.0$	Very valid	Can be used with minor revisions

Note: P= the score's average from all validators

Furthermore, in the dissemination stage, the researcher experimented the module to two culinary art class at eleventh grade with total 64 students and gave the questionnaire to collect the respond of students and teacher who already studied using the certain module. Researchers compared the use of the module in classes that studied using school textbooks alone with classes that studied using school textbooks and modules in order to assess the efficiency of using the module during the dissemination stage. The T test was then applied to the given data. The degree to which the class studied using school textbooks and module outperforms the class which just studied using school textbooks was what determines the effectiveness of the module. Otherwise, fixes for problems that could improve the functionality of the module will be made. Meanwhile, the data obtained from the questionnaire given to students and lecturers was analyzed using the classification in Table 2 (Widoyoko, 2016).

Table 2. The formula to classify module's category

Formula	Classification
$X > \bar{X}_i + 1,8 \times sb_i \Leftrightarrow X > 27,2$	Very good
$\bar{X}_i + 0,6 \times sb_i < X \leq \bar{X}_i + 1,8 \times sb_i \Leftrightarrow 22,4 < X \leq 27,2$	Good
$\bar{X}_i - 0,6 \times sb_i < X \leq \bar{X}_i + 0,6 \times sb_i \Leftrightarrow 17,6 < X \leq 22,4$	Enough
$\bar{X}_i - 1,8 \times sb_i < X \leq \bar{X}_i - 0,6 \times sb_i \Leftrightarrow 12,8 < X \leq 17,6$	Not good
$X \leq \bar{X}_i - 1,8 \times sb_i \Leftrightarrow X \leq 12,8$	Very bad

Note:
$\bar{X}_i = 1/2$ (maximal ideal score + minimal ideal score) = $\frac{1}{2} \times (32 + 8) = 20$
$sb_i = 1/6$ (maximal ideal score - minimal ideal score) = $\frac{1}{6} \times (32 - 8) = 4$
X = the sum of the score

After revised the module according to teacher and students feedback, the module could be disseminated more. Supplementary dissemination of the module can also be achieved by distributing it to classrooms in the same school.

Data collection and application

At define stage, the data was collected using interview guidelines and literature study. Meanwhile, at development stage, the data collected from instruments, such as validator form for material expert, media expert and practitioner, and student form response. Finally, in the dissemination stage, we utilized the data for critical thinking skill of students using critical thinking test in logic math topic in the form of essay and collected student and teacher response using. We also used the questionnaires to collected the feedbacks from teacher and students who already studied using this module.

Results

The study's findings are categorized as follows: definition, design, development, and dissemination.

Define Stage

This phase attempts to determine the issues and specify requirements for module development. The Logic content for SMKN 4 Mataram class XI students will be turned into a module. This study employed observation, documentation, and interview data collecting procedures as data collection methods. The define stage comprises five primary steps, which are front-end analysis, analysis of learner, and task analysis (Asriani et al., 2017).

To illustrate the reasons behind module development, a front-end analysis is carried out. The study involved two main methods: first, a review of the teaching materials for the class XI Logic material for the Independent Curriculum which was published by the Education and Culture Ministry at the Vocational School level; second, an interview with math teachers at SMKN 4 Mataram City regarding the significance of combining critical thinking modules for class modules used during learning. According to interviews with school mathematics teachers, teachers have not taught utilizing modules that help build students' critical thinking skills, particularly in Logic subject. The book that has been used thus far is a ministry package book. Teachers require a module that includes detailed phases of learning that can be developed.

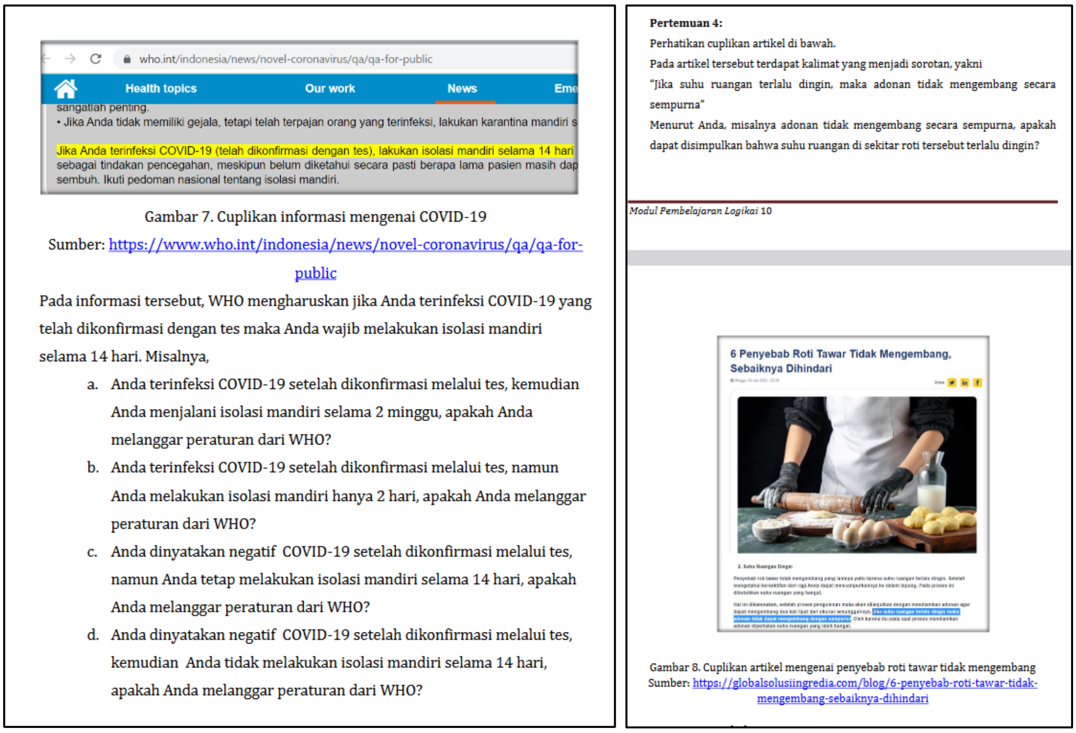
Student analysis is a stage for identifying student characteristics where field trials are used. Trials will be held in class XI for students majoring in Culinary Art I and Culinary Art II. There are 35 students in the Culinary Art I class, and 31 male and female students in the Culinary Art II program. Students in both courses preferred practical instruction over studying primarily through books and written questions, based on teacher assessments.

Determining the main skills that students have learned is the aim of task analysis. Fundamental competencies and particular learning objectives are selected at this level. One of the specific goals to be achieved in the educational materials provided is to increase students' abilities on thinking critially. Following that, concept analysis is done to determine the concept and learning processes taken. The content used is logic material about statements, negation, conjunctions, disjunctions, implications, biimplications, and forming conclusions. The program includes steps for problem-based learning together with logical content. Furthermore, specific learning objectives to be attained are specified by putting critical thinking ability indicators in each learning objective. Students will be able to identify the material relevance when solving contextual problems employing implication and biimplication rules, according to the learning objectives outlined.

Design Stage

The initial phases of product design are included in the design stage. Preparing benchmark testing, selecting media, selecting the module format, and basic design are the steps at this point. The design stage includes initial efforts at product design. At this point, preparations are made for benchmark testing, media and format selection, and basic design. The creation of benchmark exams is based on the required learning outcomes. The instructional tools used to evaluate students' critical thinking skills convert the benchmark exam into a knowledge test. In the media selection process, we choosed the paper based module because both the field trials's subject told interviewers that they perceived easier using paper based module than they did with alternative media like electronic media. Concurrently, the teaching materials have been developed in a module style that aligns with the Merdeka Curriculum. Subsequently, a preliminary design for the module under development is produced.

Figure 2 depicts the original module design that was in use. According to Figure 1, the module's original design included a number of articles and genuine data that served as the basis problem for learning. For example, in the material regarding drawing conclusions, the question taken is the issue of developing white bread dough which is related to the culinary arts department. The question uses a sentence excerpt, namely if the room temperature is too cold, then the dough will not rise perfectly. For example, if the dough does not rise perfectly, can it be concluded that the temperature around the bread is too cold? This problem directs students to draw conclusions using various existing methods.


who.int/indonesia/news/novel-coronavirus/qa/qa-for-public
Health topics Our work News
sangatlah penting.
• Jika Anda tidak memiliki gejala, tetapi telah terpajan orang yang terinfeksi, lakukan karantina mandiri s
Jika Anda terinfeksi COVID-19 (telah dikonfirmasi dengan tes), lakukan isolasi mandiri selama 14 hari sebagai tindakan pencegahan, meskipun belum diketahui secara pasti berapa lama pasien masih dap sembuh. Ikuti pedoman nasional tentang isolasi mandiri.

