RESEARCH ARTICLE

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The Development of RBL-STEM Learning Materials to Improve Students' Combinatorial Thinking Skills in Solving Local (a, d)-edge Antimagic Coloring Problems for Line Motif Batik Design

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ABSTRACT

Combinatorials require critical thinking procedures and convincing reasoning in the problem-solving process. Indicators of the combinatorial skills include identifying some cases, recognizing patterns from all cases, generalizing all cases, proving mathematically, and considering with other combinatorial problems. To apply higher-order thinking skills, we apply research-based learning with a STEM approach. To develop student combinatorials, educators must also equip the learning process with teaching materials. This research develops RBL learning materials with a STEM approach to improve students' combinatorial skills. The teaching materials that developed have met the criteria of valid, effective, and practical. The validity scores that obtained on each device were 3.66 for RTM, 3.53 for MFI, and 3.69 for THB. The observation results of learning implementation were 3.79 with a percentage of 94.75%, and student responses were 97% positive so that they met practical criteria. Based on the test results, researchers found that 82.75% of students were complete so that they met the effective criteria.

Keywords: combinatorial thinking skills, Line Motif Batik design, local (a, d)-edge antimagic coloring, RBL-STEM learning materials.

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I. Introduction

Combinatorial thinking skills is one of the abilities in cognitive development at a formal operational stage characterized by students being able to consider a whole alternative possible way of solving in certain situations (Widiyastuti& Holy, 2017). Whereas (Dafik 2018) says that combinatorics is one of the fields of mathematics that relate to calculations, both as a means and an end in obtaining results and characterization of properties of finite structures. Lockwood (in Jean, 2022) explains that the process of counting is a simple example of combinatorial thinking. The model of combinatorial thinking skills consists of three components, namely the process of counting, the formulation of problems, and the final result. Dafik (in Anggraeni *et al.*, 2019) specify five indicators of combinatorial thinking skills including identifying some cases, recognizing patterns from all cases, generalizing all cases, proving mathematically and considering with other combinatorial problems.

The learning model used in the application of this Combinatorial is Research-Based Learning (RBL) with a STEM approach. RBL is research-based learning, research-based learning is a learning model associated with various activities such as analyzing, synthesizing, and evaluating, as well as enabling students and educators to improve the assimilation and application of knowledge (Susiani *et al.*, 2018).

STEM is a learning approach that motivates students to come up with mind-on and hand-on-learning through the problem-solving process (Gita *et al.*, 2021). STEM integration is defined as a combination of science, technology, engineering, and mathematics (Ridlo, 2020). STEM education also aims to build an understanding of STEM literacy which refers to an individual's thinking to apply four interrelated domains (Fathoni *et al.*, 2020).

Mathematics is a knowledge that covers various things, one of which is graph theory. Graph theory first became known through a problem about the Königsberg bridge that was solved by the Swiss mathematician Leonhard Euler. Graph is a discrete structure consisting of a set of objects called vertices and sides that connect existing nodes (Chartrand &Leisnak, 1986). Many topics are studied in graph theory, including local coloring (a, d)-antimagic side.

Coloring is said to be the locale (a, d)-antimagic side of the graph G if the set of side colors forms an arithmetic sequence with the value of begin with *a* and the difference with *d*.

Problems in graph theory, especially in the problem of local (a, d)-edge antimagic coloring side in solving it require quite complex skills so that the development of learning materials that can facilitate students is needed, namely by developing learning materials that can improve students' combinatorial skills with the RBL-STEM approach in solving local coloring problems (a, d) −antiajaib side and its application to line motif batik design.

II. METHOD

The stages that are used in this study refer to the development of the Thiagarajan 4-D Model which consists of the defining stage, the design stage, the development stage, and the dissemination stage.

The data that was obtained from the observation of student activities during the learning process were statistically tested using parametric statistical tests. The statistical test in this study used R-Shiny software through a learning center and a virtual statistics laboratory that can be accessed through the http://statslab-rshiny.fmipa.unej.ac.id/RProg/BasicStat/, website, which was built by Tirta (2016).There are two variables in this study, namely the free variable and the bound variable. The free variables tested are research-based learning materials with STEM approach, while the bound variables are students' combinatorial skills. Furthermore, paired sample t-test was carried out on pre-test and post-test results. The Thiagarajan 4-D model learning device development scheme can be seen in Fig. 1.

