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The Development of RBL-STEM Learning Materials to Improve Students' Conjecture Thinking Skills in Solving the Antimagic Rainbow Coloring Problem in Greenhouse using Artificial Neural Networks

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Abstract

Learning materials are instruments or equipment used to carry out learning activities. Learning tools serve as guidance during teaching and learning, whether in the classroom, laboratory, or outside the class. This research aims to determine the validity, practicality, and effectiveness of the developed learning tools. This development research refers to the Thiagarajan model (4D), which includes the stages of defining, designing, developing, and disseminating. The developed teaching materials have met the criteria for validity, practicality, and effectiveness. The validity scores obtained for each tool are 3.6 for RTM, 3.5 for LKM, and 3.6 for THB. Practicality scores were obtained from observations of the implementation of learning, resulting in a score of 3.8 with a percentage of 94%, indicating that the learning was well-implemented. Based on the test results, the researcher found that 19 students scored above 60, which means that 83% of the students in this class have completed the course and met one of the effectiveness criteria.

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Keywords: RBL-STEM, Learning Materials, Antimagic Rainbow coloring, Conjecture Skills, Greenhouse, Artificial Neural Networks

Introduction

Learning devices are tools or equipment used to support learning activities, including the syllabus, Semester Learning Plan (RPS), Student Task Design (RTM), Student Worksheets (LKM), Conjecture Thinking Skills Test (CTS test), and observation sheets. The learning devices used must be appropriate for the learning objectives. Therefore, the development of learning devices is essential to meet the availability of materials according to curriculum demands, characteristics, objectives, and problem-solving requirements (Depdiknas, 2008). Research-based learning is a learning model that is associated with activities of analysis, synthesis, and evaluation, as well as enhancing the abilities of students and lecturers in terms of assimilation and application of knowledge (Mursyidah *et al*., 2023).

A conjecture is a statement that has not yet been mathematically proven, but has empirical evidence in the form of cases and examples (Junizon *et al*., 2017). One study related to conjecture is about students' cognitive processes in constructing mathematical conjectures (Wayan Puja Astawa *et al*., 2018). According to (Supriani & Sholahudin, 2019), in mathematics teaching, the skill of formulating mathematical conjectures is a requirement that must be applied in learning so that students can have the ability and apply it in daily life and improve learning outcomes. Therefore, to support students' conjecture skills, there is a need for a learning device that can support the success of the learning process.

Mathematics has many branches of study that can be applied in daily life, one of which is graph theory. Graphs were first introduced by Leonhard Euler, a Swiss mathematician who discussed graphs to solve problems in the city of Konigsberg. Euler's discussion of graphs invited many scientists to develop it further, one of which is the antimagic rainbow coloring. Dafik *et al*. (2021) defined antimagic rainbow coloring as a combination of two graph concepts, rainbow coloring, and antimagic labeling. The problem in graph theory, especially in solving the antimagic rainbow coloring problem, requires fairly complex skills. Therefore, the development of a learning device is needed to facilitate students, by developing the RBL-STEM learning device to improve students' conjecture thinking skills in solving antimagic rainbow coloring problems in greenhouse agriculture with artificial neural networks.

The problem in graph theory, especially in the problem of antimagic rainbow coloring, requires quite complex skills, so the development of a learning tool is needed to facilitate students, namely by developing a learning tool that can improve students' conjectural skills with the RBL-STEM approach in solving the problem of antimagic rainbow coloring and its application in greenhouse agriculture with artificial neural networks.

Research Methodology

The stages used in this research refer to Thiagarajan's development model, namely the 4D-Model which consists of the stages of defining, designing, developing, and disseminating. (Hobri, 2021).

