World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Development of RBL-STEM Materials to Improve Students' Combinatorial Thinking Skills to solve Rainbow Antimagic Coloring Problems and Its Application Scheme on Air Quality Monitoring System with GNN

MH Ilham Nuraizi [1, *], Dafik [2] and Arika Indah Kristiana [1]

[1] *Départment of Postgraduate of Mathematics Education, Faculty of Teacher Training and Education, University of Jember, Indonesia.*
[2] *Départment of Postgraduate of Mathematics Education, Faculty of Teacher Training and Education, University of Jember, Indonesia.*

World Journal of Advanced Research and Reviews, 2025, 26(02), 638-646

Publication history: Received on 20 December 2024; revised on 04 February 2025; accepted on 07 February 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.26.2.0313

Abstract

RBL-STEM is a learning model that combines the Research-Based Learning model and the STEM approach. The RBL model is a student-centered learning model, in RBL students will find a problem that requires a solution. RBL-STEM will require students to solve problems in life with integrated aspects of science, technology, engineering and mathematics. In many research studies, RBL-STEM has been proven to improve students' mathematical thinking skills. This research develops an RBL-STEM learning tool on rainbow antimagic coloring material and its application scheme on air quality monitoring system with graph neural network and sees the effect of the developed tool on students' combinatorial thinking skills. The development of RBL-STEM learning tools to improve students' combinatorial thinking skills in this study meets the criteria of valid, practical and effective. The validity value obtained is 3.87. The observation results of learning implementation amounted to 3.89 with a percentage of 97.33%, and student responses were 97.50% positive so that they met the practical criteria. Based on the results of the posttests, 95% of students were declared complete so that they met the effective criteria. Quantitative analysis in this study was obtained from analyzing pretest and posttest data, where normality test and paired sample t-test were conducted. Based on the normality test, it can be concluded that the pretest and posttest scores are normally distributed, because the significance value is greater than 0.05, namely 0.121 and 0.090. Furthermore, the paired sample t-test was carried out which showed a sig value. (2-tailed) of 0.000. This result shows that there is a significant increase in the combinatorial thinking ability of students after participating in RBL-STEM learning.

Keywords: Combinatorial Thinking Skills; RBL-STEM; Rainbow Antimagic Coloring

1. Introduction

Many methods and approaches can be used to improve students' combinatorial thinking skills, including by collaborating the Research-Based Learning (RBL) learning method and the Science, Technology, Engineering, Mathematics (STEM) approach. The combination of this learning model and approach is commonly called RBL-STEM.Combinatorial thinking skills are the process of obtaining multiple solutions to problems including discrete problems. Combinatorial thinking skills can be categorized in high-level thinking skills that require critical and creative thinking abilities [1]. Given the suitability of combinatorial thinking skills with the demands of mastering 21st century skills, it is very necessary for students to have combinatorial thinking skills to stimulate 21st century skills which include communication skills, creativity, critical thinking skills, and collaboration skills.

* Corresponding author: MH Ilham Nuraizi

Research-Based Learning (RBL) is a learning method that focuses on students or student center learning and integrates the learning process with research [2]. The Research-Based Learning (RBL) learning model requires students to develop and build knowledge through the steps of a research such as seeking information, formulating hypotheses, collecting data, analyzing, making conclusions and preparing reports [3]. Meanwhile, the STEM-based approach is an approach in education where Science, Technology, Engineering, Mathematics are integrated with processes that focus on solving problems in everyday life and in professional life [4].