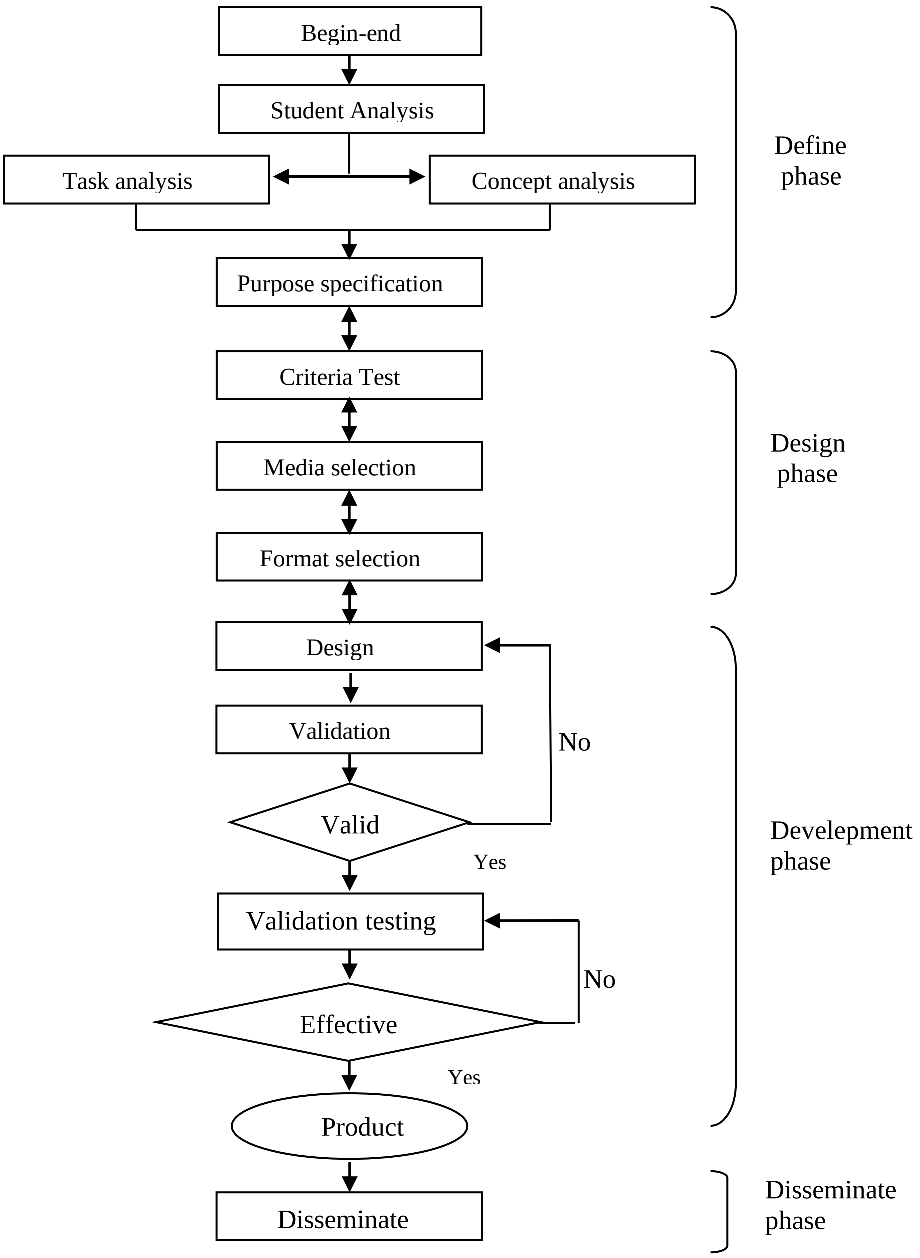


Fig. 1. 4-D model learning device development scheme.

III. FINDINGS

This research uses a research-based learning model with a STEM approach so that students can learn and develop knowledge and skills in the fields of Science, Technology, Engineering, and Mathematics.

STEM explanation is as follows: (1) Science, students are expected to understand the problems of batik design of line motifs, analyze the layout of batik motif designs on fabrics and pay attention to the use of colors, so as to create good and attractive colors. (2) Technology, students are expected to use a web browser to identify the concept of local (a, d)-edge antimagic coloring and disjoint union concepts, use the site, sciencedirect and others to find the latest studies related to concepts, and utilize GeoGebra Classic Fx Draw and Corel Draw Software to draw graphs on batik design of line motifs. (3) Develop techniques and apply the concept of local (a, d)-edge antimagic coloring based on the concept of disjoint union, from the graph algorithm in developing the batik design problem of line motifs. (4) Mathematics, students are expected to develop local number functions (a, d)-edge antimagic coloring based on the disjoint union concept online motif batik design problems, determine the basic design of batik based on graph representation, and determine coloring based on the side weight of the graph that has been obtained.

