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The development of rbl-stem learning materials to improve students' combinatorial thinking skill in solving local (*a,d*)-edge Antimagic coloring problems for Line Motif Batik Design

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Abstract

Combinatorial thinking is a problem-solving approach that involves analyzing and synthesizing different elements or possibilities to create new combinations or arrangements. It is a critical skill in various fields, including mathematics, computer science, biology, and optimization problems. Combinatorial thinking allows individuals to explore and understand the relationships between elements and discover novel solutions through systematic enumeration and manipulation. To develop students' combinatorial thinking skills, we need to support the learning process with learning materials of specific model and approach. In this study, we will develop RBL learning materials with a STEM approach to improve students' combinatorial thinking skills. We will use R&D (research and development) model for doing study of this research, namely Thiagarajan 4-D model. The developed learning materials met the criteria of being valid, effective and practical. The validity scores obtained for each material were 3.53 for RTM, 3.69 for LKM and 3.66 for THB. The observation results of learning implementation were 3.61 with a percentage of 90%, and the student responses were 3.75 with a percentage of 93.75 positive, so they met the practical criteria. Based on the test results, the researchers found that 82.75% of the students were complete so that they met the effective criteria.

Keywords: Line motif batik design; RBL-STEM Learning materials; Combinatorial thinking Skills; Local (*a,d*)-edge antimagic coloring.

1. Introduction

The 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). Whercas (Dafik 2018) says that combinatorics is one of the fields of mathematics that relate to calculations, both as means and an end in obtaining results and characterization of properties of finite structures. Lockwood (in Jean, 2022) explain that the process of counting is a simple example of combinatorial thinking skills. The model of combinatorial thinking skills consists of three components, namely the process of counting, the formulation of problems, the final result. Dafik (in Anggraeni et al., 2019) specify five indicators of combinatorial thingking skills including identifying some 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 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).

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STEM is a learning approach that motivates students to come up with mid-on and hand-on-learning through the problem-solving process (Gita et al., 2021). STEM integration is defined as combination of science, technology, engineering and mathematics (Ridho, 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 knowledge that covers various things, one of which is graph theory. Graph theory first became known through a problem about the Konigsberg bridge that was solved by the swiss mathamtician Leonhard Euler. Graph is a discrete structure consisting of a set of objects called vertices and sides that connecting existing nodes (Chartrand & Leisnak, 1986). Many topics are studied in graph theory, including local (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 arithematic sequence with the value of begin with a and difference with d.

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

2. Material and methods

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 a stage, and the dissemination stage. The data was obtained from the observation of student activities during learning process were statistically tested using parametric statistical tests. The statistical test in this study R-Shiny sofrware through a learning center and a virtual statistics laboratory that can 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 bound variable. The free variables tested are research-based learning materials with STEM approach, while the bound variables are students' combinatorial thinking skills. Furthermore, paired simple t-test was carried out on pre-test and post-test results. The Thiagarajan 4-D model learning materialsdevelopment scheme can be seen in Figure. 1.

