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)

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The development of RBL-STEAM learning tools to enhance students' creative thinking skills in designing ethnomathematics-based batik motifs using local (a, d)-edge antimagic coloring

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World Journal of Advanced Research and Reviews, 2025, 27(01), 1955-1965

Publication history: Received on 14 June 2025; revised on 20 July 2025; accepted on 22 July 2025

Article DOI: https://doi.org/10.30574/wjarr.2025.27.1.2736

Abstract

Education plays a crucial role in preparing a creative and adaptive generation. In response to global challenges, the RBL-STEAM approach—which integrates research with science, technology, engineering, arts, and mathematics—offers a promising strategy to foster innovative thinking. This study aims to identify RBL-STEAM learning activities, describe the development process and outcomes of the learning tools, and analyze their impact on students' creative thinking skills. Employing a research and development (Rand) method, the resulting products included student task designs, worksheets, and learning outcome tests. The development process yielded a validity score of 96.04%, with an effectiveness rate of 90.83% and a practicality score of 94.06% based on trials involving 35 students. The results revealed significant improvements in students' creativity, supported by statistical tests, visual data, NVivo analysis, and word cloud techniques. The findings indicate that the RBL-STEAM approach effectively enhances creative thinking skills, particularly in addressing problems related to local (a, d)-edge antimagic coloring.

Keywords: Creative Thinking; RBL-Steam; Learning Development; Local $(\boldsymbol{a}, \boldsymbol{d})$-Edge Antimagic Coloring

1. Introduction

Education plays a vital role in shaping individuals and society, particularly in preparing younger generations to face future challenges with relevant skills, including creative thinking. According to Indonesian Law No. 20 of 2003, the primary goal of national education is to develop students' potential and build a dignified national character and civilization [1]. In the context of rapid globalization and technological advancement, creative thinking skills are essential for generating innovative solutions to complex problems. Therefore, learning approaches such as Research-Based Learning integrated with STEAM (RBL-STEAM) offer a relevant strategy by holistically combining science, technology, engineering, arts, and mathematics into the learning process.

Research-Based Learning (RBL) and Science, Technology, Engineering, Arts, and Mathematics (STEAM) are two instructional approaches proven effective in developing creative thinking skills. RBL is a learning method that actively involves students in research activities to discover and construct new knowledge. As a form of student-centered learning (SCL), RBL integrates research into the learning process [2]. Students are encouraged to identify problems, collect data, analyze information, and draw conclusions based on their findings. This approach fosters critical, analytical, and creative thinking through hands-on experience and deep reflection. Previous studies have explored the

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implementation of RBL, including its use in analyzing students' metacognitive skills [3], and the effect of RBL-based instruction on enhancing students’ creative thinking abilities [4].

STEAM, on the other hand, integrates science, technology, engineering, arts, and mathematics into a single learning framework to solve real and complex problems. The inclusion of the arts component in STEAM promotes a more holistic learning experience and encourages students to develop their creativity [5]. This interdisciplinary approach requires students to think critically, creatively, and collaboratively. The integration of RBL and STEAM (RBL-STEAM) provides a robust framework for cultivating creative thinking, as students are challenged to develop research projects based on real-world issues that demand innovative solutions. Several studies have highlighted the effectiveness of STEAM, such as research on creating classroom environments that encourage creative problem-solving through STEAM-based learning [6], and the implementation of the STEAM model in early childhood education through online learning [7]. The integration of research-based learning with STEAM that includes the arts is especially relevant when connected with ethnomathematical batik concepts. This approach allows for a holistic integration of science, technology, engineering, arts, and mathematics within an interconnected cultural context.

In Indonesia, batik is a cultural heritage rich in both artistic and mathematical value. Each batik motif carries deep philosophical meaning and aesthetic value, reflecting the culture, history, and societal values of the people. These philosophical meanings are closely tied to Javanese culture, which is rich in symbols deeply rooted in the daily lives of the Javanese community [8]. Additionally, batik patterns often display complex geometric structures that can be analyzed using mathematical concepts. Ethnomathematics is the study of the relationship between mathematics and culture [9]. In this context, it explores how indigenous communities understand and apply mathematical ideas within their cultural practices. Specifically in batik, ethnomathematics examines how mathematical concepts such as symmetry, patterns, and transformations are employed in the design of batik motifs.