Gambar 7. Cuplikan informasi mengenai COVID-19
Sumber: https://www.who.int/indonesia/news/novel-coronavirus/qa/qa-for-public

Pada informasi tersebut, WHO mengharuskan jika Anda terinfeksi COVID-19 yang telah dikonfirmasi dengan tes maka Anda wajib melakukan isolasi mandiri selama 14 hari. Misalnya,

a. Anda terinfeksi COVID-19 setelah dikonfirmasi melalui tes, kemudian Anda menjalani isolasi mandiri selama 2 minggu, apakah Anda melanggar peraturan dari WHO?
b. Anda terinfeksi COVID-19 setelah dikonfirmasi melalui tes, namun Anda melakukan isolasi mandiri hanya 2 hari, apakah Anda melanggar peraturan dari WHO?
c. Anda dinyatakan negatif COVID-19 setelah dikonfirmasi melalui tes, namun Anda tetap melakukan isolasi mandiri selama 14 hari, apakah Anda melanggar peraturan dari WHO?
d. Anda dinyatakan negatif COVID-19 setelah dikonfirmasi melalui tes, kemudian Anda tidak melakukan isolasi mandiri selama 14 hari, apakah Anda melanggar peraturan dari WHO?

Pertemuan 4:
Perhatikan cuplikan artikel di bawah.
Pada artikel tersebut terdapat kalimat yang menjadi sorotan, yakni
"Jika suhu ruangan terlalu dingin, maka adonan tidak mengembang secara sempurna"
Menurut Anda, misalnya adonan tidak mengembang secara sempurna, apakah dapat disimpulkan bahwa suhu ruangan di sekitar roti tersebut terlalu dingin?

Modul Pembelajaran Logikai 10

6 Penyebab Roti Tawar Tidak Mengembang, Sebaiknya Dihindari

Gambar 8. Cuplikan artikel mengenai penyebab roti tawar tidak mengembang
Sumber: https://globalsolusiingredia.com/blog/6-penyebab-roti-tawar-tidak-mengembang-sebaiknya-dihindari

Figure 2. Initial design of module

Develop Stage

The development stage includes validation by specialist, operational trials, early testing, and product revisions. Specialist validation is carried out by an expert in material, an expert in media (module), and an expert from practitioner view. In contrast to module media expert validity, which evaluates the appearance, language, completeness, and suitability of the module's sequences, material expert validation evaluates the accuracy and suitability of the material presented for learning objectives. Practitioner validation will be carried out by the math teacher at SMKN 4 Mataram, who will serve as the module's pilot. This validation's objective is to evaluate the module's value for educational activities. The following Table 3 provides the validation results from the three specialist.

Table 3. The validation's result from validators

Specialist in Content		**Specialist in Media**		**Specialist from Practitioner View**	
Factor of Eligibility	Average Score	Factor	Average score	Factor of Eligibility	Average score
Content	4	Module size	4	Content	4
Presentation	4	Modul-cover design	3,5	Presentation	4
Language	3,5	Module-content design	3,5	Language	3,5
Content contextuality	4				
The score's average for each expert	3,88		3,67		3,83
The score's average of all validators			3,79		

Table 3 shows that the three validators have an average score of 3,79. Table 1 indicates that this score falls into the "very valid" category. It indicates that, with little changes, the module is usable. Moreover, Table 4 presents the recommendations made by the three validators.

Table 4. The Recommendations from Validators

Specialist in Material	Specialist in Media	Practitioner
• **The language in the practice questions about creating questions needs to be clarified.**	• Modules can be equipped with mind maps to help for students to understand the entire contents of the module	The problem in negation needed to be updated to the problem related to student

The validator's recommendations were incorporated into the modified module. Revisions include changing the wording of the exercise problem. One of the modules developed in response to that recommendation was shown in Figure 3. The first trial then made use of the updated module.

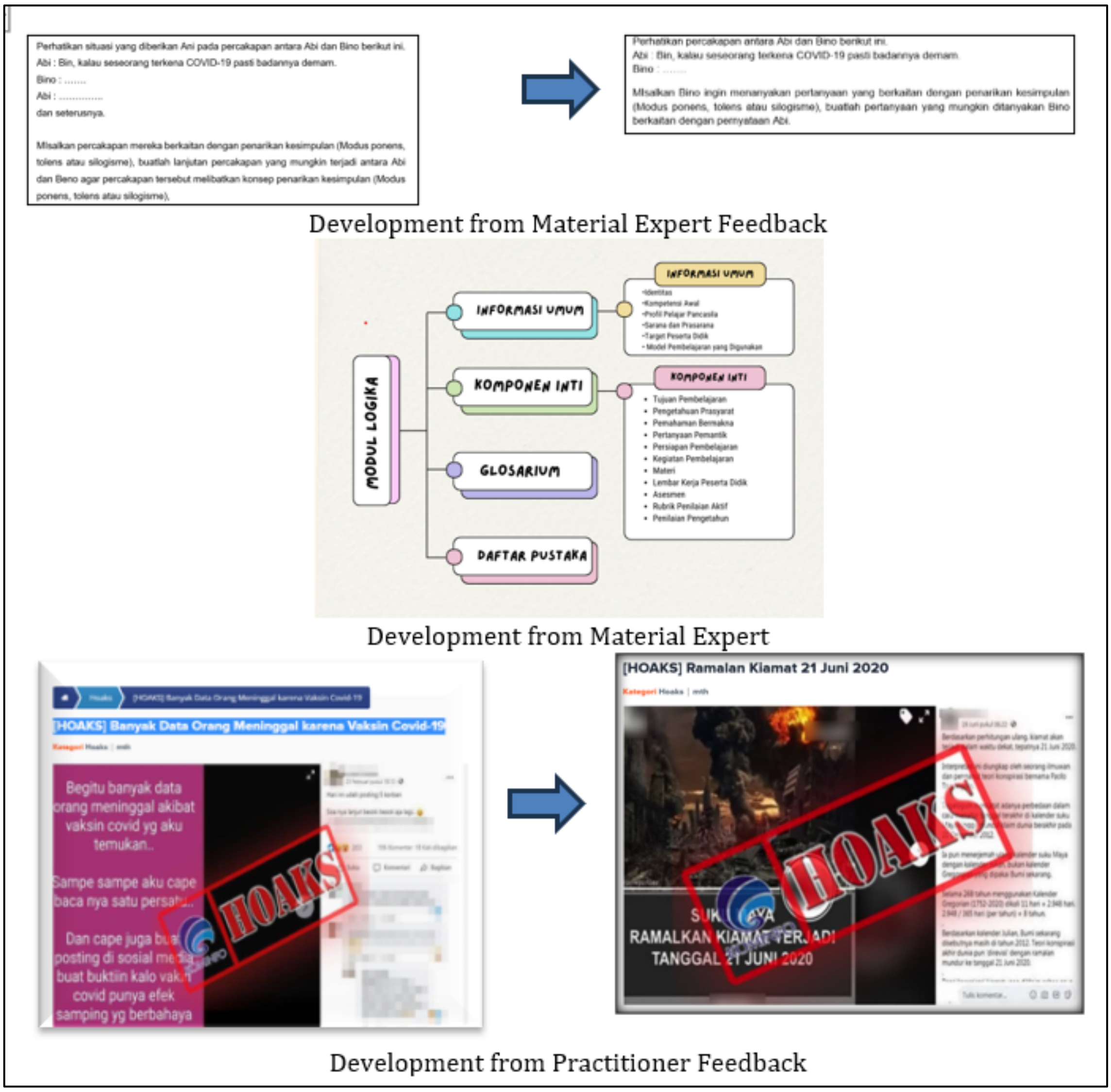


Figure 3. The modification of module from validator's suggestion

Field trials were conducted at SMKN 3 Mataram's Class XI Culinary Art class. Following that, teachers and students complete a questionnaire to provide feedback on areas of the module that may be improved. The average score from student feedbacks was 2,89. This indicates that the module is rated as good in Table 2. Meanwhile, 3.75 is the average score for teachers. According to Table 2, teacher classified this module as a very good module. As the responses from both teachers and students indicate that the module is excellent, it is prepared for dissemination stage.

Dissemination Stage

The disseminating stage involves final product improvement, outreach to the field, and actions to assess textbook effectiveness based on student results. The efficacy test was conducted at SMKN 3 Mataram using experiments. Class

XI Culinary Art I is an experimental class that uses textbooks and modules, while class XI Culinary Art II is a classroom setting. The comprehension test in the module was used to assess each class's critical thinking skills after they had studied in accordance with the experimental criteria. To analyze the result, the T-test was then used .

The following are specifics regarding the test's effectiveness result in both of the XI classes at SMKN 4 Mataram. First, tests of homogeneity and normality were run on the critical thinking skills data from both classes. Table 3, Table 4, and Table 5 present the findings.

Table 3. The Experiment Test Result's

	Shapiro-Wilk		
	Statistic	df	Sig.
Culinary Art I	.943	31	.100
Culinary Art II	.937	31	.070

The sig. values obtained are 0.100 and 0.070 based on Table 3 for Culinary Art I and II, respectively. Significance = 0.05 for both. Since sig values > 0.05, it indicated that critical thinking skills data in Culinary Art I and II were from a population that was normally distributed. Likewise, the independent T-test can be performed because both sets of data have a normal distribution.

The T test was conducted with the following assumptions: H_0 = the the were equivalent to those of the Culinary II class, and H_1 = the Culinary I class critical thinking skills outperformed the Culinary II class with $\alpha = 0.025$ is the significance chosen. Table 4 displays the outcomes of the independent T test.