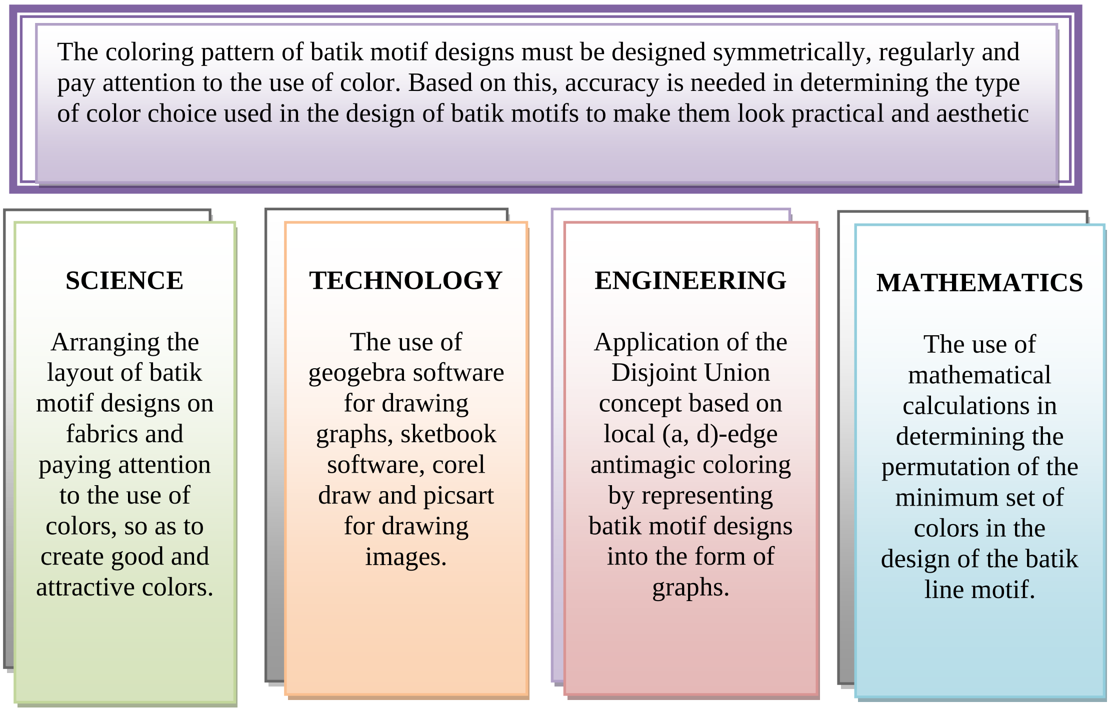


Fig. 2. STEM aspect in research

RBL-STEM-based worksheets can facilitate students in analyzing and implementing local (a, d)-edge antimagic coloring studies for coloring determination in line motif batik design. The purpose of the local (a, d)-edge antimagic coloring concept is to add beauty and harmony of colors and color patterns that can later be developed by forming a consistent coloring pattern in order to obtain strategic location points and be able to use the most minimum color. Students can test the results obtained using the concept of local (a, d)-edge antimagic coloring can be tested in general. Students can also determine the set of points, side sets, labeling functions, and local side weights (a, d)-edge antimagic coloring functions on a graph. So that the learning in this research, namely research-based learning with STEM approach, allows students to develop knowledge and skills in the following fields of Science, Technology, Engineering, and Mathematics. Stage science students raise fundamental problems relating to the design of batik line motifs where students must determine the layout and coloring of each motif in order to create beautiful and efficient color combinations. Second stage *(technique)*, were students develop breakthroughs regarding problem solving is given using coloring techniques as well as to improve students' combinatorial skills. Students previously identified a simple type of graph for coloring. The third stage (technology), students are introduced to the use of geogebra software in solving the problem of batik design of line motifs. The fourth stage is Mathematics-Engineering, the construction of a theorem on the topic of local (a, d)-edge antimagic coloring on previously undiscovered graphs. The fifth stage is mathematics, where students conduct trials on the coloring, they have obtained to prove the accuracy of the solution. The sixth stage is the report stage where students make presentations related to solving the problem of batik design with line motifs. A detailed STEM-based RBL integration framework can be seen in Fig. 2.

The expected result in this research from the problem presented is the creation of a coloring that can later be developed by forming a consistent coloring pattern and conform the concept of local (a, d)-edge antimagic coloring based on disjoint union to add beauty and color harmony.