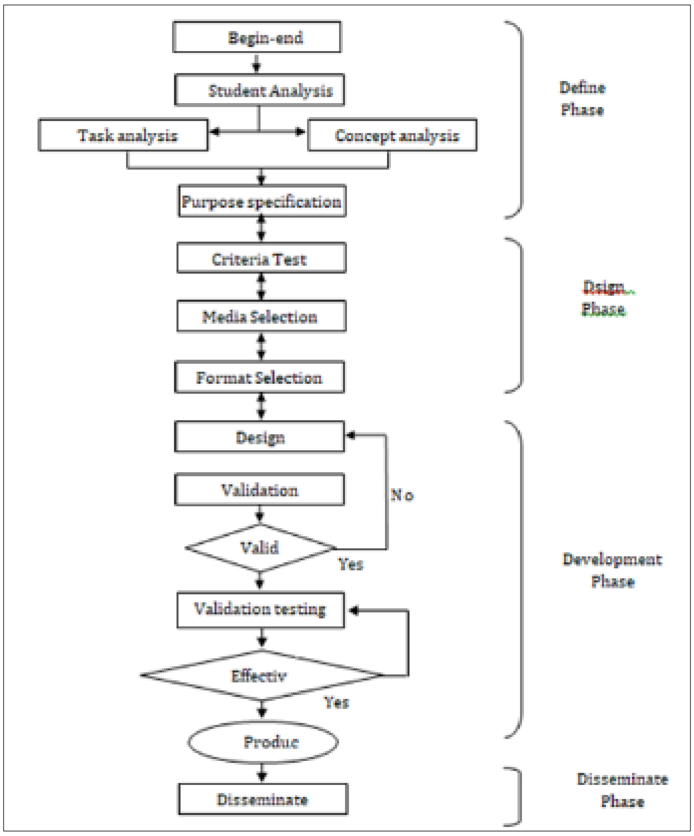

Figure 1 4-D model for learning material development scheme

3. Results

In this section we will discuss each of the six stages of the research-based learning model with a STEM approach. These six stages will illustrate how students, in the learning process using the research-based learning model with a STEM approach, engage with the concept of local coloring $(a,)$-anti-magic page to enhance their combinatorial thinking skills in solving problems related to the design of line motif batik.

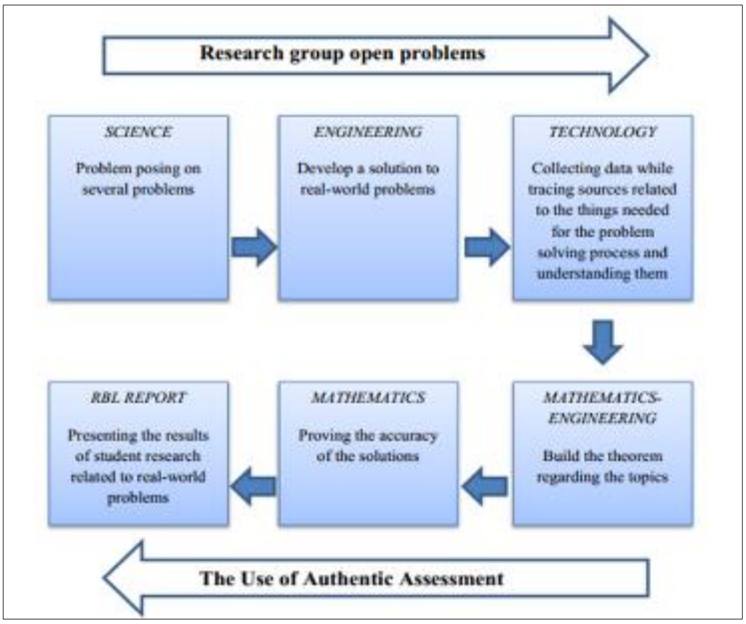

Figure 2 RBL-STEM Stages.

- The First Stage (Science), Presenting a fundamental problem related to the design of line motif batik, where students must determine the layout and coloring of each motif to create beautiful and efficient color combinations.
- The Second Stage (Engineering), Where students are asked to develop breakthroughs in solving the given problem using coloring techniques while enhancing their combinatorial skills. Students are initially tasked with identifying the types of simple graphs for coloring.
- The Third Stage (Technology), Students are introduced to the use of GeoGebra software in solving problems related to the design of line motif batik.

	
a	b

Figure 3 (a) Batik Motif Design, (b) Batik Clothing Motif Design

- The Fourth Stage (Mathematics-Engineering), Constructing theorems on the topic of local coloring (a,d)-anti-magic side on previously undiscovered graphs.
- The Fifth Stage (Mathematics), Where students conduct experiments regarding the coloring they have obtained to prove the accuracy of the solution.

The Sixth Stage (RBL Report), Where students make presentations related to the resolution of problems in the design of line motif batik.The development of the RBL-STEM learning tool aims to analyze students' combinatorial thinking skills in solving problems related to local coloring (a,d)-anti-magic side. This development process refers to the Thiagarajan model (4D), which includes the stages of defining, designing, developing, and disseminating.

3.1. Definition Phase

This definition stage aims to identify and define learning needs by analysing the objectives and limitations of the material to be presented. There are five steps in this phase, namely:

Analysis Beginning-End, 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 in 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 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 discliplines, namely: Science, Technology, Engineering,