One of the mathematical concepts relevant to batik motif design is local (a, d)-edge antimanic coloring. This concept involves edge coloring in graphs, where each color must satisfy specific properties. This type of coloring not only enhances visual aesthetics but also challenges students’ analytical and creative skills in developing new patterns. Local (a, d)-edge antimanic coloring is a graph coloring technique in which each edge is assigned a color such that the sum of edge colors incident to each vertex differs from that of any other vertex. This is an advanced concept in graph theory with practical applications in network design and optimization, and it can also be utilized to create intricate and visually appealing batik motifs.

The development of learning tools that integrate RBL-STEAM, ethnomathematics, and local (a, d)-edge antimanic coloring is highly relevant in the context of higher education in Indonesia. These tools not only deepen students’ understanding of mathematical and scientific concepts but also encourage the application of such knowledge within local cultural contexts, such as designing batik motifs. By combining these three approaches, the learning design aims to enhance students’ creative thinking skills while promoting cultural preservation through scientific methods. This research addresses the need to align education quality and curriculum relevance with contemporary demands, focusing on the innovation of RBL-STEAM-based learning tools to foster creativity through the integration of local wisdom and modern mathematical concepts.

2. Material and methods

2.1. RBL (Research Based Learning)

Research-Based Learning (RBL) is an instructional model that allows students to learn and construct knowledge through research steps such as information gathering, hypothesis formulation, data collection, analysis, conclusion drawing, and report writing [10]. Malysia defines RBL as a learning method that incorporates contextual learning, authentic learning, problem-solving, cooperative learning, direct instruction, and inquiry-based approaches [11]. Additionally, RBL actively develops students’ independent research skills and provides opportunities to apply them in practice [12].

According to Dafi, the objectives of Research-Based Learning (RBL) include enhancing the contextual relevance of learning through exposure to research findings, strengthening students’ thinking skills as researchers, and internalizing research values, practices, and ethics within the learning process. RBL also aims to actively involve students in research activities, improve the quality of research in higher education, and foster continuous learning and innovation to encourage creative thinking and ensure up-to-date instructional quality [13].

Ridha outlines several characteristics of RBL, such as the existence of research groups (RGs) that conduct teaching, research, and community service activities; the integration of research and classroom instruction; and the use of creative and inquiry-based approaches in the learning process [14]. Furthermore, Dafi describes seven stages of RBL: (1) problem posing from open-ended research issues, (2) developing problem-solving strategies, (3) data collection and hypothesis formation, (4) data analysis and validation, (5) formulation of conjectures, corollaries, lemmas, theorems, and generalizations, (6) group discussion with research members, and (7) compiling research reports [15].

2.2. STEAM (Science, Technology, Engineering, Arts, and Mathematics)

STEAM stands for Science, Technology, Engineering, Arts, and Mathematics. It evolved from STEAM with the addition of the arts component to enhance student motivation in science, technology, engineering, and mathematics learning. Integrating the arts as an essential discipline creates an ideal learning environment for STEAM education [16]. The inclusion of arts provides students with greater opportunities to engage actively and creatively in problem-solving processes [17]. STEAM learning emphasizes creating classroom environments where students learn through creative problem solving [18].

The STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach is essential in preparing individuals to face future challenges. According to Sabeti et al., STEAM education significantly enhances students' scientific literacy and technological competence through the integration of multiple disciplines [19]. This approach equips learners with a strong understanding of scientific principles, the ability to apply knowledge in technological contexts, and essential skills in critical, creative, and innovative thinking. Furthermore, Perman sari notes that STEAM also improves students' thinking proficiency, technological literacy, and problem-solving skills, fostering the development of innovative thinkers [20].

2.3. Creative Thinking

Thinking is generally understood as a mental process. According to WI dana and Setiadi, creative thinking is an individual skill to generate new ideas and produce complex, unique solutions by viewing problems from different perspectives [21]. Istomin's et al. describe creative thinking as the ability to connect unrelated ideas or objects and define a creative person as someone who can perceive and link things from new angles, offering fresh, unique, and innovative solutions to real-life problems [22]. In essence, creative thinking is a cognitive skill that allows individuals to discover and connect new elements, leading to the generation of original ideas and alternative approaches.