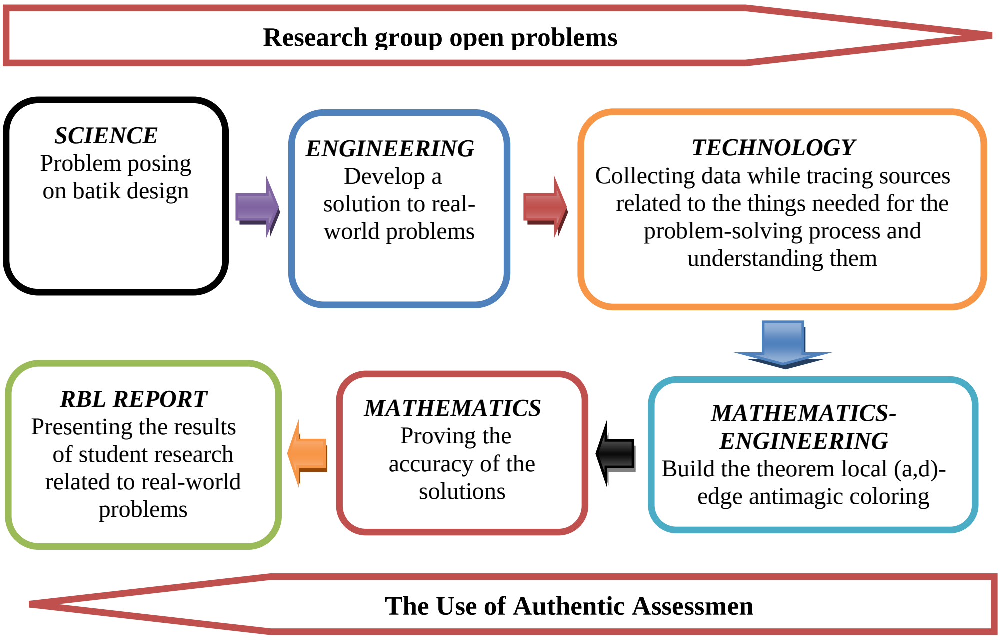


Fig. 3. RBL-STEM Stages.

Therefore, the RBL-STEM model shows in Fig. 3 will perform the following stages (1) Posing problems on several problems, (2) Developing solutions to real-world problems, (3) Collecting data while tracing sources related to things needed for the problem-solving process and understanding them, (4) Building theorems on the topic, (5) Proving the accuracy of the solution, (6) Presenting the results of student research that relate to real-world problems.

The stages of device development consist in defining, designing, developing and disseminating. The defining stage begins with analysis (beginning-end) where the selected topic is local (a, d)-edge antimagic coloring because local (a, d) −edge antimagic coloring is a new topic so it needs to be developed. Solving this problem requires students to be active and creative so that students can find the expected coloring patterns. Then continued with student analysis which aims to obtain data on the characteristics of S1 Mathematics Education students FKIP Jember University. Furthermore, a concept analysis is carried out, then ends with an analysis of tasks to identify students' combinatorial skills.

The learning materials that were created are RTM, MFI and THB. RTM is organized based on local (a, d)-edge antimagic coloring topics, and research-based learning models with a STEM approach. The student worksheet learning materials contains STEM problems, namely the problem of batik design of line motifs, by determining the main motif of the line batik design that has been presented at the MFI then from the main motif that has been found by students represented in the form of a graph. In addition, students also determine the use of color in the main design of batik using the concept of local (a, d)-edge antimagic coloring. The next learning materials is the learning outcomes test, where the results of this test are used to measure students' combinatorial abilities by conducting pre-tests and post-tests individually.

The defining stage is a preliminary study that aims to establish a preliminary design and establish the conditions needed in learning by analyzing the limitations and objectives of a material to be developed. There are five steps in the defining stage, namely start-to-end analysis, student analysis, concept analysis, and task analysis.

Stage (beginning-end) has the aim of establishing and bringing up the basic problems needed in the development of learning materials so that they can give rise to alternative learning materials that are expected. The results of the analysis show that students have difficulty in understanding the concept of local coloring (a, d)-edge antimagic coloring. Students have difficulty in determining local chromatic numbers (a, d)-edge antimagic coloring.Therefore, in order for students to understand the concept, students are required to have independence in constructing their own knowledge, the learning model used is the RBL-STEM learning model so that students more understand the concept that being studied.The STEM approach is used so that students can make relate of local (a, d)-edge antimagic coloring problems with daily life problems that related to four disciplines, namely: Science, Technology, Engineering, & Mathematics.

Student Analysis, in this study, student analysis was carried out on FKIP Mathematics Education students in the 3rd semester labeling class. Student analysis aims to find out in detail the characteristics of students and it is important to do because it is to find out the level of student skills, cognitive aspects, and other aspects so that consideration is obtained in developing learning materials that are in accordance with student characteristics. The learning activities carried out centered on students' combinatorial skills in solving local (a, d)-edge antimagic coloring problems using the RBL-STEM learning model. In solving problems, students are required to be active in learning activities and combinatorial thinking in solving given problems.