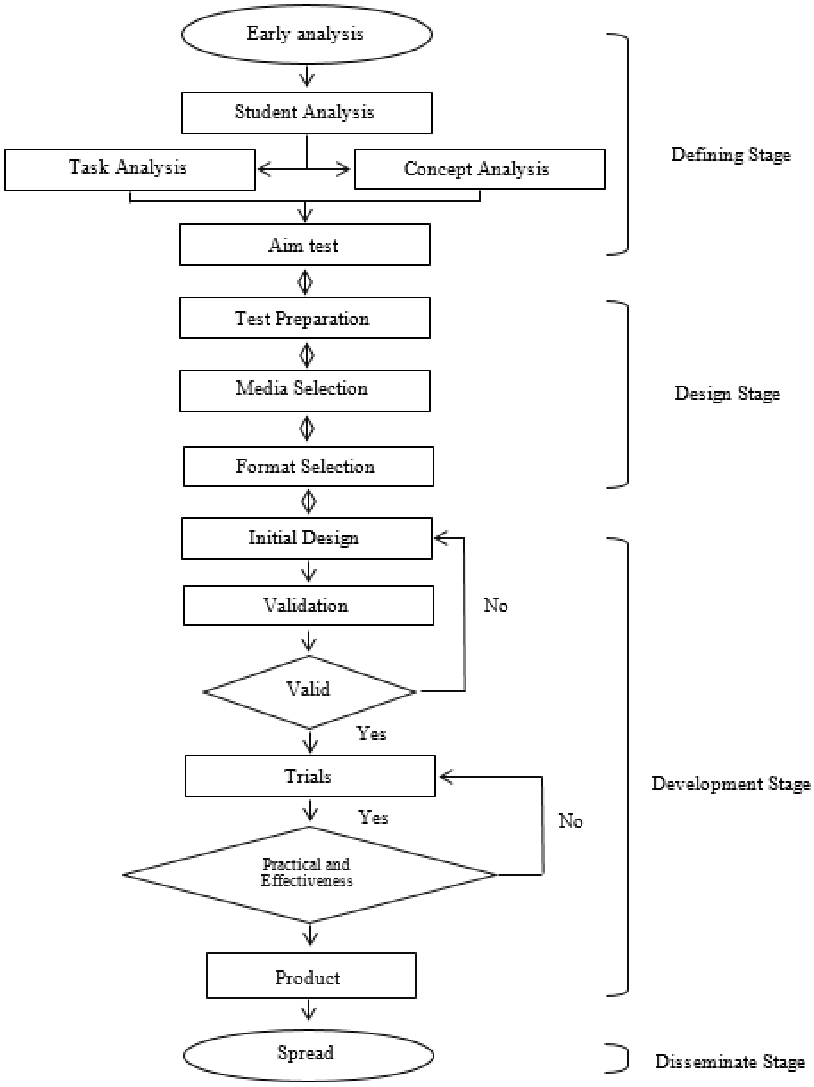

Fig 1: The scheme of developing 4-D model learning tools.

Result and Discussion

Stem Components

This research utilizes a research-based learning model with a STEM approach so that students can learn and develop knowledge and skills in Science, Technology, Engineering, and Mathematics. STEM explanation is as follows: (1) Science, students are expected to understand the presented problem regarding the placement of plant species and soil moisture to determine plants that potentially require little or much water. (2) Technology, students are expected to use the internet to search for definitions and solutions to the provided problems. Moreover, students can search and learn about the latest studies on the topic of antimagic rainbow coloring. (3) In Engineering, students are expected to develop the antimagic rainbow coloring topic in several graphs and solve the problem of the placement of plant species. (4) Mathematics, students can apply the concept of antimagic rainbow coloring in several graphs and form a graph of a plant, starting by labeling the points of the graph and calculating the weight of each point's side in the graph.

The problem faced by most residents relates to irrigation or watering for irrigating agricultural land. In irrigation areas, several problems often arise during the irrigation process, from the water intake point to the distribution to agricultural plots. In the modern world, there are many irrigation models that humans can use, one of which is the green house irrigation system. If water availability is insufficient, it can hinder agricultural productivity, leading to lower agricultural yields. To overcome this problem, a solution that can be used is by using the concept of a magical rainbow coloring to determine the placement of plant types as well as to know the watering time for the plants..