Table 4. The independent t-test's result

		t	**df**	**Sig. (2-tailed)**
Culinary Art I_Culinary Art II	Equal variances assumed	3.922	64	.000
	Equal variances not assumed	3.858	55.832	.000

The sig (2-tailed) in Table 4 is 0.000. Given that the test is one-tailed and is based on the hypothesis, 0.000/2 = 0.0005 is the significance value that was employed. The significance value of 0.025 is exceeded by this sign. This indicates that H0 is rejected, which suggests that the Culinary Art Class I students have greater critical thinking skills than the Culinary Art Class II students. Thus, the module's effectiveness in enhancing students' critical thinking abilities may be concluded.

Discussion

The result showed that the module met the validity and effectiveness criteria. It implies that the module is able to be utilized by teacher in their lesson to enhance student critical thinking skill. The module featured the question related to student daily activities. This contextual condition helps student to enhance their critical thinking (Lestari et al., 2021; Toheri et al., 2020). Hence, the feedbacks from the practitioner to adjust the question about negation into the more contextual one could be one of the main factors to elevate the quality of this module.

Despite the validity of the module categorized as very good, there are still another aspect to revised from the module, such as the clarity of the language. The language aspect experiences the lowest score among other aspects at this module validity test. Language can become barrier to do evaluating as the factor of thinking critically. As Manalo and Sheppard (2016) state that the clarity of the instruction language in the question help student to demonstrate their critical thinking in their written work. The revision of the instruction language in the question could be one of the aspects to supports this module effectiveness.

The instructional materials, such as modules, are one of the aspects that affect how well students learn (Megayanti et al., 2020). The effectivenes of the modules studied in this study prove that statement. Modules become an creative method of instruction that can support students' success and produce superior results (Logan et al., 2021). Certain learning model which utilized module as their primary tools can enhance student outcomes like critical thinking (Hikayat et al., 2020; Retnowati et al., 2020).

After the module's effectiveness has been determined, the dissemination of this module was done thorough service activities with the community of math teachers at vocational schools around Mataram City, Indonesia. This activity enabling math teachers from other vocational schools in the city to utilize this module in their lessons.

Conclusion

The result analysis revealed that the mathematics module for the 11th grade of vocational school majoring in Culinary Art in Logic material satisfied the requirements for use in learning after it was evaluated by practitioners, media specialist, material specialist, students and teacher.

Recommendations

In this research, the module was construct based on culinary art student activity. The module can be changed by the teacher based on the environment and student conditions hence the question still contextual to student daily life. This also can be the next area of research to adjust the question about math logic according to student major in their vocational school.

Limitations of Study

This study was only done in culinary art student at SMKN 4 Mataram, Indonesia. Further dissemination at culinary art student in another province in Indonesia should be done to improve the effectiveness of this module.

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Mathematics Instructional Design/Teaching Practice Article

Enhancing digital security through randomized cryptology: a novel algorithm utilizing prime numbers, pi, linear encryption, and matrices

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Abstract

Recently, the widespread use of computer technology and the development of the internet have facilitated access to information. However, this has also increased the importance of information security. Public and private sector organizations need robust databases to protect their digital assets. For this reason, many security-oriented products and projects are being developed. Especially with the rapid progress of the internet age and the increasing importance of digital security, the field of cryptology has attracted great interest. Cryptology is the science of ciphers. The infrastructure of cryptology is based on mathematics. In order to ensure the security of information in the digital environment, a strong database is needed. This is achieved with strong encryption algorithms. Algorithms that incorporate the principle of randomness and allow repeating letters to take different values are stronger against external attacks. For these reasons, the aim of this study is to create a cryptology algorithm that is resistant to password cracking techniques, adopts the principle of randomness, contains mathematical formulas and has a decryption. In this study, prime numbers, pi number, linear encryption technique and matrices are used. In the encryption algorithm, it is aimed to adopt the principle of randomness with prime numbers and pi number. By using linear encryption technique and matrices, new sequence numbers of each letter were obtained, and it was aimed to strengthen against the frequency analysis method, which is one of the password cracking techniques, by ensuring that the repeating letters take different number values.

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Introduction

With the development of computer technology, access to information has become easier. However, this situation has brought along certain problems. One of these problems is the protection and secure transmission of information. For these reasons, one of the increasingly important branches of science is cryptology. Cryptology is the science of ciphers and is the transmission of various messages to the recipient in a secure environment by encrypting them with certain methods (Jones, 2005). Cryptology is divided into two sub-branches: cryptography and cryptanalysis (Figure 1). Cryptography is the process of encrypting public data by hiding it (Yılmaz, 2010). On the other hand, cryptanalysis is the process of converting encrypted data into original form (Buluş, 2006).

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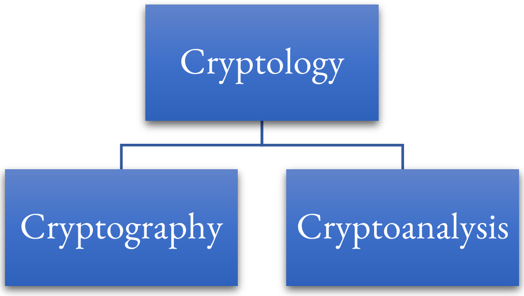

Figure 1. Sub-branches of cryptology

Various encryption methods have been used throughout history. Caesar, zigzag, vigenere, hill, stenagrofi, vernam, linear (affine) encryption are some of the methods used. Linear encryption is a technique applied by selecting (a,b) keys and creating a linear function of the type y=ax+b (mod n) (n being the number of letters in the alphabet). In this technique, the independent variable (x) is given the sequence numbers of the letters and new values (y) are obtained. The important point in this technique is that the numbers a and n must be prime (Mollin, 2007).

Various techniques are used to decrypt ciphertext. One of them is frequency analysis. In every language, each letter has a frequency of use. According to this method, the number of each letter in the cipher text is divided by the total number of letters. Thus, the cipher text is decrypted according to the frequency of letter usage in that language (Coşkun & Ülker, 2013).

Although cryptology seems to be a branch of science in itself, in fact, a large part of its infrastructure is mathematical science. Mathematical concepts such as number theory, prime numbers, matrices and modular arithmetic form the basis of cryptology. As a different teaching material, activities using various encryption techniques have been encountered in mathematics education in recent years (Bahadır & Özdemir, 2012; Chua, 2006; Güler, 2007; Katrancı & Özdemir, 2013; Özdemir & Erdoğan, 2011; Özdemir & Yıldız, 2012; Sahal & Özdemir, 2018; Welsh, 1988). With the developing technology, the security of information has gained importance. Public and private institutions want to have a strong database in order to survive safely in the digital environment. A strong database requires a strong encryption algorithm. In this direction, in this study, the following problem is sought by creating a cryptology algorithm.

- Can an algorithm be created that incorporates the principle of randomness?
- Can an algorithm be constructed that contains more than one mathematical concept and can be adapted to an encryption technique at the same time?

Purpose of the Instructional Activity

Recently, cryptology has emerged as a branch of science that attracts attention. The biggest reason for this is the rapid progress of the internet age and the increasing importance of digital security. For this reason, public and private institutions want to have a strong database in order to survive safely in the digital environment. The strength of encryption algorithms is that they are resistant to cyber-attacks. Every password is cracked sooner or later. The important thing is that this period is long. One of the criteria for a password to be strong is that it incorporates the principle of randomness. For these reasons, the aim of this study is to create a cryptology algorithm that is resistant to password cracking techniques, adopts the principle of randomness, contains mathematical formulas and has a decryption.

Structures of Math Teaching Practice

Information on the Teaching Activity

In this study, prime number, linear (affine) encryption technique, matrix, pi number are used. Pi and prime numbers are chosen because they are resistant to any cracking attacks since they do not have a specific order. The encryption algorithm consists of 4 steps.

Determination of New Sequence Numbers of Letters in the Alphabet Using Linear Encryption Technique

In order to apply the linear encryption technique, two primes (keys) are chosen and a function is created (f(x) = ax + b (mod 29), where a and b are the chosen primes and a<b). Then a character table is created. The table consists of 29 letters

and each letter is numbered starting from 1 (Table 1). For the text to be encrypted, new sequence numbers are determined according to the linear encryption technique using the sequence number of each letter.

For example, for the letter A, the new value f(1)= a.1+b (mod29) is found. Let the letters in the text to be encrypted be c, d, e, f, g, h. Let us consider the new number values as the numbers given in Table 2 by applying the linear encryption technique.