Concept Analysis, this step aims to identify and systematically compile the concepts that will be taught to students based on the initial analysis that has been carried out. Based on the results of the initial analysis, the end of the analysis of the concept of local (a, d)-edge antimagic coloring can be seen in Fig. 4.

Task analysis, task analysis is carried out to provide an overview of the assignments to be given to students. In this study, the task given was in the form of a problem of coloring batik design with line motifs that apply the concept of graph coloring. Students are expected to find different color combinations for each motif in order to create an attractive design and then find the function formula and its representation in other forms.

The next stage is development, all devices that are developed are validated by validators, namely lecturers of the Mathematics Education study program FKIP Jember University. In general, based on the assessment of the two validators, all learning materials in the form of RTM, LKM, and THB can be used with a little revision. Cover LKM and THB can be seen in Fig. 5.

A device is said to be valid if it meets a score of $3,25 \leq V_a < 4$. All results from the device validity assessment data are calculated based on the average of each aspect of the indicator value which will be followed by the determination of the validity criteria of the learning device. Here are the steps in determining the average score of the total of all aspects of the validity of the learning devic.

First. Recapitulate validity data which includes aspects (A_i), indicators (I_i) and values (V_a), then determine and calculate the average values of all validators for each indicator using the formula:

$$I_i \frac{\sum_j^n V_i^j}{n} \qquad (1)$$

where:
V_i^j – Value of the validator to-j for the indicator to-i
n – The number of validators

Calculate the average of the values for each aspect with the formula:

$$A_k \frac{\sum_i^{m_k} I_i}{m_k} \qquad (2)$$

where:
A_k – average value of k aspect
m_k – The multiplicity of indicators in the$-k$ aspect

Calculating the average of values from all aspects with the formula:

$$V_a \frac{\sum_{k=1}^{p} A_k}{p} \qquad (3)$$

where:
V_a – average total score of all aspects
p – The multiplicity of aspect

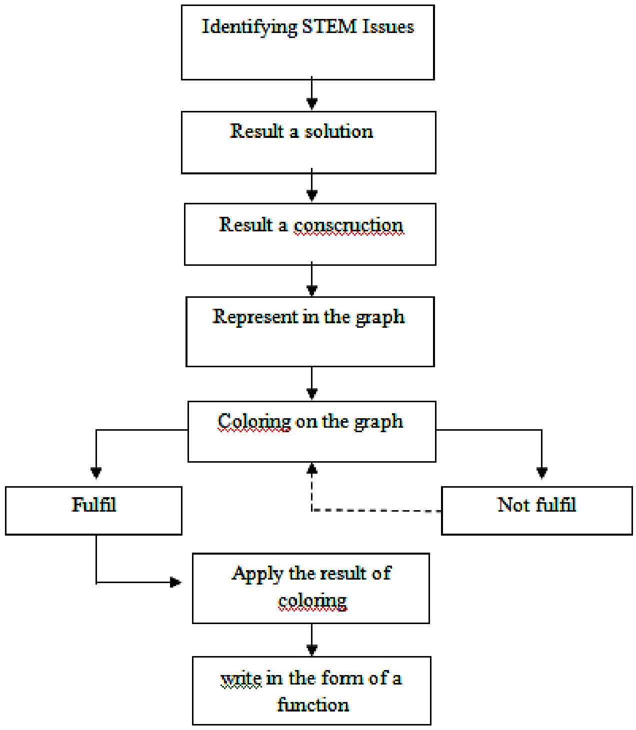


Fig. 4. Map Concept of Local Coloring (a, d)-edge Antimagic Coloring on Batik Design Line Motifs.