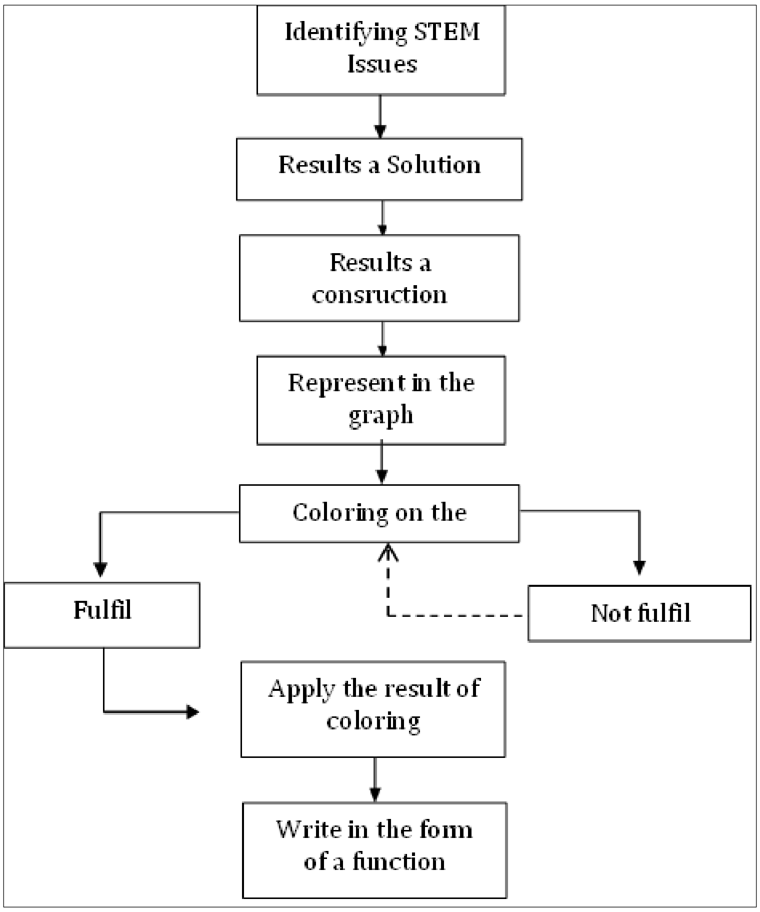

Figure 4 Map Concept of Local (a,d)-edge Antimagic coloring on batik design line motifs. & Mathematics.

Student Analysis, In this study, student analysis was conducted on 5rd-semester Mathematics Education students at University PGRI Argopuro Jember. 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 so that consideration is obtained in developing learaning materials that are in accordance with student characteristics. The learning activities carried out centered on students' combinatorial thinking 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 skills in solving given problems.

Concept Analysis, 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 $(a,)$-edge antimagic coloring can be seen in Figure. 4.

3.1.1. 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.

3.1.2. Design phase

The planning stage aims to design learning devices that will be used so that a sample learning materialsis obtained. At this stage, the design of research-based learning tools using the STEM approach is carried out to determine the effect of learning tools on improving students' combinatorial thinking skills on local (a,d)-edge antimagic coloring. There are four steps at this stage, namely:

Test development, The test used aims to measure the changes that occur in students after the learning activities. The test is developed based on the formulated learning objectives, accompanied by the creation of a grid and scoring guidelines. The test is given to students with the aims of measuring the combinatorial thinking skills of students in solving problems related, to batik design with line motifs.

Media selection, The selection of media is based on results of task analysis, concept analysis, and students characteristics conducted in the definition stage. In this study, the presentation of material related to the concept of local (a,d)-edge antimagic coloring is done using power point. Another supporting medium is the RBL-STEM LKM on the subject of local (a,d)-edge antimagic coloring. The LKM includes indicators of combinatorial thinking skills, and with the present of the LKM as a medium, it is expected that students can be more active and enthusiastic in learning. Students are also expected to understand to concept of local (a,d)-edge antimagic coloring more easily, apply the concept to the graph, find the chromatic number of graph, and determine the point and edge weight functions of the graph.

Figure 5 Cover LKM and THB

Format selection, The selection of the format in developing instructional materials aims to formulate and determine the design of instructional media, the selection of strategies, approaches, methods, and learning resources to be used during teaching and learning activities. In this study, the learning model used is research-based learning with the STEM approach in the study of local $(a,)$-edge antimagic coloring, and its corresponding learning stages are chosen as the instructional format. This is done because the research aims to develop RBL-STEM instructional materials in the study of local $(a,)$-edge antimagic coloring to enhance students' combinatorial thinking skills.

Initial planning, Initial design is the entire design of instructional tools that must be completed before conducting trials. The instructional tools include Student Task Design (RTM), Learning Outcome Test (THB), Student Worksheets (LKM), and Questionnaires.

3.2. Development phase

In this phase, the teaching tools were revised based on feedback from the validators and data from the trials. The activities in this stage include validation of the tools by validators, followed by revisions and field trials with students as research subjects. The results of the activities in the development phase are explained below. The cover of LKM and THB can be seen in Figure 5.