Table 1. Creating Characters and Determining Sequence Numbers

Letter	A	B	C	Ç	D	E	F	G	Ğ	H	I	İ	J	K	L
Sequence number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Letter	M	N	O	Ö	P	R	S	Ş	T	U	Ü	V	Y	Z	
Sequence number	16	17	18	19	20	21	22	23	24	25	26	27	28	29	

Table 2. New Sequence Numbers of Letters as an Example

Letter	c	d	e	f	g	h
New sequence numbers	5	7	8	9	10	12

Pi Number (π) and Writing the Message to be Sent as a Matrix

The new sequence number of the letter in each word in the message to be sent and the decimal parts of the number pi (π= 3,1415926535897932...) are written in separate matrices (starting from the left and writing from top to bottom) to form mx2 type matrices (m is the number of letters in each word). If there is a blank space in the matrix, zero is written and the result of the operation is determined as the new sequence numbers of the letters (Figure 2). For example, let the letters be c, d, e, f, g, h. The first 6 digits of pi after the comma are 1, 4, 1, 5, 9, 2. These values are written as a matrix and addition is performed (Figure 2).

$$\begin{matrix} 5 & 9 \\ 7 & 10 \\ 8 & 12 \end{matrix} + \begin{matrix} 1 & 5 \\ 4 & 9 \\ 1 & 2 \end{matrix} = \begin{matrix} 6 & 14 \\ 11 & 19 \\ 9 & 14 \end{matrix}$$

Figure 2. Writing as a Matrix

Table 3. New Values of Letters as a Result of Matrix Summation

Letter	**c**	**d**	**e**	**f**	**g**	**h**
New number value according to linear encryption method	5	7	8	9	10	12
Matrix sum result new sequence numbers	6	11	9	14	19	14
According to the matrix sum result, the new equivalents of the letters in the alphabet are	e	ı	ğ	k	ö	k

Sending the Message to the Recipient

For linear encryption, the key values and the ciphertext are written together and sent to the receiver. For example, let the key values be (2,3) and the ciphertext be e, ı, ğ, k, ö, k. To the receiver 2, 3 is transmitted as e, ı, ğ, k, ö, k. If there is more than one word, a comma is placed between the words.

Deciphering the Ciphertext (Deciphering)

The receiver first determines the key values. It then applies a linear encryption technique by substituting the key values for each letter and determines new sequence numbers for each letter. It determines the sequence numbers of the letters in the sent ciphertext from Table 2. Then, for each word, according to the number of letters, it writes the number values of pi after the comma as a matrix and performs subtraction. It decrypts the ciphertext by matching the result with the new sequence number of each letter.

Implementation of Math Teaching Practice

Example; Text to be encrypted: MUTLU

Switches: 2 and 3

Determination of New Sequence Numbers of Letters in the Alphabet Using Linear Encryption Technique

Text to be encrypted: "MUTLU" (Happy) (this word is chosen to show that although there are two letters u, they take different values). The prime numbers 2 and 3 (keys) are taken as the new sequence numbers of the letters. For example, if a linear encryption technique is applied for letter A, f(1)=2.1+3=5 and f(2)=2.2+3=7 for letter B.

Table 4. Application of Linear Encryption Technique to Letters

Letter	**A**	**B**	**C**	**Ç**	**D**	**E**	**F**	**G**	**Ğ**	**H**	**I**	**İ**	**J**	**K**	**L**
Sequence Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Linear encryption technique Application	5	7	9	11	13	15	17	19	21	23	25	27	29	2	4
Letter	**M**	**N**	**O**	**Ö**	**P**	**R**	**S**	**Ş**	**T**	**U**	**Ü**	**V**	**Y**	**Z**	
Sequence Number	16	17	18	19	20	21	22	23	24	25	26	27	28	29	
Linear encryption technique Application	6	8	10	12	14	16	18	20	22	24	26	28	1	3	

Table 5. Application Of Linear Encryption Technique To The Letters In The Word "MUTLU"(Happy)

For the letter M,	f(16)=2.16+3=35, 35=6 (mod29)
For the letter U,	f(25)=2.25+3=53, 53=24 (mod29)
For the letter T,	f(24)=2.24+3=51, 51=22 (mod29)
For the letter L,	f(15)=2.15+3=33, 33=4 (mod29)

Table 6. New sequence numbers of letters in the word "MUTLU" according to linear encryption technique

Letter	Sequence number	New sequence number
M	16	6
U	25	24
T	24	22
L	15	4
U	25	24

Pi Number (π) and Writing the Message to be Sent as a Matrix

With the new values of the letters, the decimal part of pi is written in the matrix and addition is done. In order not to leave any empty space in the matrix, 0 is written in the empty space.

$$\begin{matrix} 6 & 4 \\ 24 & 24 \\ 22 & 0 \end{matrix} + \begin{matrix} 1 & 5 \\ 4 & 9 \\ 1 & 2 \end{matrix} = \begin{matrix} 7 & 9 \\ 28 & 33 \\ 23 & 2 \end{matrix}$$

Figure 3. Matrix Addition of the Letters in the Word "MUTLU" and the Number Pi

Table 7. Matrix sum result new values of letters in the word "MUTLU"

M = 7	U = 28	T = 23	L = 9	U = 33	space = 2

Table 8. New alphabet correspondences of letters in the word "MUTLU"

M	U	T	L	U	Space
F	Y	Ş	Ğ	Ç	B

How to Send to the Recipient

2,3 FYŞĞÇB

Conclusion

In our encryption algorithm, prime numbers, linear encryption technique, matrix, pi number are used. In the algorithm, it is aimed to ensure the principle of randomness by using pi and prime numbers, which do not have a specific order. This will make the algorithm strong against external threats. By using linear encryption technique, the letters were given new sequence numbers and their order was changed. Thus, the algorithm was able to give new values to the new numbers of the letters by adding them with matrices. In this case, the numbers of the letters were removed from the regular formula structure. In addition, repetitive letters in the same word are given different number values to avoid letter repetition. The prime number (key) to be selected in each new message is changed. Thus, the linear encryption technique is strengthened against password cracking techniques such as frequency analysis by changing the sequence number of each letter. In this respect, it can be said to have a strong algorithm.

Limitations

In our encryption algorithm, linear encryption technique is used, but a new encryption algorithm can be created by using a different encryption technique instead. When creating encryption algorithms, care is usually taken to use prime numbers. This is because a strong encryption algorithm is more resistant to password cracking techniques if it has the principle of randomness. Therefore, different sequences of numbers can be used with no particular rule between them.

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Research Article

Reform and practice of higher mathematics teaching with outcome-based education concept

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Abstract

In order to gain a deeper understanding of the application effect of Outcome-Based Education (OBE) concept in higher education, this study chose the university's Higher Mathematics course as the research object. Take Finance Class 1 as the experimental group and Finance Class 2 as the control group, and randomly select 30 students from each class for the study. The independent sample t-test method was used for hypothesis testing, and normality and homogeneity of variance tests were used to make sure the reliability of the data and credibility of obtained results. These results show that the experimental group students have significantly higher grades than the control group, indicating that in the classes that adopt the OBE concept for teaching reform, students have achieved significant improvement in grades. This discovery not only validates the effectiveness of the OBE concept in the field of education, but also provides new ideas and methods for educational reform. By cultivating students' comprehensive qualities such as problem-solving ability, innovation ability, and teamwork skill, the OBE concept helps to improve their academic performance and promote their comprehensive development.

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Introduction

The Outcome Based Education (OBE) concept was first proposed by American educator William Spady in 1981. Compared to traditional teaching concepts, this teaching concept has advantages such as clear learning objectives, emphasis on practical applications, diverse evaluation methods, and student participation and feedback. By setting clear learning objectives, students are able to clarify their expected skills and knowledge levels. The focus is on practical applications, enabling students to utilize the knowledge they have learned to deal with real-world problems. Adopting diversified evaluation methods to gain a more comprehensive understanding of students' actual abilities. Encourage students to actively join in the learning process, develop problem-solving and creative thinking. At the same time, provide timely feedback to help students better understand their learning progress. This makes OBE teaching more adaptable to individual student differences, cultivates more comprehensive abilities, and has been applied in multiple disciplines, proving to be an effective method for educational reform (Mark, 2010; Thomas, 2008).

In recent years, there have been many practices regarding the OBE teaching philosophy, and many scholars have conducted research on its reform achievements. Liu W, Li W & Lu Y (2024) adhere to the OBE concept of engineering

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education, focus on cultivating the design ability of complex engineering control systems, and continuously carry out comprehensive reforms from the aspects of curriculum system optimization, teaching mode innovation, practical platform virtual and real collaboration, and ability goal achievement evaluation. They explore the interactive and exploratory teaching mode of BPS and CPS, which deeply integrates concepts, methods, and approaches. Lin P, Song S, & Fan J (2024) conducted teaching reform and practice on the course of Food Immunology based on the OBE teaching philosophy. Starting from the perspective of ideological and political education in the course, they regarded moral education and talent cultivation as the cornerstone of teaching reform. They explored and practiced teaching reform from the aspects of reorganizing teaching content, integrating theory and practice, improving teaching modes, strengthening teacher team construction, and combining various assessment methods. Wang et al. (2023) designed and practiced ideological and political case studies for university chemistry courses with the OBE concept, including design ideas, teaching goals, introduction design, and teaching processes. By conducting a questionnaire survey and comparing grades, a comparative evaluation was conducted between the experimental and control group of students. These results indicated that under the OBE concept, not only did students improve their course grades, but also developed their logical thinking ability and innovative consciousness, stimulating their interest in learning. Based on a questionnaire survey of seven universities in Shanghai, Hu M & Li L (2022) explored the impact mechanism of the interaction between various teaching stages under the OBE orientation on learning output from an empirical data analysis perspective. Their research results found that teaching objectives have a significant positive promoting effect on learning output, and teaching design plays a partial mediating role. Formative evaluation and summative evaluation positively regulate the relationship between teaching objectives and learning output. It also positively regulates the relationship between instructional design and learning outcomes. Zhang et al. (2021) constructed a comprehensive robot training teaching model reform based on OBE. By comparing the results before and after the reform, student grades significantly improved, and the number of learning outcomes such as winning works and applying for patents also increased significantly, confirming the effectiveness of OBE based reform.