The application of RBL-STEM in learning can encourage students to construct, develop, evaluate, communicate, utilize technology, apply knowledge. Given some of the things that have been described above, it is currently very relevant for researchers to develop RBL-STEM-based learning tools on mathematics topics. One of the mathematics topics that has attracted attention recently is graph theory on the rainbow antimagic coloring (RAC) subtopic, graph theory can also stimulate students to think combinatorially because in graph theory studying the structure and properties of collections of objects in this case in the form of vertex and edge. Rainbow antimagic coloring (RAC) is one of the new discussions in graph theory, rainbow antimagic coloring (RAC) was introduced in 2019 by Dafik by combining two topics namely rainbow connection and antimagic labeling [5]. Rainbow antimagic coloring (RAC) can be applied to solve mathematical problems in everyday life, in this study rainbow antimagic coloring (RAC) will be applied to the air quality monitoring system. The selection of this problem is a development of mathematics and is also collaborated with several components of other fields of science, such as graph neural networks (GNN).

There are several studies related to the development of RBL-STEM learning tools including research conducted by Jannah in 2022 with the title "Development of Research-Based Learning Tools with a STEM Approach in Improving Student Metaliteracy in Solving Sequential Pair Set Problems" [6]. Another research was conducted in 2023 by Dahlan with the title "Development of RBL-STEM Teaching Materials to Improve Computational Thinking Skills in Solving Antimagic Vertex Rainbow Coloring Problems and Their Application to Batik Motif Design" [7]. Based on the RBL-STEM syntax that other researchers have done in solving a mathematical problem, a similar study was conducted in developing an RBL-STEM learning tool to improve students' combinatorial thinking skills in solving rainbow antimagic coloring (RAC) problems. To measure that a learning device can be used and can improve combinatorial thinking skills, a learning outcome test is carried out by measuring the results of student pretests and postests. So that researchers conducted a study entitled "Development of RBL-STEM Materials to Improve Students' Combinatorial Thinking Skills to Solve RAC Problems and Their Application Schemes to Air Quality Monitoring Systems with GNN".

2. Material and methods

2.1. RBL-STEM

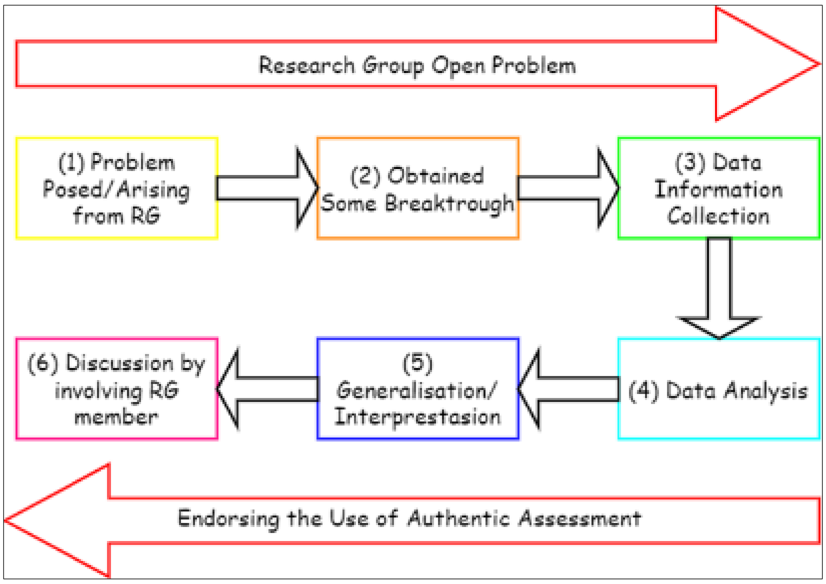

Figure 1 RBL Syntax

Research-Based Learning (RBL) is one of the learning models that collaborates several models in it such as contextual learning, authentic learning, problem solving based learning, cooperative learning, hands-on & mind-on learning and learning with an inquiry approach [8]. The application of the RBL learning model is intended to encourage the development of higher-level thinking skills for both educators and students, so that students not only gain knowledge and information that is believed but also have the ability to think at a high level, be creative and communicative [9]. Regarding the learning syntax of the Research-Based Learning model [10] has formulated in their article in graphical form, the graphical syntax of the Research-Based Learning model can be seen in Figure 2.