Science	*Technology*	*Engineering*	*Mathematics*
Soil moisture analysis.	Matlab software, Microsoft Excel, Arduino, ThingSpeak, and ThingView.	To determine the placement of plant types using the concept of anti-magic rainbow coloring.	Testing the effectiveness of using anti-magic rainbow coloring for plant type placement using mathematical algorithms.

Fig 2: STEM elements in the presented problems.

The expected outcome of the research based on the presented problem is to determine the soil moisture and plant placement based on the edge weight so that the automatic watering time of plants can be known. The placement of plants is adjusted according to the edge weight produced by the addition of two adjacent points. The research, which employs a research-based learning model with a STEM approach, uses the following stages: (a) Identifying problems related to plants that potentially require little or much water; (b) Obtaining breakthroughs using neural network graphs and the concept of antimagic rainbow coloring; (c) Collecting data to be used in solving the presented problem; (d) Developing plant placement based on the concept of antimagic rainbow coloring; (e) Testing the resulting plant placement; (f) Reporting research results and observing the conjecture skills of students.

The stages used in this research refer to the development of Thiagarajan's 4D-Model, which consists of the stages of defining, designing, developing, and disseminating. The defining stage starts with the initial-final analysis, where the selected topic is local antimagic rainbow coloring because antimagic rainbow coloring is a new topic that needs to be developed. Solving this problem requires students to be active and creative so that they can find the expected coloring patterns. This is followed by an analysis of the students' characteristics aimed at obtaining data on the characteristics of S1 Mathematics Education students at the FKIP University of Jember. Next, concept analysis is carried out, which is then concluded with a task analysis to identify the students' conjecture skills.

The learning tools created are Student Task Design (RTM) and Student Worksheet (LKM). RTM is designed based on the topic of antimagic rainbow coloring and a research-based learning model with a STEM approach. The student worksheet learning tools contain STEM problems, namely soil moisture and plant placement problems, by determining the edge weights presented in the LKM. Then, from the first problem discovered by the students, it is represented in the form of a graph. In addition, students also determine the use of colors on the graph representation image to determine edge weights using the concept of antimagic rainbow coloring. The next learning tool is the Learning Outcome Test, where the test results are used to measure the combinatorial ability of students by conducting pre-tests and post-tests individually.

Fig 3: The initial design of LKM and THB

The next stage is development, where all the developed learning tools are validated by validators. Overall, based on the assessment of both validators, all learning tools in the form of RTM, LKS, and THB can be used with minor revisions.

Instrument Validation

A tool is considered valid if it meets the score of 3.25 ≤ Va < 4. Based on the recapitulation of RTM validation results, the average validation score is 3.6, with a percentage of 90%. Based on the validity criteria, the developed RTM meets the validity criteria as it meets the score of 3.25≤V_a<4. The recapitulation of RTM validation results is presented in Table 2.

Table 1: Validation Recapitulation of RTM

Rated aspect	Average score	Average percentage
Format	3.5	88%
Content	3.75	94%
Language and writing	3.5	88%
The average score of all aspects	3.6	90%

Based on the validation recapitulation results of the RTM presented in Table 1, the average validation score is 3.6, with a percentage of 90%. According to the validity criteria, the developed RTM meets the validity criteria because it meets the score of 3.25≤V_a<4. The validation recapitulation results of the LKM are presented in Table 2.

Table 2: Validation Recapitulation of LKM.

Rated aspect	Average score	Average percentage
Format	3.5	88%
Content	3.4	85%
Language and writing	3.5	88%
The average score of all aspects	3.5	87%

Based on the validation recapitulation of LKM in Table 2, the average validation score is 3.5, with a percentage of 87%. According to the validity criteria, the LKM developed is considered valid because it meets the score of $3.25 \leq V_a < 4$. The validation recapitulation of THB is presented in Table 3.