Gurukkal (2020) refered to the potential of OBE in a larger global context, and higher education institutions must apply OBE education concepts to adapt to the ongoing economic revolution. In the classroom of learning English as a second language for chemical engineering students, the Pakistan Engineering Commission has started applying OBE in its affiliated engineering organizations during the undergraduate stage, using the quasi experimental approach to analyse the effectiveness of OBE. The experimental results show that students have improved their learning outcomes in terms of course content and skills (Yasmin & Yasmeen, 2021). Wang (2011) conducted in-depth research on the design as well as implementation of OBE in the context of Hong Kong, focusing on the gradual formal adoption of OBE by higher education institutions since 2006. Taking the Hong Kong Institute of Education as an example, the effectiveness of OBE was verified, and the challenges faced in implementing OBE were proposed at the end of the paper. Nopiah, Baharin & Razali (2021) used K-means clustering analysis to evaluate the practical achievements of OBE in engineering mathematics subjects, involving direct evaluation of data scores from final exams, quizzes, tests, and assignments and so on. The results showed that the average grades of the two departments studied were both above 3.5, and course outcomes of both institutions achieved over 70% in completing project outcomes, verifying the effectiveness of OBE. Overall, the research findings of scholars demonstrate the widespread practice of OBE teaching philosophy in different disciplines and national contexts, and emphasize its positive effects in improving student performance, cultivating practical application abilities, and innovation awareness.

Teaching Reform and Practice

Main problems in traditional teaching of higher mathematics

(1) The course content is abstract, complex, and highly theoretical. The abstract complexity and theoretical strength of higher mathematics courses are reflected in the depth and complexity of the many concepts and principles they cover. These abstract and complex contents require students to have high abstract thinking and logical reasoning abilities. However, these highly theoretical concepts lack intuitive practical application scenarios in the curriculum, making it difficult for students to intuitively connect abstract theories with practical problems.

(2) The evaluation method is fixed. The traditional evaluation method usually focuses on exams, focusing on testing students' memory and computational abilities of knowledge, but lacks the application and comprehensive consideration of practical understanding. The high-pressure examination environment may cause students to experience anxiety, affecting their normal performance and thus unable to demonstrate their true level of knowledge mastery (Molsbee & Benton, 2016). "Regular grades" is an effective reform of the traditional fixed evaluation method, covering the entire semester's learning process of students (Deng, 2020), but some universities have not effectively implemented it (Xiang, 2019).
(3) Lack of interaction and practical learning. Traditional teaching mainly relies on one-way teacher explanations and student acceptance, lacking interaction and cooperation among students. Students may have difficulty raising questions, sharing viewpoints, or engaging in in-depth discussions while passively receiving information. Interactive and practical learning are effective ways to cultivate practical skills (A1-Natour et al., 2021; Zhou & Huang, 2019), while traditional assessment methods focus more on testing the mastery and memory of knowledge, making it difficult to comprehensively cultivate the skills required by students in practical work.
(4) Lack of feedback mechanism. Traditional evaluation feedback is usually limited to simple scores or comments, and it takes a long time to provide in-depth and timely guidance, helping students understand the reasons for their mistakes or providing more specific academic advice. Interactive and practical learning are often accompanied by timely feedback, allowing students to stay informed of their learning progress and areas for improvement, in order to better adjust their learning strategies (A1-Natour et al., 2021).

Teaching Design Based on OBE Concept

To address this issue in traditional teaching of Higher Mathematics, we carry out teaching reform and practice based on the OBE concept. This concept is an educational method which emphasizes the actual ability development and learning outcomes of students. It focuses on ensuring that students can achieve established learning goals, rather than just focusing on the teaching process or knowledge transfer. The core philosophy of OBE includes setting clear learning objectives, student based assessment, emphasizing student participation, and continuous improvement. Through this approach, educators are committed to ensuring that students not only master knowledge, but also apply it, develop practical skills, cultivate problem-solving abilities and creative thinking during the learning process. The OBE teaching concept proposes three major teaching concepts: student-centered, results oriented, and continuous improvement (Steven et al., 2022).

We have applied the OBE teaching philosophy to higher mathematics education and carried out teaching reforms and practices as follows: (1) Clarify learning objectives. Set clear and quantifiable mathematical learning objectives, emphasizing the basic concepts, skills, and practical application scenarios that students need to master. (2) Design courses based on practical problems. Integrating theoretical knowledge of advanced mathematics with practical problems, designing course content that can stimulate students' interest and apply mathematics to practical situations. (3) Diversified evaluation methods. Introduce diversified evaluation methods, including project assignments, practical case analysis, group collaboration, etc., to comprehensively evaluate students' mathematical abilities and application levels. (4) Encourage students to actively participate. Make the students take part in the learning process actively and cultivate their problem-solving and teamwork abilities through discussions, experiments, group projects, and other means. (5) Provide real-time feedback. Establish a timely feedback mechanism, provide personalized and real-time feedback to students through regular evaluations and communication between students and teachers, and help them continuously improve their learning strategies. (6) Continuously improving the curriculum. Regularly evaluate and adjust teaching devices to admit the learning needs of students and the constantly changing educational environment, promoting continuous improvement and innovation in teaching.

Problem of Research

Considering the above description, we are trying to investigate the following problem:
Is the Higher Mathematics learning outcomes of students who have undergone OBE teaching philosophy reform better than those who have used traditional teaching methods?

Method

Research Model

This study belongs to the quasi experimental category. Students who have undergone the OBE teaching philosophy reform are selected as the experimental group, while students who have undergone traditional teaching methods are selected as the control group. This quasi experimental study connects these two groups of people, namely the experimental group and control group.

Participants

The research population consists of 211 students from Finance Class 1 and Finance Class 2 of Guangdong University of Finance and Economics. This study was conducted from September 2023 to January 2024, and random sampling technique was used for sample selection. Among them, Finance Class 1 underwent teaching reform on the OBE concept, and 30 students were randomly selected as the experimental group; Finance Class 2 did not undergo any teaching reform, and 30 students were randomly selected as the control group. Conduct post testing after the experiment.

Teaching evaluation

The course of Higher Mathematics adopts a combination of closed book examination (60%) and process based examination (40%) for assessment. The closed book exam is the final assessment, which includes all the knowledge covered in class, including single-choice questions, fill in the blank questions, and calculations, with moderate difficulty; The regular process assessment consists of student attendance (5%), course practical activities (5%), course assignments (5%), classroom open book quizzes (10%), and group cooperation projects (15%). The summary of the teaching evaluation system for Higher Mathematics is shown in Table 1, with a total score of 100 points.

Table 1. Teaching evaluation system for higher mathematics

Assessment items	Assessment process	Evaluation method	Proportion (%)
Assessment of Higher Mathematics	Formative assessment	Final exam	60%
	Summative assessment	Student attendance	5%
		Practical activities	5%
		Coursework	5%
		Classroom quiz	10%
		Group collaboration	15%

Data Analysis

The data of the scores in Higher Mathematics were tested after the experimental and control group conducted experiments. Use SPSS 27.0 software to conduct independent sample t-tests on the scores of the experimental group students and the control group students. Before conducting the t-test, it is necessary to perform normality and homogeneity of variance tests on the grades of each group of students respectively to prove the normality and consistency of variance of the sample.

Results

Post test experimental group data

After the teaching reform based on the OBE concept, the experimental group (Finance Class 1) conducted a post test to obtain the final assessment and evaluation of the course Higher Mathematics from 98 students in the experimental class. Then, random sampling technology was used to select the assessment and evaluation of 30 students for analysis. The descriptive statistics of the post test are shown in Table 2:

Table 2. Post-test experimental class

N	Min	Max	Mean	Std. Deviation
30	60.00	96.00	82.23	8.78

According to Table 2, the average score of the 30 experimental group students in the Higher Mathematics assessment was 82.23, with a maximum value of 96 and a minimum value of 60. The standard deviation of the data is 8.78.

To further analyze the distribution of the assessment scores, we have drawn the following group diagram based on the scores of experimental group students in Higher Mathematics.

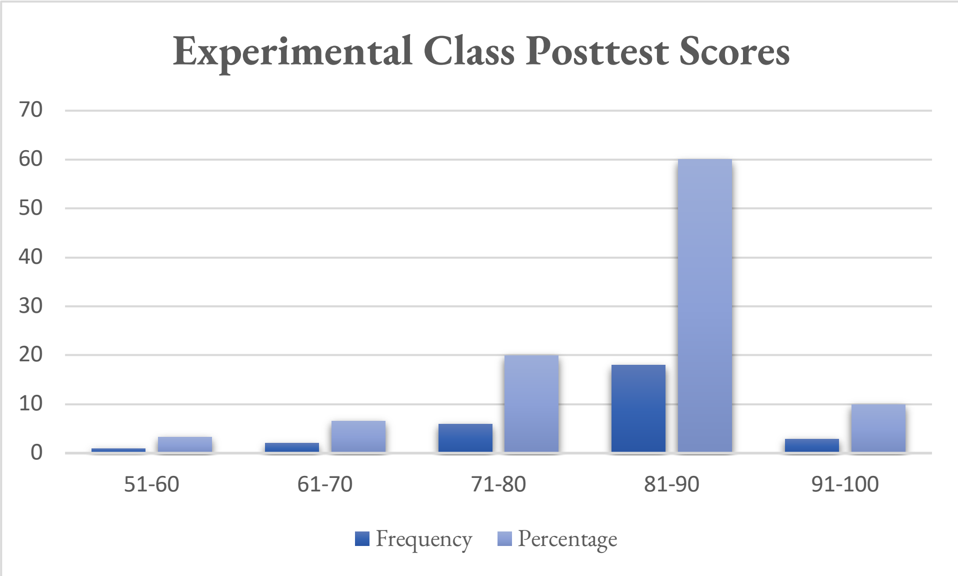

Figure 1. Scores distribution chart of experimental class

Post test control group data

The control group (Finance Class 2) underwent a post test after traditional teaching, and the same as the experimental group, 30 students were selected for analysis of their assessment and evaluation of Higher Mathematics. The descriptive statistics of the post test are shown in Table 3:

Table 3. Post-test Control Class

N	Min	Max	Mean	Std. Deviation
30	51.00	95.00	74.70	10.81

By Table 3, we know that the average score of the 30 control group students in the Higher Mathematics assessment was 74.70, with a maximum value of 95 and a minimum value of 51. The standard deviation of the data is 10.81.