According to Ananda, individuals with creative thinking skills tend to develop persistence, self-discipline, and engage in active mental practices such as: (1) asking critical questions, (2) reflecting on current events and emerging theories, (3) making connections between unrelated objects, (4) freely associating ideas, (5) using creativity to transform situations into opportunities for innovation, and (6) paying attention to intuition [23]. Creative thinking involves continuous mental activity in forming meaningful connections until no further associations can be made. In addition, Indiana identifies four key indicators of creative thinking ability: fluency, flexibility, originality, and elaboration [24].

Krulik and Rudnick (as cited in Siswanto) define creative thinking as original, reflective thought that leads to the production of complex outcomes [25]. It involves synthesizing ideas, constructing new concepts, evaluating their effectiveness, and includes decision-making skills to generate innovative products

2.4. Methods

The research procedure used in this study used Thiagarajan's development model, known as the 4D model. This model consists of the define, design, develop, and disseminate phases. A schematic diagram of the 4D model of learning device development is shown in Figure 1. Data collection techniques in this study were based on research instruments that included validation of learning devices, observation of learning implementation, data collection of learning outcomes, activity observation, and response questionnaires. In this study, data analysis was applied, namely quantitative data analysis using the SPSS application to perform statistical tests, namely paired sample t-test.

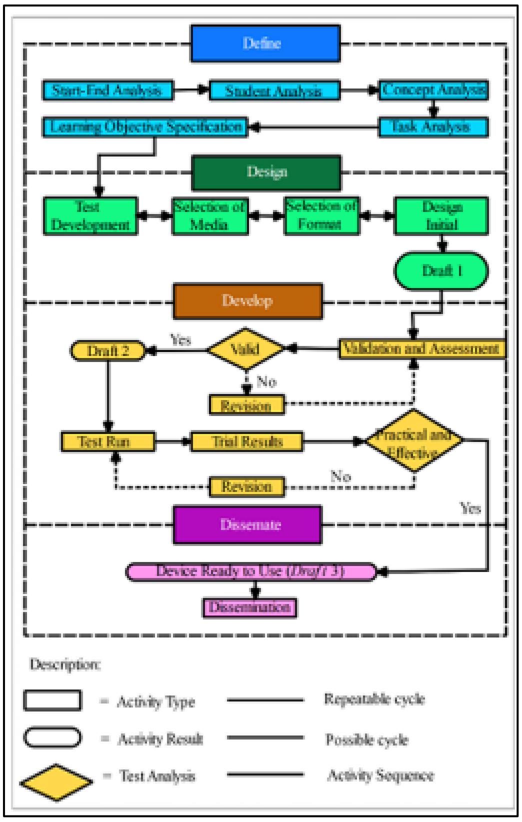

Figure 1 Stages of Learning Device Development 4-D Model

3. Results and discussion

This RBL- STEAM model requires students to be more active in learning through research. In the early stages of research-based learning syntax, problems arise from research groups that focus on open-ended issues. Researchers consider the problem of local colouring of (a, d) antimanic colouring.