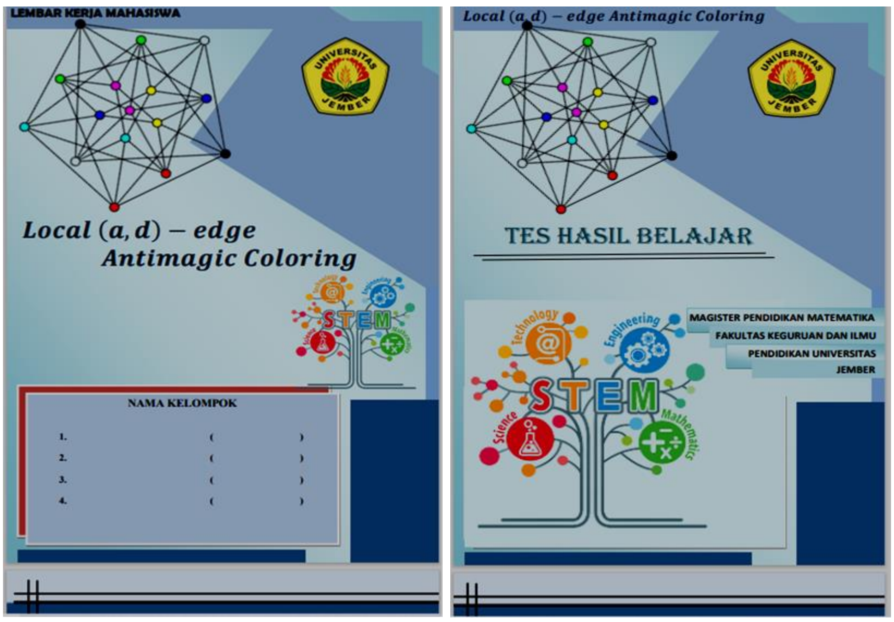


Fig. 5. Cover LKM and THB.

The validation results of the Student Work Design can be seen in Table I. Based on Table I, a score=3.66 is obtained so that the student's draft assignment can be said to be valid.

TABLE I: RTM VALIDATION RECAPITULATION RESULTS

Assessed aspects	Average score	Average percentage
Format	4.0	100%
Content	3.5	87.5%
Language and Writing	3.5	87.5%
Overall aspect average score	3.66	91.6%

Based on Table II validation of Student Worksheets obtained a score=3.53. So that the Student Worksheet can be said to be valid. A recapitulation of student worksheet validation from validators can be seen in the following Table II:

TABLE II: MFI VALIDATION RECAPITULATION RESULTS

Assessed aspects	Average score	Average percentage
Format	3.5	87.5%
Content	3.4	85%
Language and Writing	3.66	91.6%
Overall aspect average score	3.53	88.2%

Based on Table III, validation of student learning outcomes obtained a score=3.69. So that the learning outcomes test sheet can be said to be valid. A recapitulation of the validation of the test of learning outcomes from validators can be seen in the following Table III:

TABLE III: THB Validation Recapitulation Results

Assessed aspects	Average score	Average percentage
Format	3.5	87.5%
Content	3.57	89.2%
Language and Writing	3.83	95.8%
Overall aspect average score	3.69	92.3%

The practicality of this learning material is carried out by analyzing student learning activities and lecturer activities during learning. Observation of learning activities in the classroom was carried out by four observers taken from Master of Mathematics Education students, the average overall score of the observation results was 3.77 with a percentage of 94.41%. Based on the quality criteria of learning devices, a device is said to be practical if the observation results reach a score of 80%≤SR<90% and is said to be very practical if the observation results reach a score of 90%≤SR≤100%. So, it can be concluded that the device developed based on the results of observations meets the criteria of being very practical. In detail the average score obtained is like Table IV.

The effectiveness of the device that developed is seen from the completeness of the student learning outcomes test. There were 29 students as research objects, as many as 24 completed individually and 5 students were not completed. If presented, as many as 82.75% of students are complete and 17.24% of students are not complete. Because the percentage of completed students exceeds 80%, it meets classical completion. So, it can be concluded that student learning outcomes meet classical completion. Thus, student learning outcomes have met the effective criteria. The student learning outcomes data can be seen in the following Table V. Then an analysis of the results of student responses was carried out, the results of the analysis showed that the lowest positive response was 89% and the highest positive response was found in the item of novelty of the MFI device, which was 100%, this was due to the novelty of the topics that discussed in the MFI.Furthermore, an analysis of student activity was carried out, based on student activity analysis data, a percentage of 94.41% was obtained. Based on the data criteria for student activity observations, students meet the criteria for being very active if the percentage obtained is 90≤TPS≤100. It is concluded that students meet the criteria of being very active. The results of the recapitulation of student response scores are shown in the following Table VI.