STEM is an acronym for a field of study that includes science, technology, engineering, and mathematics. The term STEM was first introduced by the National Research Council (NRC) in the United States in the 1990 [11]. This approach focuses on developing students' multidisciplinary problem-solving skills and abilities and improving achievement in science, technology, engineering and math [12]. STEM offers many new technologies to the world, such as online learning, 3D printing, Internet of Things (IoT), and others. In the context of education, the STEM approach tries to combine various fields of study to prepare students to face challenges in an increasingly complex world. The STEM aspects used in this research can be seen in Figure 3.

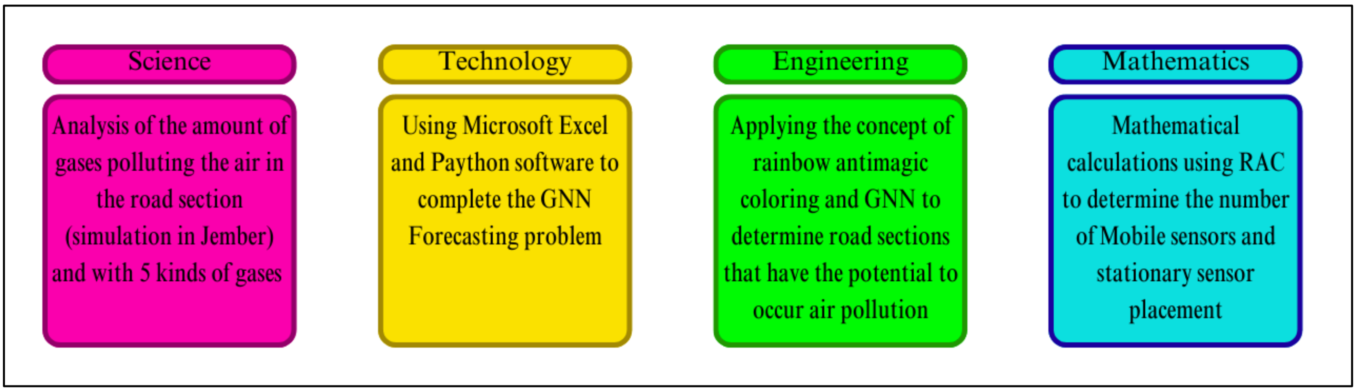

Figure 2 STEM Aspects in Research

This research aims to solve the problem of air quality monitoring system by using the concept of rainbow antimagic coloring and graph neural network. Based on the RBL syntax and STEM aspects that have been described, an RBL-STEM activity framework can be designed in this study including the stages of (a) Identifying the problem of air quality monitoring systems and gases that pollute the air by looking for references to previous research related to these two things; (b) Obtain solutions using the concept of rainbow antimagic coloring and graph neural networks; (c) Collecting information related to air quality data from published articles related to the development of air quality monitoring systems and images of road section maps from Google Maps; (d) Analyzing data by representing predetermined road sections for the placement of air quality sensors into graph representations; (e) Finding generalization patterns from rainbow antimagic coloring based on previously created graph representations; (f) Explaining or presenting the results and conclusions of the learning activities that have been carried out.

2.2. Combinatorial Thinking Skills

Combinatorial thinking skills is a process to obtain multiple solutions to solve discrete problems (Syahputra, 2016). Combinatorial thinking skills are needed to find solutions to a graph problem. Students utilize combinatorial thinking skills to find various possible solutions to the problem systematically and try to ensure that the results that have been obtained are correct and can be justified. Dafik in (Anggraeni et al., 2019) has formulated indicators and sub-indicators of combinatorial thinking skills presented in Table 1.