3.2.1. Validator assessment

The developed tools were revised in accordance with the assessments and suggestions from the validators. The tools were validated by two validators, both of whom are lecturers in the Mathematics Education program at FKIP, Universitas Jember. Overall, based on the assessments from both validators, the tools can be used with minor revisions.

Table 1 Validator field

No	Validator	Field
1	Validator 1	Graph theory
2	Validator 2	Learning

In general, based on the assessments of both validators, the tools can be used with minor modifications. Detailed assessment results from both validators are presented in Table 2.

Several suggestions from Validator 1 regarding the justification of the graphical representation, the definition of material concepts and the graphical illustrations in LKM. Suggestions from Validator 2 regarding completeness of RPS, updated RTM format and writing of RBL steps in LKM. These suggestions from the validators will be used to revise the instructional tools so that the tools developed are suitable for use in learning.

3.2.2. Device testing

Once the learning materials had been validated and revised, the next step was the trial. In this study, the subjects were students in the fifth semester of Mathematics Education at the University PGRI Argopuro Jember, who were taking the graph theory course, a total of 25 students. The results of the trial were used to evaluate the effectiveness and practicality of the teaching tools. During the teaching process, the researcher acted as a lecturer, accompanied by an observer. The activities of the lecturer and the students were observed by the observer present during the teaching and the observer evaluated the teaching activities on the basis of the observation sheet provided. The observations of the management of the teaching activities indicated that the learning activities using the research-based learning model with the STEM approach were quite good and smooth.

The learning activities took place on 19 December 2023. The learning objective for this session was for students to be able to determine the solution to a STEM problem, specifically related to the design of batik line motifs using the concept of local (a,d)-edge antimagic coloring. At the beginning of the learning activities, students were given a pre-test to assess their initial knowledge of local $(a,$d)-edge antimagic coloring. After completing the pre-test, students were given an inquiry-based student worksheet (LKM) using the STEM approach, which included several steps and blank columns to help students understand the material being studied. After completing the LKM, students were asked to present their findings. Towards the end of the learning activities, students were given a post-test to assess their final skills. The post-test questions focused on local $(a,$d)-edge antimagic coloring. After the learning session, students were asked to complete a questionnaire about their reaction to the implementation of the learning activities and the teaching tools provided. The results of the experiment, in the form of student activities and responses, were then analysed and used as considerations for revising the teaching tools to produce a final draft ready for use.

3.3. Dissemination phase

The final stage is the dissemination stage, which involves implementing the use of the developed teaching tools on a larger scale, e.g. in classes that have not been tested or in other universities by other lecturers. The developed teaching tools were validated by two validators and tested in a trial class. The validation results meet the criteria of validity, practicality and effectiveness. A tool is said to be valid if it achieves a score of $3.25 \leq V_a < 4$.

The validation results of the Student Work Design can be seen in Table 2, a score=3.53 is obtainedso that the student's draft assignment can be said to be valid

Table 2 RTM Validation Recapitulation Results

Assessed aspects	Averagescore	Average percentage
Format	3.5	87.5%
Content	3.4	85%
Language and Writing	3.66	91%
Overall aspect average score	3.53	88.2%

Based on Table 3 validation of Student Worksheets obtained a score=3.69. So that the Student Worksheet can besaid to be valid. A recapitulation of student worksheet validation from validators can be seen in the following Table 3:

Table 3 LKM 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%

Based on Table 4, validation of student learning outcomes obtained a score=3.66. 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 4:

Table 4 THB 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%

The mathematics teaching tools also meet the criteria for practicality and the feedback from practitioners does not require substantial changes to the tools, only minor adjustments. The observation score for the implementation of the learning activities was 3.61 with a percentage of 90%, indicating that the learning activities were implemented very well. In addition to being valid and practical, the tools also meet the criteria for effectiveness. The average performance of the students in this trial class is classified as students who have completed the material and the response from the students is positive. Based on the test results, the researcher found that 18 students scored above 60. This means that 70% of the students in this class completed and met one of the effectiveness criteria. The student questionnaire also gave more positive answers than negative ones. One of the aims of this research is to analyse the students' combinatorial thinking skills through the test results. In the pre-test results there were no students categorised as having high level combinatorial thinking skills. Students with moderate combinatorial thinking skills accounted for 65%, while students with low combinatorial thinking skills accounted for 35%. In the post-test results, students categorised as having high level combinatorial thinking skills reached 70%, students with moderate level combinatorial thinking skills decreased to 26% and students with low level combinatorial thinking skills decreased to 4%.