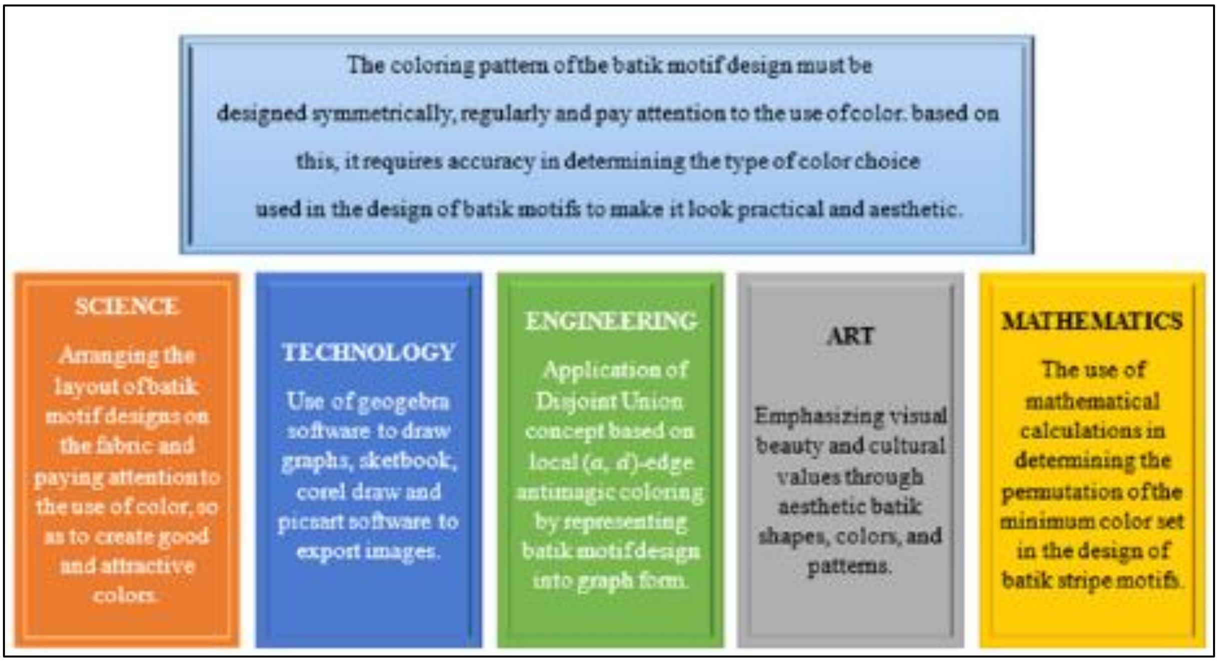

Figure 2 STEAM elements of local (a, d) antimagic coloring

The RBL-STEAM (Research-Based Learning, Science, Technology, Engineering, Arts, and Mathematics) model used in this study involves several key stages: identifying problems in line-pattern batik design using the concept of local (ad)-edge antimanic coloring; developing design solutions based on this graph coloring principle; collecting data and reviewing relevant sources related to the application of the concept; formulating supporting theorems to justify the mathematical approach; validating the accuracy of the solutions; and finally, presenting the results, where students demonstrate how the batik design can be applied in real-world contexts.

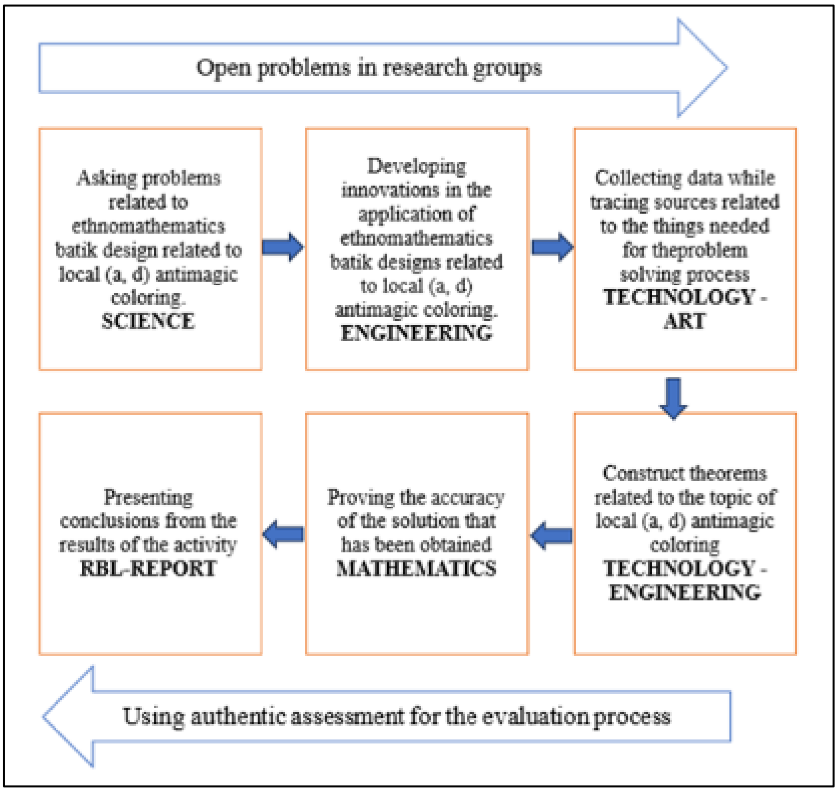

Figure 3 RBL-STEAM Activity Framework for Problem local (a, d) antimagic coloring

The first stage of the 4D model is the define stage. The purpose of this stage is to identify and formulate learning needs by analyzing the objectives and limitations of the material to be delivered. The define stage consists of four phases: initial-final analysis, learner analysis, concept analysis, and task analysis.