To further analyze the distribution of grades among the control group students, we drew the following grouping chart based on their scores in Higher Mathematics.

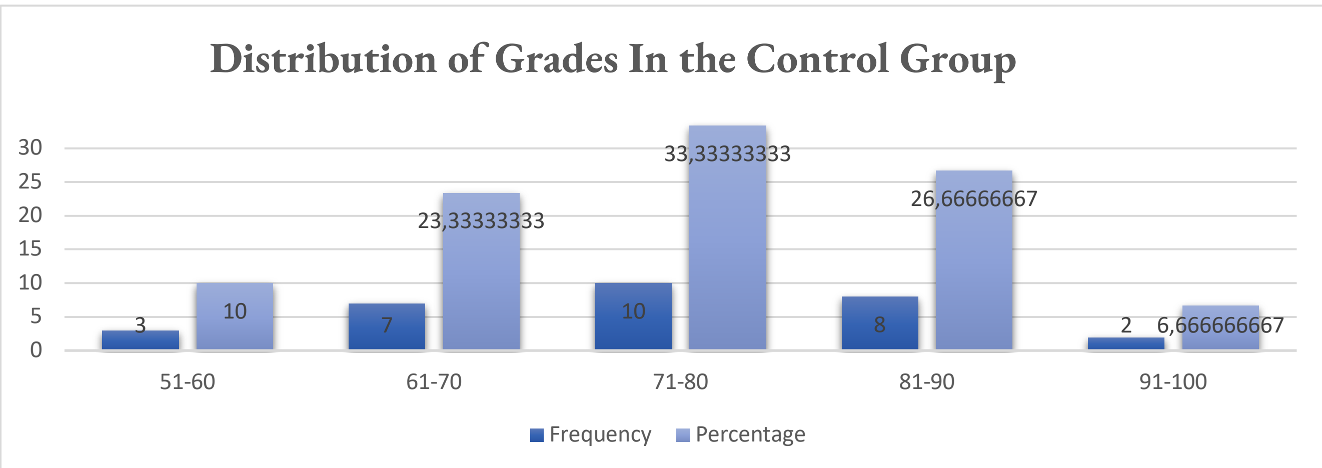

Figure 2. Scores distribution chart of control class

Comparison of results between the experimental group and the control group

Normality test

Before conducting independent sample t-tests, it is necessary for the samples to meet a normal distribution in order to obtain accurate results. If the data does not follow a normal distribution, it may lead to distorted hypothesis test results. Therefore, conducting normality tests before conducting hypothesis tests can ensure the effectiveness and accuracy of subsequent statistical methods (Yusof et al., 2020).

Among them, Kolmogorov Smirnov (K-S) normality test is to test whether the data conforms to a normal distribution by comparing the difference between the cumulative distribution function (CDF) of the sample data and the theoretical cumulative distribution function of the normal distribution. The results of K-S normality test are shown in Table 4 below.

Table 4. Normality test

	K-S Statistics	Df	P value
Experimental Group	0.156	30	0.059
Control Group	0.074	30	0.941

From the results, it can be seen that the significant values of the K-S normality test for both groups of students are greater than 0.05. Therefore, whether it is the experimental group or the control group of students, the results of the K-S normality test cannot reject the null hypothesis, and it can be considered that their scores conform to a normal distribution.

Test of homogeneity of variances

After conducting normality tests on two groups of students, the homogeneity of variance test is continued. The homogeneity of variance test is utilized to determine whether two samples come from populations with the same variance. Before conducting independent sample t-test, it is also necessary to conduct homogeneity of variance test because in independent sample t-test, it assumes that the variances of both groups of samples are the same. Levene's test of variance is based on the variance of sample data to evaluate the differences in variance between different groups or samples. It determines whether the variances of each group or sample are equal by comparing the differences between the data points of each group or sample and the mean of their respective group or sample. Table 5 shows the results of conducting homogeneity of variance tests on two groups of students.

Table 5. Test of homogeneity of variances

Levene Statistic	df1	df2	P value
1.388	1	60	0.244

From the results of the homogeneity of variance test, it can be seen that the significant value is 0.244, indicating that the null hypothesis cannot be rejected. It is believed that the scores of the experimental and control group students in Higher Mathematics are evenly distributed and have the same variance.

Hypothesis test

After passing two prerequisite tests, hypothesis testing can continue. This study adopts the independent sample t-test method to explore if the experimental group students have significantly improved scores in Higher Mathematics compared to the control group students.

Table 6. Independent sample t-test results

	Df	Mean Difference	t	P value
Equal variances assumed	58	7.533	2.961	0.004
Equal variances not assumed	56.989	7.533	2.961	0.004

According to Table 6, the probability significance value is less than 0.01, which means that the experimental group based on the OBE concept of Higher Mathematics teaching reform has significantly improved academic performance compared to the control group without reform.

Conclusion

The aim of this study is to demonstrate the impact of adopting the OBE concept in teaching reform of higher mathematics courses at Guangdong University of Finance and Economics on student performance. Under the premise of passing normality tests and homogeneity of variance tests, the experimental group (Finance Class 1) was compared with the control group (Finance Class 2), and the results showed that the students of experimental group had significantly higher grades than control group, further verifying the effectiveness of the OBE concept in educational practice.

The OBE concept emphasizes determining expected outcomes and using them as a guide to design courses and teaching methods, with a focus on student learning outcomes and practical applications. The results of this study indicate that in the experimental group that adopted the OBE concept for teaching reform, students achieved a significant improvement in their academic performance. This not only provides strong support for the practical application of the OBE concept in the field of education, but also provides new ideas and methods for educational reform.

The improvement in academic performance of the experimental group students not only means that they have achieved better results in higher mathematics courses, but more importantly, it reflects the improvement of their learning ability and practical application ability. Adopting the OBE concept for teaching reform can better cultivate students' comprehensive qualities, enabling them to have stronger problem-solving, innovation, and teamwork abilities, thereby better adapting to the development needs of future society.

Therefore, the results of this study not only have guiding significance for the educational practice of Guangdong University of Finance and Economics, but also provide useful insights for the educational reform of other universities. Adopting the OBE concept for teaching reform can effectively improve students' academic performance, promote their overall quality improvement, and lay a solid foundation for cultivating more high-quality talents. This will help promote the continuous development and progress of the education sector, and make positive contributions to promoting economic and social development.

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Research Article

Technology integrated learning optimization in calculus topic in the new normal era

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Abstract

The purpose of this research is to provide alternative mathematics learning facilitated by optimal use of technology to produce good student learning outcomes. Some of the technology-based media or platforms used in this research are WhatsApp Group, Google Meet, Pen Tablet, Screen Recorder, YouTube, and Learning Management System. This research is a descriptive case study that aims to be descriptive and provide a comprehensive picture related to technology-based mathematics learning in calculus course. The subjects in this research were 39 students of Informatics Engineering, University of Mataram, Semester I. The data obtained in this research were analyzed quantitatively using descriptive methods. Data on learning outcomes was obtained from tests that were carried out three times during lectures. The results showed that at the end of the lecture, the final score mean of students reached 80.40, with 100% of students meet the pass criteria. This shows that learning in calculus course by utilizing technology really helps lecturers and students optimize student learning outcomes.

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Introduction

The COVID-19 pandemic has an impact on the changes in human life activity, so that the new normal era occurs all over the world. The new normal era is a change in behavior in a society to keep on doing normal activities by implementing health protocols to prevent the spread of COVID-19. This change is happening in all sectors of life, including the education sector. The pandemic requires all educators and learners to adapt to new learning styles. So this contributes to the influence on learning in the new normal era. Nowadays the skills and needs of educators and learners in using technology are increasing.

Many of the advantages of learning using technology (Widianto, 2021), especially in mathematics learning, include providing students with the opportunity to learn independently, the time and place of learning are flexible, can be done anytime, anywhere, but with intermediaries using electronic media, enhancing the activity and creativity of learners in developing their ideas, and equipping learners with global knowledge. In addition, some of the principles of technology-integrated learning (Hadisi & Muna, 2015) are to enable the active participation of learners through interesting and meaningful learning, enable learners to incorporate new ideas, give the learners the opportunity to work in groups or societies, and allow students to actively and enthusiastically strive to what they want. Additionally, several studies have

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also shown that technology-based media can facilitate effective mathematics learning (Salsabila et al., 2022; Salsabila & Setyaningrum, 2020).