Table 3: Validation Recapitulation of THB.

Rated aspect	Average score	Average percentage
Format	3.5	88%
Content	3.6	89%
Language and writing	3.7	92%
The average score of all aspects	3.6	89%

Based on the validation summary of THB in Table 4.13, the average validation score is 3.6, with a percentage of 89%. Based on the validity criteria in Chapter 3, the THB developed meets the validity criteria because it meets the score of $3.25 \leq V_a < 4$.

Partiality Test

The practicality of this learning tool was analyzed by observing student learning activities and teacher activities during the learning process. Classroom learning activities were observed by five observers selected from master's students in mathematics education, with an overall average score of 3.8 and a percentage of 94%. Based on the criteria for the quality of learning tools, a tool is considered practical if the observation results achieve a score of 80% ≤ SR < 90%, and it is considered very practical if the observation results achieve a score of 90% ≤ SR ≤ 100%. Therefore, it can be concluded that the developed tool based on observation results meets the criteria for being very practical. The detailed average scores obtained are presented in Table 4.

Table 4: The result of student activity observation.

No	Rated aspects	Observer 1	2	3	4	5	Average	Percentage
1. Syntax								
1.	The overall level of implementation of the learning stages.	4	4	4	4	3	3.8	95%
2.	The implementation of the sequence of learning activities reflects research-based learning oriented towards conjecture skills.	4	4	3	4	4	3.8	95%
2. Social System								
1.	The level of implementation of the desired situation (group formation, discussion, questioning, debating, presenting opinions, respecting each other while working).	4	3	4	4	4	3.8	95%
2.	The level of implementation of interactions in learning (between students and between students and lecturers).	4	3	3	4	4	3.6	90%
3.	The implementation of the lecturer's behavior in realizing principles and concepts of combinatorics in research-based learning.	3	4	4	3	4	3.6	90%
3. Principles of reaction and management								
1.	The implementation of teachers accommodating and providing opportunities for students to ask questions, present opinions, and respond.	4	4	4	4	4	4	100%
2.	The level of implementation of the lecturer's behavior in providing assistance, guidance, and mentoring to students in learning.	4	3	3	3	4	3.4	85%
3.	The level of implementation of the lecturer's behavior in motivating learning.	4	4	4	4	4	4	100%
4.	The level of implementation of the teacher's behavior in actively involving students in learning.	4	4	4	4	4	4	100%
5.	The level of implementation of the lecturer in facilitating student learning.	3	4	3	4	4	3.6	90%
Overall average score							3.8	
Percentage of overall average score							94%	

Effectiveness Test

The effectiveness of the developed learning tool is seen from the completion of the student learning outcomes test. There were 23 students as research subjects, with 19 completing the test individually and four students not completing it. If presented in percentage, 83% of the students passed and met one of the criteria for a tool to be considered effective. Therefore, it can be concluded that the developed tool is effective.

Then, an analysis of student activities was conducted. Based on the analysis of student activity data, a percentage of 93% of student activity was obtained. Therefore, based on the criteria of observation data on student activity, the students meet the criteria of being very active. Based on this, it means that two out of three criteria for an effective learning tool have been fulfilled. The summary of student activity observation sheets based on the obtained data is presented in Table 5.