Table 1 Indicators of combinatorial thinking skills

Indicators	**Sub Indicators**
Identifying Some Case	Identifying The Characteristic Of a Problem Implementing The Characteristic Into Some Cases
Recognizing The Pattern Of The Case	Identifying The Pattern Of The Problem Solution Broadening The Pattern Of The Obtained Solution Of The Problem

Implementing The Pattern Of Mathematics Symbol	Implementing The Mathematics Symbol Calculating The Cardinality Developing The Algorithm
Proving Mathematically	Doing The Calculation Of The Argument Testing The Algorithm Developing The Bijection Testing The Bijection Implementing The Inductive, Deductive, and Qualitative Proves
Considering The Another Combinatorial Problem	Interpreting Proposing The Open Problem Knowing The New Combinatorial Problem Finding The Potential Application

2.3. Methods

The method used in this research is the development of the Thiagarajan 4-D Model. Thiagarajan 4-D Model consists of four stages, namely defining, designing, developing, and disseminating. Then the data obtained from the observation of student activity during the learning process were tested statistically. Statistical tests in this study used SPSS software. This study contains two variables, namely the independent variable and the dependent variable. The independent variable in this study is research-based teaching materials with a STEM approach and the dependent variable is students' combinatorial thinking skills. Furthermore, paired sample t test was conducted on the pre-test and post-test results. Thiagarajan's 4-D model can be seen in Figure 3.

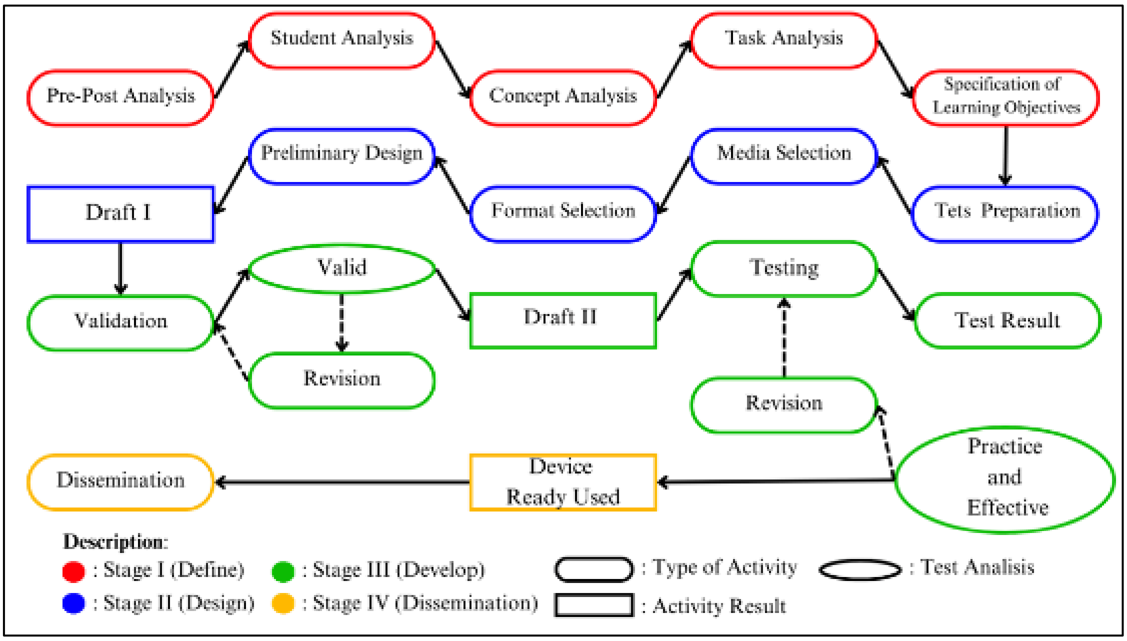

Figure 3 4-D Model Design

3. Results and discussion

The first stage in Thiagarajan's 4D for the development of RBL-STEM learning tools is Defining. The purpose of this defining stage is to see and define learning needs by analyzing the objectives and limitations of the material to be provided. This stage consists of five parts namely start-end analysis, Student analysis, Concept analysis, Task analysis and Specification of learning objectives. The start-end analysis at the defining stage is carried out to see the problems faced by students in learning activities, thus providing an overview for developing learning tools that are in accordance with student needs. Student analysis was conducted to obtain data or information related to the characteristics of undergraduate students of Mathematics Education at the Faculty of Teacher Training and Education, University of

Jember. This concept analysis aims to identify, detail, and systematically arrange the concept of rainbow antimagic coloring that will be learned by students. This task analysis aims to identify the abilities that students should have after this learning is done according to the curriculum. This activity is carried out to formulate the specification of the final learning objectives and identify students' combinatorial skills in accordance with the expected final ability.