One of the mathematics course that can be maximized with the help of technology is calculus. Calculus is one of the cross-course in the field of mathematics that must be completed by students of S1 Engineering Informatics University of Mataram. The calculus course at University of Mataram consists of several topics, such as Logic and Set; Sequences and Series; Matrix and System of Linear Equations; System of Real Numbers; Functions and Graphs; Limits and Continuity; Derivatives; and Integrals. Calculus is one of the courses to enhance predictive skill and is necessary as it is a way to further enhance deductive reasoning (Mutakin, 2015). Besides, mathematics is also known for its hierarchical matters and for producing efficient language, which engineering students are in great need of.

Several previous studies have been conducted to optimize calculus learning using technology. Maskar & Dewi, (2020) stated that the GeoGebra-assisted online calculus material could be implemented as an alternative to calculus learning. The media used consists of GeoGebra, videos from YouTube, Latex Online usage, and online evaluations such as quizzes or online tests in real-time. Then animation-based teaching materials with contextual approaches and local wisdom are able to attract student interest in learning calculus (Novianti & Shodikin, 2018). Students responded positively to the material with criteria very well seen in terms of material content, graphic-animation and readability. Moreover, the use of ICT (Information and Communication Technologies) based student worksheets can be effectively used in further calculus learning (Wahyuni & Kurniawan, 2019). Based on these findings, it can be seen that technology has a lot of positive impact on learning in the classroom.

One of the differences between this research and previous studies lies in the technology platforms used during the learning process. The platforms used in this study include WhatsApp, YouTube, Google Meet, Pen Tablet, Screen Recorder, and Learning Management System. The advantage of using these platforms is that both lecturers and students are very familiar with them. For example, the WhatsApp application is used daily by lecturers and students, especially in Indonesia, as a communication tool. Additionally, YouTube is a very familiar site for both lecturers and students to access. Similarly, Google Meet has been frequently used for learning purposes during the pandemic. It can be said that lecturers and students can easily use these various technology platforms, which positively impacts the learning process.

Optimizing the use of technology in learning at the teaching level in a particular calculus course can make learning more effective and efficient. This research aims to provide a mathematical learning alternative that facilitates the optimum use of technology to generate a good output of student learning. It can be a reference for educators when applying technology-based learning in the classroom.

Method

Research Model

This research is a descriptive case study that aims to make descriptives and provide comprehensive insights related to technology-based mathematical learning in calculus course. The calculus course carried out in this research is technology-based using several platforms namely WhatsApp Group, Google Meet, Pen Tablet, Screen Recorder, YouTube, and Learning Management System of University of Mataram.

Here are some of the topics taught in the calculus course.

- Logic and Set
- Sequences and Series
- Matrix and System of Linear Equations
- Real Number System
- Functions and Graphics
- Limit and Continuity
- Derivatives
- Integral

Participants

The subject of the research in this study is a student of Engineering Informatics University of Mataram Semester I of 39 students. The students consist of 26 male students and 13 female students. The students who were the subjects of this research were enrolled in a calculus course, which is a mandatory course. Additionally, the students were already accustomed to using the technological tools employed in this research.

Data Collection Tools & Process

The data collection techniques used in this research were documentation and testing. The documentation technique was employed to gather data related to the implementation of the calculus course that optimizes the use of technology. Meanwhile, the testing technique was used to collect data on students' learning outcomes after attending the course. The research instrument used to collect data on learning outcomes was a test on calculus material. The learning outcome test was created in the form of essays. This test was given during exams that were conducted three times throughout the course. The test data obtained in this research were analyzed quantitatively using descriptive methods. The division of topics for each calculus exam is as follows.

Table 1. The distribution of topic on the calculus exam

Exam	Topic
1st Exam	Logic and Set; Sequences and Series; Matrix and System of Linear Equations; Real Number System
2nd Exam	Functions and Graphics; Limit and Continuity
3rd Exam	Derivatives; Integral

Examination 1 consists of 5 questions, examination 2 of 6 questions, and examination 3 of 6 questions. Some examples of questions given at the time of examination in the calculus course are as follows.

Example of the 1st exam question:

Ms. Tika borrowed money of Rp.700,000,- from Ms. Risma. Ms. Risa asked Ms.Tika to pay the monthly debt of Rp.52,000, Rp.50,000, Rp.48,000, Rp.46,000, and so on. Mrs. Tika was asked to start paying the amount in October 2022. Determine in which month and year Mrs. Tika last deferred the debt to pay off.

Example of the 2nd exam question:

- Given $f(x) = \frac{4x}{(x^2-8)}$ and $g(x) = \sqrt{2x}$. Find the domain of $(f \circ g)(x)$.
- $\lim_{x\to 1} \frac{x^2+ux-x-u}{x^2+2x-3} = \cdots$

Example of the 3rd exam question:

- Given $f(x) = ax^2 - 4x + 1$ and $g(x) = 3x^2 + ax + 2$. If $h(x) = f(x) + g(x)$ and $k(x) = f(x)g(x)$; $h'^{(0)} = -3$, find $k'(0)$.
- $\int \frac{-16-6x^4}{x^2} dx = \cdots$

This research was conducted during a calculus course over one semester. The course spanned 4 months with a total of 16 sessions, comprising 13 sessions for learning activities and 3 sessions for exams. Some of the learning sessions were conducted both offline or online, utilizing various platforms such as WhatsApp Group, Google Meet, Pen Tablet, Screen Recorder, YouTube, and the Learning Management System of the University of Mataram. Exams, however, were conducted offline.

Results and Discussion

Some media or technology-based platforms used in this course are WhatsApp Group, Google Meet, Pen Tablet, Screen Recorder, YouTube, and Learning Management System of University of Mataram. Here is an explanation of the various uses of such applications or media in learning.

WhatsApp Group

WhatsApp Group is used to communicate with students related to course information. Besides, the WhatsApp Group is also used during classes, both offline and online. During the student practice, the lecturer instructed the students to share their answers in the form of photos in the WhatsApp Group. This can help to make learning more effective and efficient. Compared to pre-pandemic learning, teachers and students never used the WhatsApp Group as a learning platform. Then when exercising, students usually write their answers on a board. Sometimes it takes not a minute if the answers are written long enough. If you use WhatsApp Group, students can share their answers quickly, so the time spent is more efficient. All students in the classroom can also observe the answers shared in the WhatsApp Group and provide responses in person. Students have no difficulty following these instructions because there is wifi on campus that can be used by students to share answers.

Here's a screenshot showing the student's activity during the exercise on the topic where they shared their answers via the WhatsApp Group.

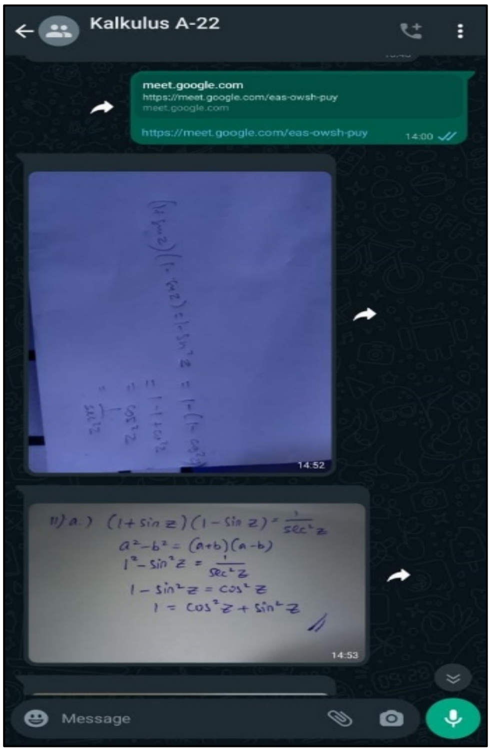

Figure 1. Student answers shared on Whatsapp groups

Google Meet

Google Meet is used when lectures are conducted online. Submission and discussion of material is carried out through Google Meet. Then, during the practice, students share their answers in the form of photos on WhatsApp Group, which can be followed by lecturers and other students. In this way, students can get feedback directly related to their answers even though learning is not carried out face-to-face.

Here's a screenshot of one of the activities at the Google Meet that took place in the calculus course.