Table 5: Summary of Student Activity Observation Sheet

No	Rated aspects	Observer					Average	Percentage
		1	2	3	4	5		
	1. Introduction							
1.	Students have attention and motivation toward the presentation of learning objectives.	4	4	4	3	3	3.6	90%
2.	Students listen to the lecturer's explanation regarding the material to be studied.	4	3	3	4	3	3.4	85%
	2. Core Activities							
1.	Students form a group.	4	4	4	4	4	4	100%
2.	Students have attention and motivation towards the presentation of research journal references.	3	3	3	4	4	3.4	85%
3.	Students collect data through discussions.	4	4	4	3	4	3.8	95%
4.	The students present the data obtained in the LKM.	4	4	4	4	4	4	100%
5.	The students analyze the data obtained in the LKM.	4	4	3	4	4	3.8	95%
6.	The students present the results of the discussion.	4	3	4	3	4	3.6	90%
7.	Students participate in pre-test and post-test enthusiastically.	4	4	4	4	4	4	100%
	3. Closing							
1.	The students can conclude the learning activities.	3	4	3	4	3	3.4	85%
	Overall average score						3.7	
	Percentage of overall average score						93%	

Next, an analysis of the student questionnaire data recapitulation was carried out, which showed that the lowest positive response, with a percentage of 83% was located in the question about the learning atmosphere and teaching methods because the teaching methods were already usual and the learning atmosphere was a bit passive through zoom meetings. Furthermore, the highest positive response was found in the item on the novelty of the LKM tool. This was because the topics discussed in LKM were relatively new for the students of the Mathematics Education Study Program at the Faculty of Teacher Training and Education of Jember University, namely antimagic rainbow coloring and artificial neural networks. Overall, the average percentage of positive responses to questions was 91%, while the negative percentage was 9%. This indicates that the majority of students gave positive responses to the learning and tools presented. This means that all three criteria for an effective learning tool have been met. Based on the student responses in the questionnaire, the score recapitulation of student responses is presented in Table 6.

Table 6: The Data Recapitulation of Student Response Questionnaire Results

No	Rated aspects	Number of Answers		Percentage Answer	
		Yes	No	Yes	No
1.	Do you feel happy about the following learning components?				
	Learning materials	22	1	96%	4%
	Students worksheets (LKM)	22	1	96%	4%
	Learning atmosphere	20	3	87%	13%
	Teaching method	22	1	96%	4%
2.	Are the following components of learning new?				
	Learning materials	22	2	96%	9%
	Students worksheets (LKM)	21	2	91%	9%
	Learning atmosphere	19	4	83%	17%
	Teaching method	19	4	83%	17%
3.	Are you interested in participating in this learning?	21	2	91%	9%
4.	Can you clearly understand the language used in :				
	Students worksheets (LKM)	21	2	91%	9%
	Last research test questions sheet	22	1	96%	4%
5.	Can you understand the meaning of each question/problem presented in :				
	Students worksheets (LKM)	21	2	91%	9%
	Last research test questions sheet	22	1	96%	4%
6.	Are you interested in the appearance (writing, images, and layout) of :				
	Students worksheets (LKM)	21	2	91%	9%
	Last research test questions sheet	20	3	87%	13%
7.	Do you enjoy discussing with group members to solve problems by exchanging	21	2	91%	9%
	Average	21	2	91%	9%

Based on the three criteria above, it can be concluded that the developed learning tool can be classified as valid, practical, and effective.

Paired sample t-test

The last stage is the dissemination stage, which applies the developed learning tool on a larger scale, such as in a class that has not been tested or in other universities by different lecturers. The dissemination stage was carried out in the Combinatorics course. The following is a description of the application of the learning tool in the class.

The analysis of the learning tool implementation was conducted using a paired sample t-test, which compared the pre-test and post-test scores to determine the effect of the learning tool implementation. The pre-test and post-test scores can be seen in Figure 4.