The second stage in Thiagarajan's 4D for RBL-STEM learning device development is Design. At this stage, the RBL-STEM device will be designed to find out how the learning device affects students' combinatorial abilities in rainbow antimagic coloring material. There are four steps that must be considered at this stage, namely test preparation, media selection, format selection and initial design. The test is prepared based on the learning indicators that have been determined. The tests made in this study are in the form of descriptions related to STEM, the concept of rainbow antimagic coloring, and air quality monitoring systems. Media selection will be adjusted to the information obtained in the process of student analysis, concept analysis, and task analysis. The media used is the RBL-STEM Student Worksheet which contains combinatorial indicators and has been adjusted to improve students' combinatorial thinking skills. Format selection aims to determine the design of the model, approach and learning resources that will be used in the development of learning tools. RBL-STEM is chosen as the model and approach that will be used to develop this learning tool with the stages in it. Before the pilot test is conducted, the initial design of the learning device must be made. The initial design of the learning device can be seen in Figure 4.

Figure 4 Preliminary Design of Learning Materials

The third stage in Thiagarajan's 4D for RBL-STEM learning device development is the development stage. The development stage consists of four parts, namely validator assessment, learing materials testing, practicality testing, and effectiveness testing. The validator assessment was carried out by two lecturers from the Mathematics Education study program at the Faculty of Teacher Training and Education, University of Jember through the validation process. This process begins with the submission of learning devices, assessment instruments, and validation sheets to the validator. In addition to providing assessments, validators also provide comments and recommendations on the learning devices that have been developed. Various suggestions from validators are used as a basis for improving learning materials and ensuring that the materials developed are suitable for use in the learning process. Based on the validation results of the research instruments in table 2, All instruments have scores above 3.25 with an average score of 3.89 and a percentage of 97.25%. Based on the validity criteria, all research instruments are considered valid if they have a score of $3.25 \leq Va \leq 4$. Thus it can be concluded that the learning tools made have been declared valid by both validators.

Tabel 2 Recapitulation of Research Instrument Validation

Validation Result	Average Score	Percentage
Learning Materials	3,87	96,75%
Student Activity Observation Sheet	3,90	97,50%
Learning Implementation Sheet	3,89	97,33%
Student Response Surveys	3,90	97,50%
Questionnaire	3,95	98,91%
Overall Average	3,89	97,25%

After all research instruments are declared valid by validators, they can be tested and used in the student learning process. This trial was conducted in a class of 40 students. The testing was supervised by five observers who came from Master of Mathematics Education students at the Faculty of Teacher Training and Education, University of Jember. The assessment results from the observer evaluation and student work are used to evaluate the practicality and effectiveness of the developed learning materials. The practicality test of learning materials was carried out by analyzing the results of the observer's assessment on the learning implementation observation sheet. Recapitulation of learning implementation observation results can be seen in table 3.

Tabel 3 Recapitulation of Learning Implementation Observation Results

Aspects Assessed	Average Score	Percentage
Syntax	3,88	97,14%
Social System	3,93	98,33%
Principle of reaction and management	3,88	97%
Overall Average	3,89	97,33%

Based on table 3, it shows that the learning implementation observation sheet is rated with an average score of 3.83 with a percentage of 95.75%. By considering the criteria for the practicality of learning materials, learning materials are considered to meet the criteria for practicality if $90\% \leq Average\ Score \leq 100\%$. Thus it can be concluded that the learning materials that have been developed meet very high practical criteria.