The initial-final analysis is conducted to identify problems faced by students in learning, particularly in understanding the concept of local (a, d)-edge antimanic coloring, which serves as the foundation for developing appropriate learning tools. Learner analysis aims to gather data on the characteristics of students in the Mathematics Education study program at the University of Jember. Concept analysis is carried out to identify, elaborate, and systematically organize the concepts to be taught, especially those related to local (a, d)-edge antimanic coloring. Task analysis focuses on identifying the key skills required in the learning process according to the curriculum, particularly in assessing students' creative thinking skills in line with the expected learning outcomes.

The second stage, known as the design stage, aims to develop the initial draft of the learning tools to be used. At this stage, the design of RBL-STEAM learning materials is intended to assess the impact of the tools on enhancing students' creative thinking in the context of local (a, d)-edge antimanic coloring. This phase includes four steps: test preparation, media selection, format selection, and initial planning.

Test preparation in this study consists of descriptive questions that integrate STEAM elements and relate to the concepts of local (a, d)-edge antimanic coloring and ethnomathematical batik. The selected media include PowerPoint, used to present the locating metric coloring material and support student comprehension, as well as the RBL-STEAM MFI (Innovative Facilitator Module), which includes indicators of creative thinking.

The selected format adopts the research-based learning model and the STEAM approach, with appropriate stages aligned to the learning process. The initial planning refers to a complete learning toolkit that must be prepared before conducting the study. These tools include the Semester Learning Plan (RPS), Student Task Design (RTM), Student Worksheet (LKM), and Student Learning Outcome Test (THB).

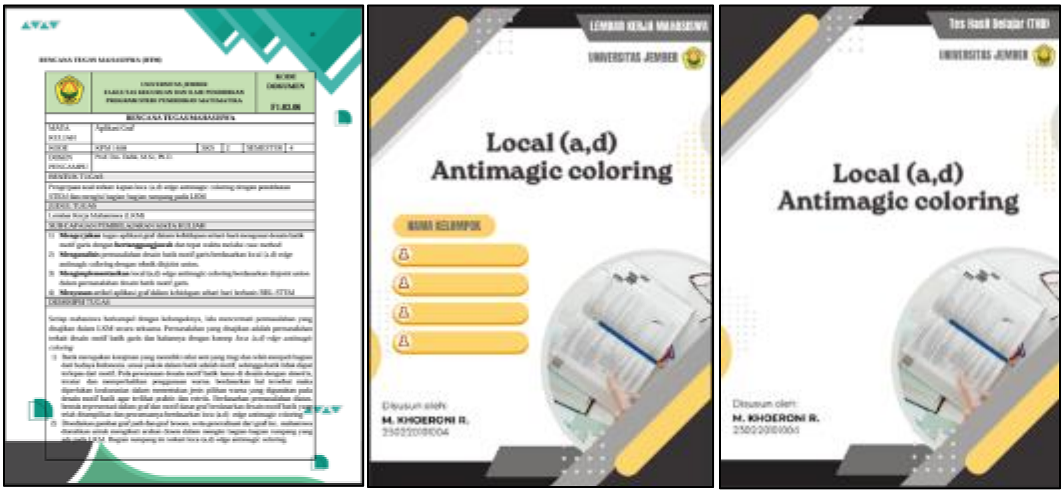

Figure 4 Initial Design of RPS, RTM, MFI, THB

The third stage is the development stage, which consists of four steps: validity testing, device testing, practicality testing, and effectiveness testing. Each learning tool developed during this stage was validated by experts and revised according to their recommendations. Once declared valid, the tools were tested in a Discrete Mathematics course, Class C, in the Mathematics Education Study Program at the University of Jember.

The results of the development stage are as follows: Based on evaluations and suggestions from two validators, revisions and improvements were made to the learning tools. According to both validators, the tools were deemed suitable for use with minor revisions. As shown in Table 1, the average validation score for the RBL-STEAM learning tools and instruments was 3.84, with a percentage of 96.04%. According to the established validity criteria, the developed learning tools meet the requirements for validity, as the score falls within the range of $3.84 \leq Va < 4$.