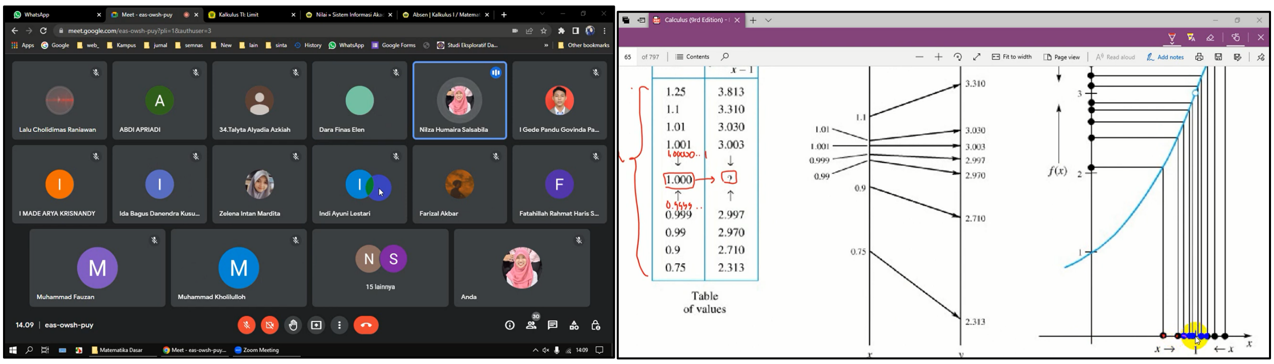

Figure 2. Calculus course through google meet

Pen Tablet, Screen Recorder, and YouTube

One of the technology media used in this course is the pen tablet. Pen Tablet is used by the instructor to facilitate the lecturer when presenting the material through the projector. Then, the screen recorder is used to record the screen of the laptop instructor when presenting the material. The results of the recordings were uploaded to YouTube so that students could re-examine the material delivered through the recordings.

Here's a screenshot of the playlist of the calculus course recordings on the YouTube platform.

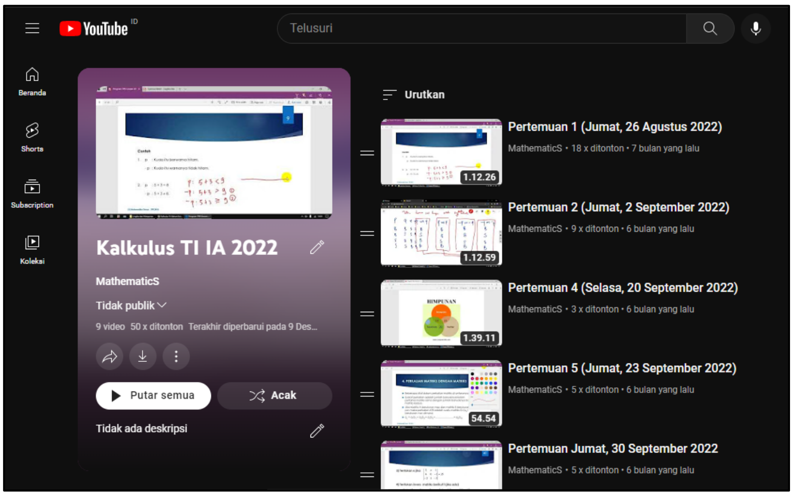

Figure 3. Playlist of calculus course recordings on Youtube

Learning Management System

The Learning Management System (LMS) used during learning activities is the LMS of the University of Mataram. In this course, the LMS forum was used to share course material, Google Meet link, and YouTube playlist link containing course recordings. In addition, LMS is used to distribute tasks to students and place students to gather answers. Students can also discuss their assignment answers asynchronously in LMS. Here are examples of assignments given to students through the LMS.

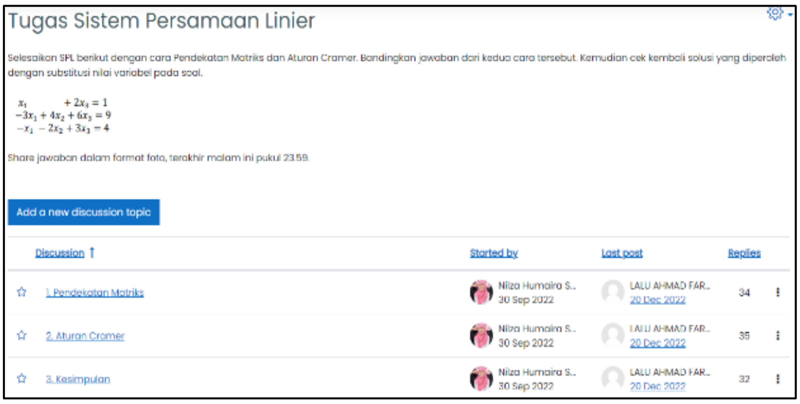

Figure 4. Delivery of duties at University of Mataram LMS

Student Learning Outcomes

The student's study results are obtained from the examinations carried out three times during the course. The examination is done offline so that the lecturer can more easily monitor the examination process. The score for the minimum completeness criteria is 64.

Table 2. Calculus course exam scores

1st Exam	Mean and Scores
Mean	73.38
Minimum Score	18
Maximum Score	100
Students with a score > 64	27 (69%)
2nd Exam	
Mean	84.59
Minimum Score	30
Maximum Score	100
Students with a score > 64	37 (95%)
3rd Exam	
Mean	83.23
Minimum Score	55
Maximum Score	100
Students with a score > 64	34 (87%)
Final Score Mean	**80.40**
Passing Students	**100%**

From the table above it can be said that the student's learning outcomes based on their exam scores yield a good output. Most students score above 64, which is the minimum grade of pass. It also appears that students who score more than 64 on the 1st exam get the lowest percentage. However, on the next exam, the student's score increases so the pass rate also increases. At the end of the class, the average final score of students was 80.40 with 100% of students meeting the pass criteria.

In this research, using the WhatsApp Group as a platform for lecturer and students to exchange important information related to course can make the information delivered to students quickly. It is known that the WhatsApp app is one of the applications that are widely used by Indonesian society. In addition, students who share their answers in WhatsApp Groups can help make learning more practical. In-class learning also does not spend much time just writing on a board. All students can also clearly see every answer shared in the WhatsApp Group. Lecturer can respond directly to students' answers when learning, both online and offline.

The practicality experienced by lecturer and students in learning while using the WhatsApp Group can optimize learning in the classroom. More time is available for lecturer and students to discuss the answers that have been shared on the WhatsApp group. This has an impact on student activity and learning outcomes that are increasingly optimum (Apsari et al., 2020).

Then the use of Google Meet in learning helps lecturer and students to keep learning online. The use of synchronous Google Meet can help students to stay active in learning. This condition will affect the student's learning outcomes. Previous research by Mudijono & Azis (2022) explained that college-level math learning using Google Meet can improve student learning outcomes.

The pen tablet used by the lecturer in learning, is very helpful in presenting the material in increasing detail. The lecturer can directly write a description of the material through a laptop screen recording. All the activities in the classroom, both material explanations and discussions are well recorded. Unlike the usual use of a board, the description of material using a board has shortcomings, one of which is that the lecturer is unable to record directly the material presented and discussed. In this calculus course, the use of whiteboard is minimized, while the technology in the classroom is optimized.

The recording of the lesson material shared on YouTube is very helpful to students in reviewing the material they have already obtained in the classroom. These advantages can help students to improve their learning outcomes. The use of YouTube as a learning tool has proven to be effective, demonstrated by the difference in average learning outcomes before and after using YouTube media, it shows that YouTube media use has an impact on student learning outcomes (Julianingsih & Widayanti, 2021).

The Learning Management System provided at University of Mataram also plays an important role in learning in the classroom. Lecturer can give a task to a student through a forum in the LMS. Besides, the collection of tasks is also through forums in the LMS. The student's task answers files can be assembled well, unlike collecting tasks by assembling the answer sheets. Student answer sheets will be more easily scattered. Lecturer will also make it easier to evaluate students by checking the student's task data available in the LMS.

In addition, through LMS students can also discuss asynchronously related to assigned tasks. Advantages of asynchronous learning, students can study anytime and anywhere with the conditions and speed of each student's learning (Darma et al., 2020). This discussion activity will help them build knowledge related to material calculus. Through that, students' learning outcomes will be improved.

Regarding the difficulties of this research, there is one minor obstacle during the learning process using technology. Some students experienced problems in the form of unstable internet connections when participating in learning activities via Google Meet. Unstable internet connection can affect the quality of mathematics learning, because students may lose access to classes or important material taught online (Dhawan, 2020). Apart from that, this causes student engagement in learning will decrease (Adnan & Anwar, 2020) and prevents students from participating actively (Huang et al., 2020).

One way to overcome these challenges is for lecturer to provide recordings of their learning activities during Google Meet sessions, captured using a screen recording application. Then students can access the recording on YouTube. Students who may have missed out on fully participating in the live Google Meet sessions can review the material presented by the lecturer in these recordings. Lecture recordings offer flexibility for students to access the content anytime and from anywhere, allowing them to revisit specific materials as needed (O'Callaghan et al., 2017). Additionally, the learning trail on WhatsApp Groups, where students share their answers during practice exercises, also helps students review missed materials when internet connectivity is inadequate.

Conclusion and Recommendations

Learning mathematics, especially calculus course, by using technology greatly helps lecturers and students to optimize the output of learning. In the new normal era, lecturers and students are becoming more skilled in using technology due to the demands of learning the effects of pandemics. The ability to use this technology needs to continue to beined, even improved to help the learning process of teaching in the classroom. The use of technology can make learning more effective and efficient.

Suggestions for further research, learning by optimizing the use of technology can be applied to other courses, besides calculus, and can be applied to students in different departments. Then the technology used in learning can also be added or replaced with another technology, the newest technology, to maximize the learning process. The campus can also make policies related to learning on campus which must utilize the latest technology in the learning process.

Limitations of Study

The research that has been carried out is only limited to calculus course and research subjects of Engineering Informatics students at the University of Mataram. The technology platforms used are also limited to WhatsApp Group, Google Meet, Pen Tablet, Screen Recorder, YouTube, and Learning Management System of the University of Mataram.

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