The effectiveness test of learning materials is based on three indicators, namely analysis of student learning outcomes in the combinatorial thinking skills test, analysis of student activity observation results in the RBL-STEM learning model and analysis of student response questionnaire results related to the RBL-STEM learning model. Looking at the answers from the posttest results that have been carried out by students, researchers found that there are 38 students who get scores above 60 or around 95% of the total students can be said to be complete. Based on the Student Mastery Determination Score criteria, it can be said that most students have achieved overall completeness. The results of observations of student activity were carried out by five observers, analyzing student activity data starting from introductory activities, core activities to closing activities. The results of the recapitulation of student activity showed that the observation of student activity received an average score of 3.90 with a percentage of 97.50%. Based on the effectiveness criteria, students meet the criteria of being very active because they meet the score of $90\% \leq Ps \leq 100\%$. The results of the recapitulation of student activity are shown in Table 4.

Tabel 4 Results of the Recapitulation of Student Activity

Aspects Assessed	Average Score	Percentage
Introduction	4	100%
Main Activities	3,88	97,14%
Closing	3.80	95%
Overall Average	3,90	97,50%

The last section to see the effectiveness of the learning tool is the analysis of student response questionnaire results related to the RBL-STEM learning model. The last section to see the effectiveness of the learning tool is the analysis of student response questionnaire results related to the RBL-STEM learning model. Overall, the average percentage obtained from the student response questionnaire is 96.50%, so that according to the student response criteria, the learning tool can be categorized as very positive, because it gets a score $80\% \leq Pr \leq 100\%$. The recapitulation results of the student response questionnaire can be seen in Table 5. Thus, the learning tools developed have been considered effective because they meet the three indicators of effectiveness.

Tabel 5 Recapitulation Results of the Student Response Questionnaire

Aspects Assessed	Percentage
Enjoyment of learning components	98,13%
Novelty of learning components	95,63%
Interest in learning	100%
Language comprehension	97,50%
Understanding the meaning of each problem/issue	95%
Interest in appearance	100%
Enjoyment of discussion	100%
Improved combinatorial skills	97,5%
Overall Average	97,50%

The Dissemination Stage is the final stage of the Thiagarajan (4D) model, at this stage the use of learning materials that have been developed is applied on a larger scale such as in classes that have not been tested, in other study programs or in other universities that have similar courses. The purpose of this stage is to find out that the learning materials that have been developed work well for wider learning activities.

Furthermore, researchers will use quantitative data analysis to show that there is a significant change in combinatorial thinking skills. The following is a graph of the distribution of student pretest and posttest scores can be seen in Figure 5, while the percentage level of students' combinatorial thinking skills can be seen in Figure 6.

