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The development of RBL-STEM learning materials to improve students' metaliteracy in solving watermarking image problems using rainbow antimagic coloring

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Abstract

The rapid development of information in this era emphasizes the importance of improving students' metaliteracy skills. One of the models and approaches that can be applied is Research Based Learning (RBL) integrated with Science, Technology, Engineering and Mathematics (STEM). The purpose of this study is to identify RBL-STEM activities, explain the steps and results of creating RBL-STEM learning materials, and examine data on the results of creating learning resources to increase students' metaliteracy level. Research and development (R&D) was the methodology used. The products of this research are the results of the development of learning tools in the form of students' assignment designs, students' worksheets, and learning outcome tests. The learning tool development process yielded data that met a validity requirement of 95.5%. The trial involved 40 students', and the use of the RBL-STEM learning resources was found to be effective with a 96.77% effectiveness criterion and practical with a 97.71% practicality criterion. In addition, students' responded positively to the learning experience and were highly engaged. Students' metaliteracy increased as they solved rainbow antimagic coloring problems, according to the pretest and posttest study. This study also identified three levels of metaliteracy proficiency: high, medium, and low. The research findings were validated using statistical analysis, phase image, N-Vivo, and word cloud, which also demonstrated an improvement in students' metaliteracy skills. Thus, RBL-STEM has the potential to improve students' metaliteracy in real-world contexts, such as the application of watermarking image.

Keywords: Metaliteracy; Research Based Learning; STEM; Rainbow Antimagic Coloring; Watermarking Image

1. Introduction

Education is one of the keys to the development of the nation's life [1]. The development of the nation's life can be done by changing and accelerating the development of education. Education is the main foundation for preparing individuals to face the challenges of the digital era, which is now in the 4.0 era [2]. This era is characterized by the rapid development of information and communication technology. It presents a variety of new problems that need to be solved, especially in the protection of data security and integrity. The context of education in the 4.0 era requires a transformation of learning models and approaches to improve students' readiness to face technological challenges in an increasingly complex digital era [3]. One of the models and approaches that can be used is the Research Based Learning (RBL) model with the Science, Technology, Engineering, and Mathematics (STEM) approach.

Research Based Learning (RBL) is a research-based learning model that involves various activities such as analysis, synthesis, and evaluation and helps to improve the understanding and application of knowledge [4]. Research-based

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learning (RBL) requires contextual and realistic problems and involves at least four scientific studies, namely science, technology, engineering, and mathematics [5]. The science, technology, engineering, and mathematics (STEM) approach is an approach that integrates science, technology, engineering, and mathematics with processes that focus on solving problems in everyday life [6]. The STEM approach allows students to integrate knowledge across disciplines and develop skills relevant to the needs of industry and society in the digital age. The faster the development of information in the digital age, the more necessary it is to improve students' metaliteracy skills.

Metaliteracy is the ability to manage, evaluate, and use information critically, which is one of the important aspects of education in era 4.0 [7]. This metaliteracy skill is the ability of students to access, understand, evaluate, and manage information critically in the context of digital learning and technology [8]. The development of students' metaliteracy skills in managing information and technology can be done using learning tools with the RBL-STEM model [4]. The development of metaliteracy can be supported by completing watermarking images using rainbow antimagic coloring.

Image watermarking is a technique for inserting information into digital images to protect copyright, maintain authenticity, or add additional data without significantly changing the appearance of the image [9]. This technique is often used to ensure that the source or ownership of an image can be identified even after the image has been processed or modified [10]. One aspect that requires special attention in this digital era is digital image security, where image watermarking techniques become a solution to insert secret information into images without significantly changing their appearance [11]. This research develops a learning tool that combines the concept of image watermarking with rainbow antimagic coloring technique, so that students will understand the basics of coloring and apply it to image watermarking problems.

Rainbow antimagic coloring is the coloring of graph edges with unique labels such that the number of labels on the edges connected to each vertex is different (antimagic), forming a "rainbow" pattern with different colors of edges [12] Integrating adjacency with the rainbow antimagic coloring method can be an important part of students' learning experience in understanding, applying, and developing complex image watermarking techniques. Rainbow antimagic coloring also has a high level of security because it hides secret information in digital images in a way that is not easily detectable. Thus, it can help improve their understanding of critical aspects of digital data security and develop the metaliteracy skills needed in the modern information technology era.