Table 1 Recap of RBL-STEAM Device Validation

Validation Result	Average Score	Percentage
Draft Student Assignments (RTM)	3.77	94.25%
Student Worksheet (LKM)	3.87	96.75%
Learning Outcome Test (THB)	3.82	95.5%
Student Activity Observation Sheet	3.82	95.5%
RBL-STEAM Implementation Sheet	3.94	98.5%
Student Response Questionnaire	3.83	95.75%
Overall average score	3.84	96.04%

The revised and validated learning tools were then tested on students in a class consisting of 35 participants. The experiment was supervised by eight observers, all of whom were Master's students in Mathematics Education at the Faculty of Teacher Training and Education (FKIP), University of Jember. Evaluations, including observer assessments and student work, were used to measure the practicality and effectiveness of the learning tools. The practicality test was based on two indicators: analysis of classroom implementation and student response questionnaires. The implementation analysis was based on the RBL-STEAM implementation observation sheet, evaluated by the eight observers. The overall average observation score was 3.94, with a percentage of 98.5%. According to the practicality criteria, the learning tools are considered highly practical, as they fall within the range of $90\% \leq SR \leq 100\%$. Based on student responses collected through questionnaires, the summary of student response scores is shown in Table 2. The overall average percentage of positive responses was 95.75%. Based on the analysis of both practicality indicators, the learning tools are considered practical for classroom use.

Table 2 Summary of Data from Student Response Questionnaire Results

Assessed Aspects	Percentage
Enjoyment of the learning component	92.14%
Students' environmental literacy skills feel trained	86.03%
Learning components are new	95.71%
Students clearly understand the language used	94.29%
Students understand the meaning of each problem presented	97.14%
Students are attracted by the appearance	98.57%
Students are interested in learning	94.29%
Students enjoy discussing with group members	94.29%
Overall average score	96.06%

The effectiveness of the learning tools was assessed using two indicators: analysis of student learning outcomes and observation of student activities. Student learning outcomes were measured through a post-test conducted on June 12, 2025, involving 35 participants. Based on the post-test results, 35 students (84.06%) scored above the minimum mastery threshold, indicating that the class achieved mastery learning collectively.

Observations included three phases: introduction, core activities, and closing. Student activity analysis was based on observation sheets evaluated by eight observers. As shown in Table 3, the overall average activity observation score was 3.63, with a percentage of 90.83%. In addition, most observer comments were positive, and no changes were made to the learning tools. According to the effectiveness criteria, the learning tools meet the standard for being highly effective, as they fall within the range of $90\% \leq SR \leq 100\%$.

Table 3 Recapitulation of Student Activity Observation Results

Validation Result	Average Score	Percentage
Introduction	3.93	98.37%
Core Activities	3.80	95.09%
Closing	3.62	90.62%
Overall average score	3.80	95.22%

The final stage is the deployment stage, which involves implementing the developed learning tools on a larger scale, such as in other classes that have not been part of the initial trial or in study programs offering similar courses. The purpose is to determine whether the developed tools perform effectively in broader teaching contexts. In addition, quantitative data analysis will be used to assess the improvement in students' creative thinking skills. Figure 5 presents the distribution of students' pretest and posttest scores, while Figure 6 illustrates the percentage distribution of students' creativity levels.