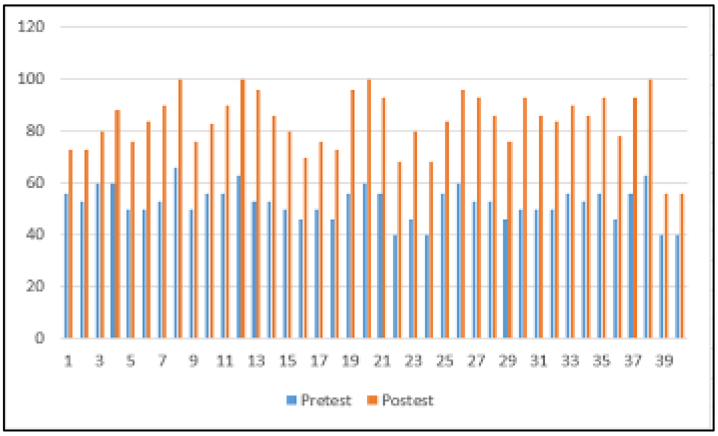

Figure 5 Distribution of Student Pretest and Posttest Scores

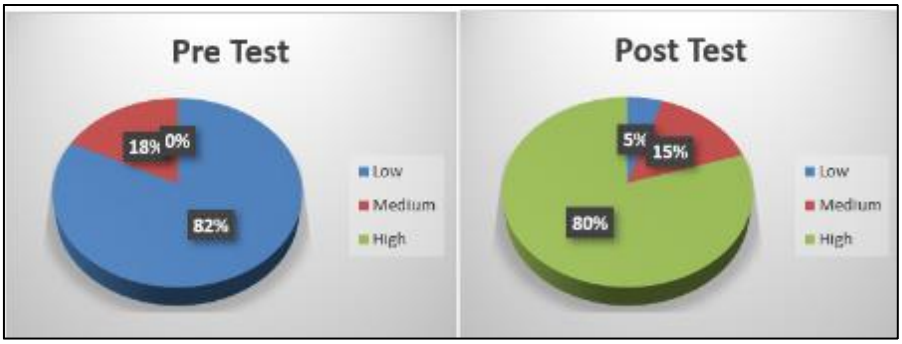

Figure 6 Percentage Level of Students' Combinatorial Thinking Skills

In the pre-test results of combinatorial thinking skills, there were no students in the high category, 18% students in the medium category, and 82% students in the low category. While in the results of the combinatorial thinking skills post test, there were 83% of students in the high category, 10% of students in the medium category, and 7% of students in the low category. Furthermore, the normality test was carried out as a requirement before the paired sample t test could be carried out, this statistical test was carried out using SPSS software. The results of the data normality test are presented in Figure 7.

Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Nilai Pre Test	.129	40	.094	.956	40	.121
Nilai Post Test	.094	40	.200*	.952	40	.090

Figure 7 Normality Test Result

Based on the results of the data normality test in Figure 7, it shows that the pretest and posttest scores are normally distributed because the significance value $(sig.) > 0.05$, namely the significance of the pretest value is $0.121 > 0.05$ and the significance of the posttest value is $0.090 > 0.05$. The last test is the paired sample t test presented in Figure 8.

Paired Samples Test

		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
					Lower	Upper			
Pair 1	pretest - posttest	-39.552	8.923	1.657	-42.946	-36.158	-23.871	28	.000

Figure 8 Paired Sample t Test Result

The results of the paired sample t test in Figure 8 show that the $Sig.(2 - tailed)$ is equal to $0.000 < 0.05$. The paired sample t test results show that there is a difference in scores before and after learning using the RBL-STEM learning materials. Thus, it can be concluded that there is an increase in students' combinatorial thinking skills.

This research has produced a learning materials with an RBL-STEM approach model to improve students' combinatorial thinking skills in solving rainbow antimagic coloring problems and their application schemes in air quality monitoring systems with GNN. The learning materials developed have passed the validation process from two validators and were tested in an experimental class. The learning materials developed have also met the criteria of validity, practicality, effectiveness. RBL-STEM learning materials have also been proven effective in improving students' combinatorial thinking skills, in the future learning materials with the RBL-STEM approach model to improve students' combinatorial thinking skills need to be further developed for different materials or learning materials with the RBL-STEM approach model on rainbow antimagic coloring material can be developed to improve other thinking skills.

4. Conclusion

After testing and analysis, it can be concluded that the learning materials developed meet the criteria of valid, practical, effective and can improve students' combinatorial thinking skills. The results of quantitative data analysis were obtained from processing pretest and posttest data, from both data the normality test and paired sample t-test were carried out. Based on the normality test, the pretest and posttest values are normally distributed, because the significance value $(sig.) > 0.05$, namely the significance of the pretest value is $0.121 > 0.05$ and the significance of the posttest value is $0.090 > 0.05$. Furthermore, a paired sample t-test was conducted which showed the $Sig.(2 - tailed)$ equal to $0.000 < 0.05$. The paired sample t-test results show that there is a difference in scores before and after learning using the RBL-STEM learning materials. Thus, it can be concluded that there is an increase in students' combinatorial thinking skills.

Compliance with ethical standards

Acknowledgments

We gratefully acknowledgment the support from department of Postgraduate Mathematics Education and Combinatorial Education and Research Based Learning (CEREBEL) of the year 2025.

Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] E. Lockwood, “A model of students’ combinatorial thinking,” *J. Math. Behav.*, vol. 32, no. 2, pp. 251–265, Jun. 2013, doi: 10.1016/j.jmathb.2013.02.008.

[2] T. Saptuti Susiani, M. Salimi, and R. Hidayah, “Research Based Learning (RBL): How to Improve Critical Thinking Skills?,” *SHS Web Conf.*, vol. 42, p. 00042, 2018, doi: 10.1051/shsconf/20184200042.

[3] M. Salimi, “RESEARCH-BASED LEARNING SEBAGAI ALTERNATIF MODEL PEMBELAJARAN DI LEMBAGA PENDIDIKAN TENAGA KEPENDIDIKAN,” *Jpsd*, vol. 3, no. 1, pp. 1–9, 2017.

[4] T. Mulyani, “Pendekatan Pembelajaran STEM untuk menghadapi Revolusi Industry 4.0,” *Semin. Nas. Pascasarj. 2019*, vol. 7, no. 1, p. 455, 2019.

[5] Z. L. Al Jabbar, Dafik, R. Adawiyah, E. R. Albirri, and I. H. Agustin, “On rainbow antimagic coloring of some special graph,” *J. Phys. Conf. Ser.*, vol. 1465, no. 1, 2020, doi: 10.1088/1742-6596/1465/1/012030.

[6] F. Jannah, E S W. Dafik. A, “KERANGKA AKTIVITAS PEMBELAJARAN BERBASIS RISET DENGAN PENDEKATAN STEM: PENERAPAN MATERI HIMPUNAN PASANGAN BERURUTAN DALAM MENINGKATKAN METALITERASI SISWA PADA PENYELESAIAN MASALAH PENJADWALAN PESAWAT,” Hibah Ris. Keilmuan, p. 48, 2022.

[7] D. Irawan, D. Dafik, and I. M. Tirta, “The Development of RBL-STEM Learning Materials to Improve Students’ Computational Thinking Skills in Solving Rainbow Vertex Antimagic Coloring Problems and It’s Application for Batik Motif Design,” Int. J. Curr. Sci. Res. Rev., vol. 06, no. 07, pp. 5294–5304, 2023, doi: 10.47191/ijcsrr/v6-i7-144.

[8] Sumardi, R. P. N. Puji, Dafik, and Z. R. Ridlo, “The Implementation of RBL-STEM Learning Materials to Improve Students Historical Literacy in Designing the Indonesian Batik Motifs,” Int. J. Instr., vol. 16, no. 2, pp. 581–602, 2023, doi: 10.29333/iji.2023.16231a.

[9] Suntusia, Dafik, and Hobri, “The effectiveness of Research Based Learning in improving students’ achievement in solving two-dimensional arithmetic sequence problems,” Int. J. Instr., vol. 12, no. 1, pp. 17–32, 2019, doi: 10.29333/iji.2019.1212a.

[10] R. S. D. Gita, J. Waluyo, Dafik, and Indrawati, “On the shrimp skin chitosan STEM education research-based learning activities: Obtaining an alternative natural preservative for processed meat,” IOP Conf. Ser. Earth Environ. Sci., vol. 747, no. 1, 2021, doi: 10.1088/1755-1315/747/1/012123.

[11] A. Fathoni, S. Muslim, E. Ismayati, T. Rijanto, Munoto, and L. Nurlaela, “STEM : Inovasi Dalam Pembelajaran Vokasi,” J. Pendidik. Teknol. dan Kejuru., vol. 17, no. 1, pp. 33–42, 2020.

[12] S. Sufirman, D. Dafik, and A. Fatahillah, “Pengembangan Perangkat Pembelajaran RBL-STEM Untuk Meningkatkan Metaliterasi Siswa Menerapkan Konsep Relasi Fungsi Dalam Menyelesaikan Masalah Dekorasi Teselasi Wallpaper,” Cgant J. Math. Appl., vol. 3, no. 1, 2022, doi: 10.25037/cgantjma.v3i1.69.