Some research related to Research-Based Learning (RBL) is the development of RBL-STEM learning tools to improve students' computational thinking skills to solve anti-magic rainbow coloring problems and its application to traffic flow problems using spatial-temporal GNN [13]. Another research is the development of research-based learning tools with a STEM approach to improve students' metaliteracy in solving sequential pair set problems [14]. Based on the RBL-STEM syntax that other researchers have done in solving a mathematical problem, a similar study was conducted in developing RBL-STEM learning devices by solving watermarking image problems using rainbow antimagic coloring with the aim of developing students' metaliteracy skills. Based on the above description, the topic used is "Development of RBL-STEM learning tools to improve students' metaliteracy by solving watermarking image problems using rainbow antimagic coloring".

2. Material and methods

2.1. Research-Based Learning (RBL)

Research-Based Learning (RBL) is an emerging model in education that enables students to acquire knowledge and skills through research processes such as information gathering, hypothesis generation, data collection, analysis, and report writing [15]. Research-based learning (RBL) aims to create learning experiences that encourage analysis, synthesis, and evaluation. In addition, RBL also aims to improve the ability of students and teachers to apply knowledge [16]. Research-Based Learning (RBL), combined with learning tools, can improve students' evidence skills and their activities during the learning process [17]. The Research-Based Learning (RBL) model encourages students to actively participate in research activities such as developing research questions, collecting and analyzing data, and presenting their findings. Through direct involvement in research, students not only improve their understanding of the material, but are also expected to develop the character of a scientific mind (scientist) in students. The research-based learning (RBL) model consists of three core elements, referred to as the triple helix, namely educators/teachers/lecturers, learning classes, and research groups.

2.2. Science, Technology, Engineering, Mathematics (STEM)

In 1990, the National Science Foundation (NFS) introduced a new innovation in education in the United States, namely STEM-based learning, which stands for Science, Technology, Engineering and Mathematics [18]. This approach is an approach that seeks to produce human resources with quality cognitive, psychomotor and affective. STEM-based learning to solve cases by applying knowledge and skills simultaneously. This approach emphasizes not only the mastery of scientific concepts, but also the application of these concepts in real-world situations through a problem-solving process [7]. Thus, STEM is not only an innovative approach to learning, but also has the potential to help prepare the younger generation to become competent individuals ready to face future challenges. This research will apply a Research-Based Learning (RBL) based learning model with a STEM approach to improve metaliteracy skills in solving watermarking image problems with rainbow antimagic coloring.

2.3. Metaliteracy

Metaliteracy is an overarching framework that includes information literacy [19]. Metaliteracy describes an overarching framework and serves as a broad and independent guide compared to other types of literacy. For example, information literacy is a form of metaliteracy in the digital age because it requires higher-order thinking skills to manage different types of documents in various media formats in a collaborative environment [20]. Metaliteracy skills emphasize the importance of an individual's ability to effectively manage, evaluate, and participate in various forms of information in the evolving digital age. The use of metaliteracy demonstrates one's literacy mindset and emphasizes the critical thinking and reflection required as a producer, collaborator, and distributor [21].