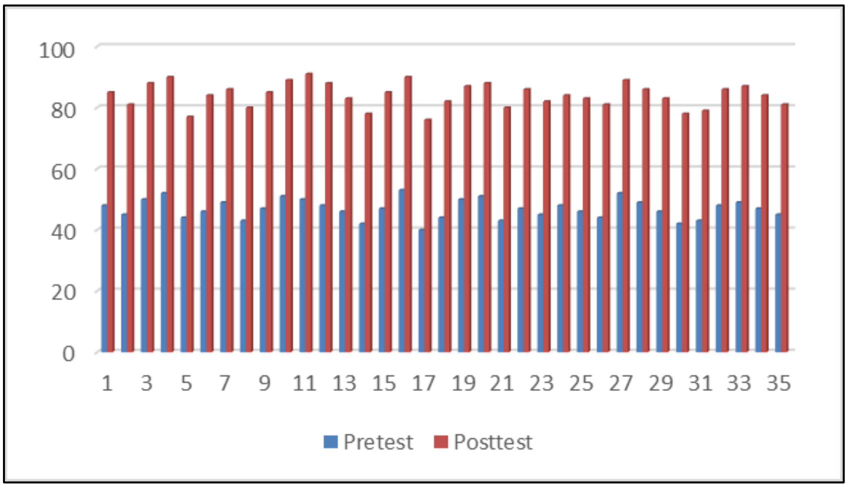

Figure 5 Graph of Distribution of Pretest and Posttest Scores

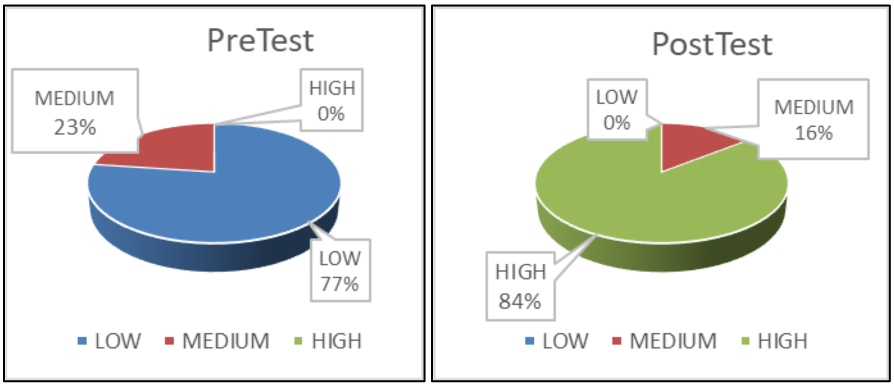

Figure 6 Percentage of Students' Environmental Literacy Level

In the pretest results, none of the students were categorized as having a high level of creative thinking skills. Students with moderate creative thinking skills accounted for 23%, while the remaining 77% were at a low level. Conversely, the posttest results showed a significant improvement, with 84% of students achieving a high level of creative thinking and 16% at a moderate level. Subsequently, a normality test was conducted as a prerequisite for performing a paired sample t-test, which was analyzed using SPSS software.

Table 4 Normality Test Results

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	do	Sig.	Statistic	do	Sig.
Pretest	0.070	35	0.200*	0.983	35	0.841
Post-test	0.088	35	0.200*	0.975	35	0.605

The results of the normality test in Table 4 indicate that both pretest and posttest scores are normally distributed, as the significance values (Sig.) are greater than 0.05. Subsequently, a paired sample t-test was conducted, and the results are presented in Table 5.

Table 5 Paired Sample Statistics

Paired Samples Statistics					
		Mean	N	Std. Deviation	Std. Error Mean
Pair 1	Pretest	46.8571	35	3.20975	0.54255
	Post-test	84.0571	35	3.97006	0.67106

The results presented in Table 5 show that the average posttest score is higher than the average pretest score. The average pretest score was 46.86%, which increased to 84.06% in the posttest. Additionally, it is noted that the number of data points analyzed for both the pretest and posttest was 35.

Table 6 Paired Sample Correlations

Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	Uji Pretest and Uji Post-test	35	0.954	0.323

The results in Table 6, based on 35 data points, show that the correlation coefficient between the pretest and posttest scores is 0.954. Furthermore, the significance value (p-value) is less than 0.05, indicating that the correlation between the two mean scores is both strong and statistically significant.

Table 7 Paired Sample Test

Paired Samples Test					
		Paired Differences	t	df	Sig. (2-tailed)
		95% Confidence Interval of the Difference			
		Upper			
Pair 1	Uji Pretest - Uji Post-test	-36.74519	-166.224	34	0.000

The results in Table 7 show that the probability value or Sig. (2-tailed) is 0.000, which is less than 0.05. Therefore, it can be concluded that there is a significant difference between the scores before and after the implementation of the RBL-STEAM learning tools on students' creative thinking skills.

4. Conclusion

Based on the results of the study on the development of RBL-STEAM learning tools to enhance students' environmental literacy, the developed learning tools met the criteria of validity, practicality, and effectiveness. The analysis involved processing pretest and posttest data using normality tests and paired sample t-tests. The normality test results indicated that the pretest and posttest scores were normally distributed, as the significance value (Sig.) was greater than 0.05. Furthermore, the results of the paired sample t-test showed that the Sig. (2-tailed) was 0.000, which is less than 0.05. This indicates a significant difference between the scores before and after learning with the RBL-STEAM tools, reflecting a notable improvement in students' creative thinking skills after participating in the learning process. The findings of this study may serve as a reference for developing RBL-STEAM learning tools aimed at enhancing students' creative thinking abilities.

Compliance with ethical standards

Acknowledgments

This research was funded by the PUI-PT Combinatorics and Graph, CGANT, University of Jember, in 2025. We also extend our gratitude to LP2M, University of Jember, for their invaluable support in facilitating this project.

Disclosure of conflict of interest

I would like to disclose that I am the author responsible for this research and have worked closely with the other authors as a team. While I will strive to remain objective throughout the article preparation process, I feel it is important to disclose my relationship with the other authors.

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