TABLE IV: STUDENT ACTIVITY OBSERVATION RESULTS

No	Assessed Aspects	Observer 1	2	3	4	Average	Percentage
	I. Introduction						
1.	Students have attention and a sense of motivation towards the presentation of learning objectives	3	4	4	4	3.75	
2.	Students listen to the lecturer's explanation regarding the study material that will be studied	4	4	4	4	4	
	Number of average scores of aspects I					7.75	
	Average score of aspect I					3.87	96.87%
	II. Main Activities						
1.	Students form groups	3	4	4	4	3.75	
2.	Students have attention and motivation to the presentation of references in the form of RBL-STEM-based research journals	4	3	3	4	3.5	
3.	Students collect data through discussions in RBL-STEM learning	4	4	3	3	3.5	
4.	Students present data obtained on RBL-STEM-based MFIs	3	4	4	4	3.75	
5.	Students analyze data obtained at RBL-STEM-based MFIs	4	4	4	4	4	
6.	Students present the results of the discussion	4	3	4	3	3.5	
7.	Students take pre-test and post-test enthusiastically on RBL- STEM learning	4	4	4	4	4	
	Number of average scores of aspect II					26	
	Average score of aspect II					3.71	92.85%
	III. Closure of Activity						
1	Students can make conclusions from learning activities	4	3	4	4	3.75	
	Number of average scores of aspect III					3.75	
	Average score of aspect III					3.75	93.75%
	Overall score of aspects					11.33	
	Overall aspect average score					3.77	94.41%

TABLE V: STUDENT LEARNING OUTCOMES DATA

Description	Amount	Precentage
Student who complete	24	82.75%
Incomplete student	5	17.24%

TABLE VI: STUDENT RESPONSES TO LEARNING

No	Response aspect	Total Answer		Percentage of Answers	
		Yes	No	Yes	No
1	Do you feel good about the learning material?	38	0	100%	0%
2	Do you feel good about student worksheets (MFIs)?	36	2	95%	5%
3	Do you feel good about the learning atmosphere?	37	1	97%	3%
4	Do you feel good about the method of teaching?	37	1	97%	3%
5	Is the learning material new?	38	0	100%	0%
6	Is the student worksheet (MFI) new?	38	0	100%	0%
7	Is the learning atmosphere new? Is the way of teaching learning new?	38	0	100%	0%
8	Is the way of teaching learning new?	36	2	95%	5%
9	Are you interested in participating in this lesson?	37	1	97%	3%
10	Are you able to clearly understand the language that used in student worksheets (MFIs)?	35	3	92%	8%
11	Can you clearly understand the language used on the final test question sheet?	37	1	97%	3%
12	Can you understand the meaning of each question/problem presented on the student worksheet (MFI)?	34	4	89%	11%
13	Can you understand the meaning of each question/problem that presented on the final test question sheet?	38	0	100%	0%
14	Are you interested in the appearance (writing, drawings, and location of images) on student worksheets (MFIs)?	37	1	97%	3%
15	Are you interested in the appearance (writing, drawings, and location of the drawings) on the final test question sheet?	38	0	100%	0%
16	Do you enjoy discussing with group members to solve problems by exchanging answers?	38	0	100%	0%
	Average	37	1	97%	3%

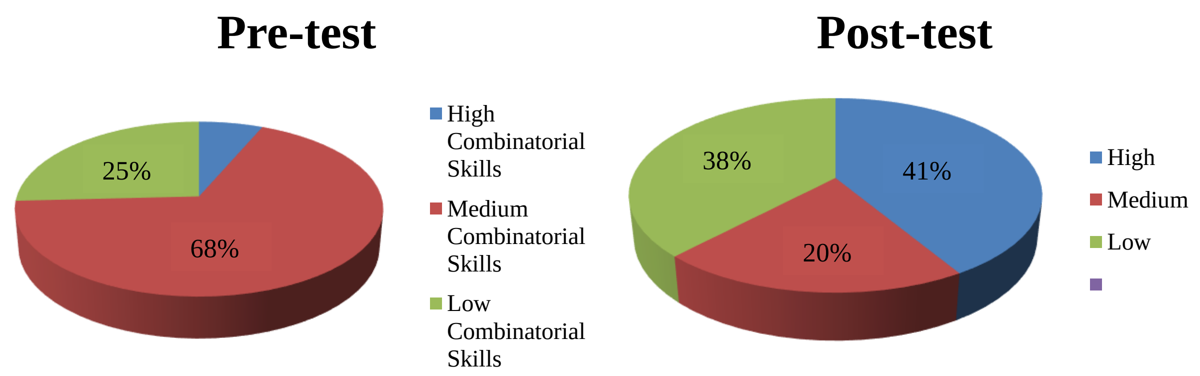


Fig. 6. Percentage of Student Combinatorial Skill Level.