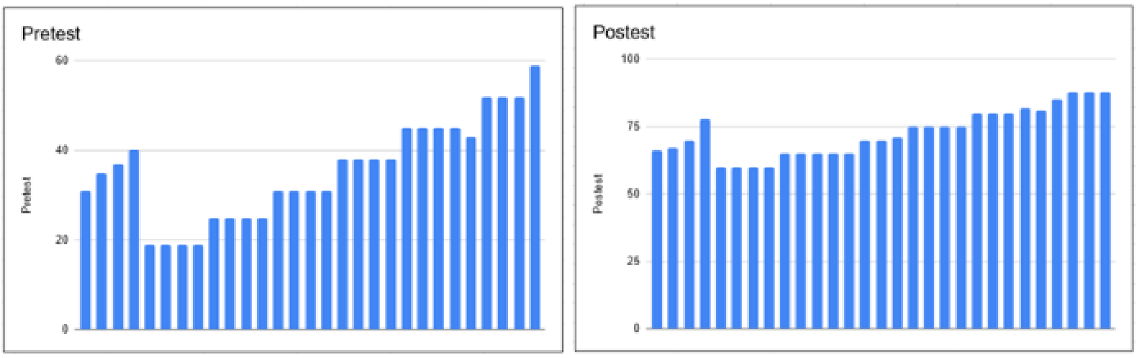

Fig 4: Translated to English: Pretest Score (left) and Posttest Score (right).

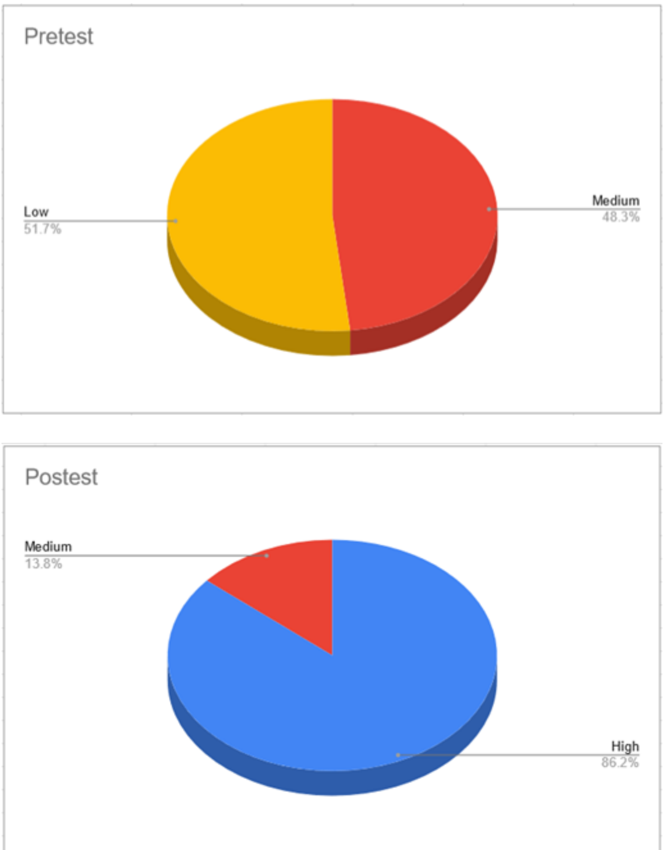

Fig 5: Percentage of Students' Conjecture Thinking Skill Levels

Based on Figure 5, it can be seen that there are two levels of conjecture thinking skills when students were working on the pre-test, namely the medium level, with a percentage of 48.3%, and the low level, with a percentage of 51.7%. In addition, there are two levels of conjecture thinking skills when students were working on the post-test, namely the high level, with a percentage of 86.2%, and the medium level, with a percentage of 13.8%.

The next step is to test the normality of the pre-test and post-test values. The normality test is conducted using an online available R application. After the normality test, a p-value of 0.07 was obtained, indicating that the data is normally distributed. The normality test results can be seen in Figure 6.

statistic	p.value	method	data.name
0.93	0.07	Shapiro-Wilk normality test	datasetInput()[, input$var.y]
0.93	0.07	Shapiro-Wilk normality test	datasetInput()[, input$var.y]