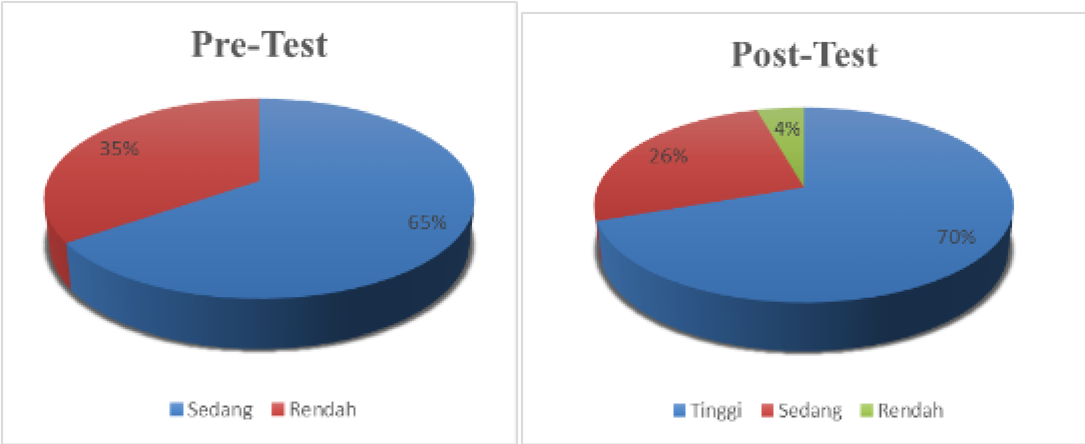

Figure 6 Percentage of student combinatorial thinking skill level

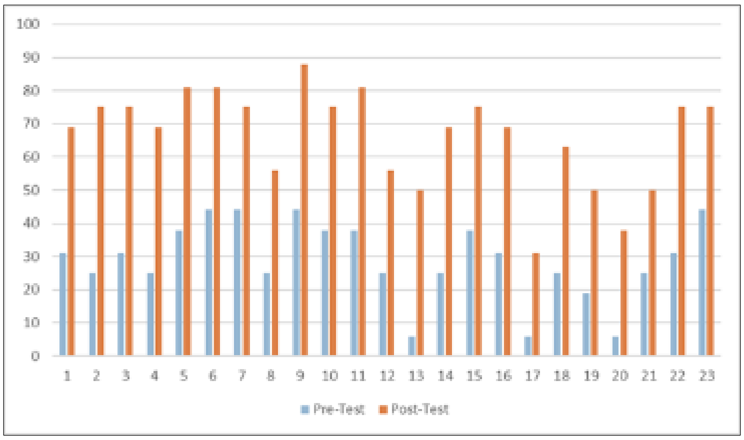

Figure 7 Summary of pretest and posttest scores.

4. Discussion

Research-based learning materials with a developedSTEM 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 inthe 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.

5. Conclusion

Based on the conducted research on the development of RBL-STEM instructional tools to enhance students' combinatorial thinking skills, the following conclusions can be drawn.

- RBL-STEM learning activities involve several steps, including: (1) presenting students with a real-world problem related to the study of local (a,d)-edge antimagic coloring (science); (2) encouraging students to develop problem-solving strategies or strategies for a problem (engineering); (3) guiding students to collect data and explore relevant sources needed to solve and understand the problem (engineering); (4) analysing patterns of labelling in local (a,d)-edge antimagic coloring in a general sense and determining the chromaticity of local (a,d)-edge antimagic coloring in a graph (engineering); (5) Students developing theorems related to the chromatic number of local (a,d)-edge antimagic coloring in a graph and determining the label point and edge weight functions of the graph, as well as proving the truth of the obtained theorems (Engineering, Mathematics); (6) Participation in group research forums with members and other researchers discussing real-world problems related to the study of local (a,d)-edge antimagic coloring (RBL report).

- The process of developing the tool and the results of the development include several stages. The first stage is definition, where initial and final analysis, student analysis, material concept analysis, task analysis and objective analysis are carried out. The next stage is planning, where teaching tools are planned by designing tests and instruments, selecting media, choosing formats and creating initial designs. This is followed by the development phase. All developed tools are validated by validators and revised based on the suggestions given. Once validated, the tools are tested and disseminated using the Internet of Things, such as social media. The results of tool development include student worksheets (LKM) and learning outcome tests (THB). After testing and analysis, it can be concluded that the tools meet the criteria of validity, practicality and effectiveness.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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