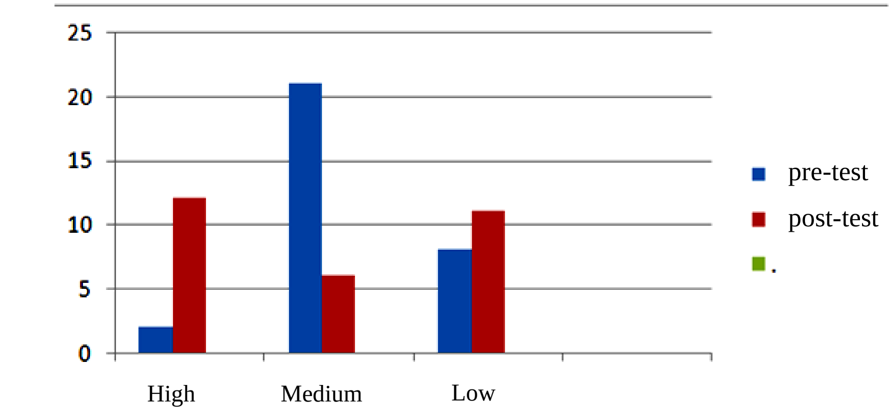
The last stage is deployment stage that implements the use of already developed learning materials on a larger scale. The deployment stage is carried out in the class of Statistics Course Analysis of the application of learning devices using paired sample t-test so that we compare pretest scores and posttest values to find out the influence of the application of learning devices.

In the pretest, there were 3 students with a percentage of 7% who could be categorized as students at a high combinatorial level. At the moderate combinatorial level there are 26 students with a percentage of 68%, and 9 students with a percentage of 25% are at a low combinatorial level. Meanwhile, in postes there are 17 students with a percentage of 41% who can be categorized as students at a high combinatorial level. At the moderate combinatorial level there are 7 students with a percentage of 20%, and 14 students with a percentage of 38% are at a low combinatorial level. This data can be displayed on the chart of Fig. 6 and Fig. 7.

Furthermore, paired sample t-test was carried out on pre-test and post-test results. Before that, a normality test is carried out. Test this statistic using r-shiny online software, is http://statslab-rshiny.fmipa.unej.ac.id/RProg/BasicStat/. The results of the normality test output are presented in Fig. 8.

Based on Fig. 8, the significant value of p.value is 0.11>0.05. This means that the distribution of pre-test and post-test result data is normally distributed. Furthermore, a 2-group paired t test was carried out; the results of the homogeneity test output are presented in Fig. 9.

Based on Fig. 9, the p-value significance value is 0.02486<0.05. Then it can be known that there is a significant difference between the pre-test value and the post-ttest value. Therefore, it can be concluded that there is an influence on the application of RBL-STEM based learning materials.



	High	Medium	Low
pre-test	3	26	9
post-test	17	7	14

Figure 7. Student Combinatorial Skill Level Category Graph

+ SET DATA ▾ CEK NORMALITAS ▾ STATS DASAR ▾ REGRESI ▾

statistic	p.value	method	data.name
0.94	0.11	Shapiro-Wilk normality test	datasetInput()[, input$var.y]
0.94	0.11	Shapiro-Wilk normality test	datasetInput()[, input$var.y]

Fig. 8. Normality Test Results Pre-test and Post-Test Values.

```
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 = -2.3709, df = 28, p-value = 0.02486
alternative hypothesis: true difference in means is not equal to 0
95 percent confidence interval:
 -16.325797  -1.191445
sample estimates:
mean of the differences
             -8.758621
```

Fig. 9. 2-Group T Test Results Paired Pre-Test and Post-Test Values.

IV. Conclusion

Devices that have been developed and meet valid criteria are piloted in the trial class. The validity score obtained on each device is 3.66 for the student assignment plan (RTM), 3.53 for the student worksheet (MFI), and 3.69 for the learning outcomes test (THB). The observation result of the learning implementation score was 3.89 with a percentage of 94.41%. In addition to being valid and practical, the material also meets the criteria for effectiveness. On average, 97% of students in this trial class are classified as complete students and the response from students is positive. Based on the test results, researchers got 24 students who scored above 60. This means that 82.75% of students in this class have completed and met one of the effectiveness criteria. Student response questionnaires also give more positive responses than negative responses.

Discussion

Research-based learning materials with a developed STEM approach must meet valid, practical, and effective criteria. The device that has been developed is carried out a validation process first by two validators of mathematics education lecturers FKIP Jember University.The validation results show that this learning material belongs to the valid category. In addition, the learning materials that have been developed have also met the criteria for practical and effective learning materials.

This research-based learning model is recommended in the implementation of education in order to produce higher student motivation and can improve learning outcomes and be able to apply it in life. This research-based learning if applied in the classroom to produce students who are more active, creative, and able to think more critically compared to students who use conventional learning. This is in accordance with research conducted by Suntusia (2019), Suntusia explained that learning that is carried out in conventional classes causes students to tend to be passive and lack the drive to develop their potential.

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