Fig 6: The result of the Normality Test

```
Uji-T 2-Kelompok Berpasangan: Data= IMPOR Y1= Pretest Y2= Postest

        Paired t-test

data:  datasetInput()[, input$var.yt2p1] and datasetInput()[, input$var.yt2p2]
t = -64.742, df = 28, p-value < 2.2e-16
alternative hypothesis: true mean difference is not equal to 0
95 percent confidence interval:
 -38.27738 -35.92952
sample estimates:
mean difference
      -37.10345
```

Fig 7: Result of Paired Sample T Test

After the data was declared normal, the next statistical test conducted was a paired sample t-test using the R application. The result of the paired sample t-test in Figure 7 shows that the obtained p-value is $22{,}2 \times 10^{-16}$. A p-value < 0.05 indicates that there is a significant difference between the pre-test and post-test scores. In addition, the decision-making for the hypothesis can be seen from the value of the t-test. In Figure 7, it is known that the value of the t-test is -64.742. The negative value of the t-test is that the pre-test scores were lower than the post-test scores. In this case, the negative t-test value can have a positive meaning. Thus, the t-test value becomes 64.742. The value of the t-table is known to be 2.04. Since the t-test value is greater than the t-table value, it can be concluded that there is a significant difference between the pre-test and post-test scores. Therefore, it can be concluded that there is an effect of research-based learning device implementation with STEM applications.

Discussion

The developed tool is a research-based mathematics learning tool with a STEM approach to enhance students' conjecture skills in analyzing the rainbow coloring of non-magical irrigation network problems based on artificial neural networks. The developed tool has been validated by two validators and tested in a trial class. The validation results meet the validity, practicality, and effectiveness criteria. The tool has met the validity criteria with a range of $3{,}25 \leq Va < 4$, and the validators' suggestions did not change the tool as a whole, but only a small part. The validity scores obtained for each tool are 3.6 for RTM (valid), 3.5 for LKM (valid), and 3.6 for THB (valid).

The developed mathematics learning tool based on STEM approach research to improve students' conjecture skills in analyzing non-magic rainbow coloring in solving neural network-based irrigation problems has also met the criteria of practicality, where the suggestions from practitioners only made minor changes to the tool. The observation score of the learning implementation resulted in 3.8 with a percentage of 94%, indicating that the learning was carried out very well. In addition to being valid and practical, the tool also meets the effectiveness criteria. The average score of the students in the trial class belongs to students who passed, and the student's response is positive. Based on the test results, the researcher obtained 19 students who scored above 60. This means that 83% of the students in this class have passed and met one of the effectiveness criteria. The student response questionnaire also provided more positive responses than negative ones.

The research results were tested using a two-sample T-test, obtaining a p-value of$0{,}1168 > 0{,}05$. Therefore, it can be concluded that in the pre-test scores, there is no significant difference between the control class and the experimental class. However, in the post-test results, there is a significant difference between the control class and the experimental class, as the p-value is $0{,}01026 < 0{,}05$. Hence, it can be concluded that the use of the device in the experimental class can significantly improve students' conjecture skills.

The research-based learning model is recommended for implementation in education to generate higher student motivation and improve learning outcomes, as well as to enable students to apply their learning in real-life situations. When applied in the classroom, research-based learning can produce students who are more active, creative, and capable of critical thinking compared to those using conventional learning methods. This is in line with a study conducted by Suntusia (2019), who explained that learning in a conventional classroom tends to make students passive and lacks the drive to develop their potential.

Conclusion

The developed tool that meets the validity criteria was tested in a trial class. The validity score obtained for each tool was 3.6 for the student task plan (RTM), 3.5 for the student worksheet (LKM), and 3.6 for the learning outcomes test (THB). The observation result for the implementation of the learning process scored 3.8, with a percentage of 94%. Besides being valid and practical, the tool also meets the effectiveness criteria. On average, 97% of students in the trial class belong to students who passed and had a positive response. Based on the test results, the researcher found 19 students who scored above 60. This means that 83% of students in this class have passed and met one of the effectiveness criteria. The student response questionnaire also received more positive responses than negative ones.

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