2.4. Methods

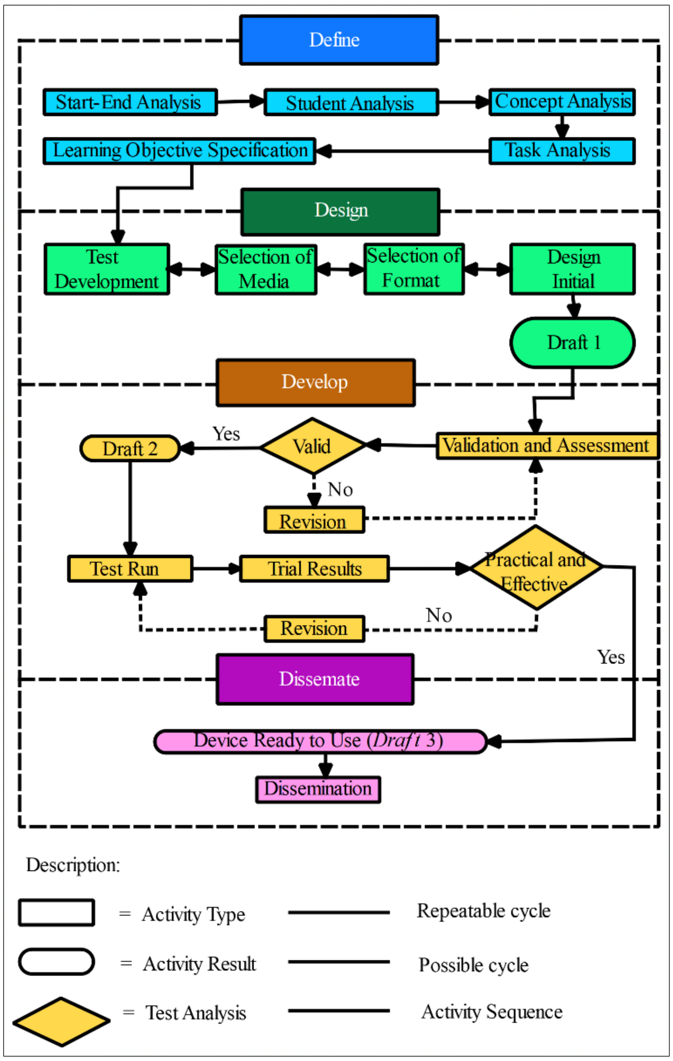

Figure 1 Stages of Learning Device Development 4-D Model

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.

3. Results and discussion

This RBL-STEM 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 problems. Researchers consider the problem of watermarking images as shown in Figure 2.

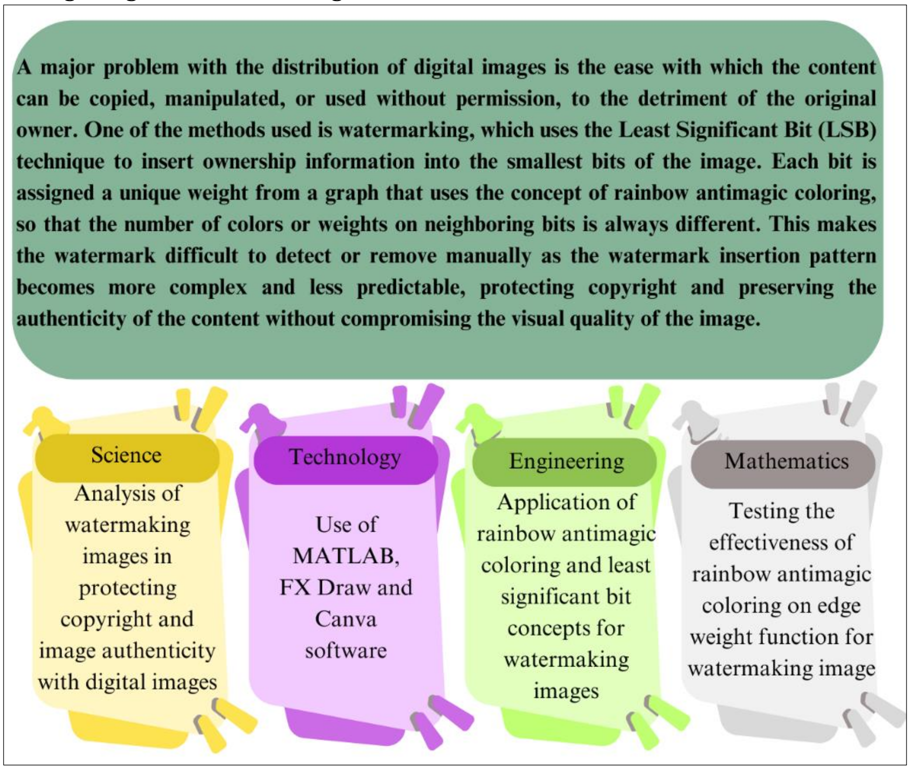

Figure 2 STEM elements of image watermarking scheme

This research aims to solve the problem of image watermarking using rainbow antimagic coloring. Therefore, the RBL-STEM model has the following activity framework, 1) the first stage that students must do is to understand previous research related to image watermarking using rainbow antimagic coloring, 2) obtain innovations in the application of image watermarking based on rainbow antimagic coloring, 3) construct the weight function of rainbow antimagic coloring, 4) analyze data related to image watermarking and the use of software in its processing, 5) generalize data by applying to other similar problems, 6) draw conclusions from the results of the activity by presenting the results obtained related to solving image watermarking problems using side weights from the concept of rainbow antimagic coloring.

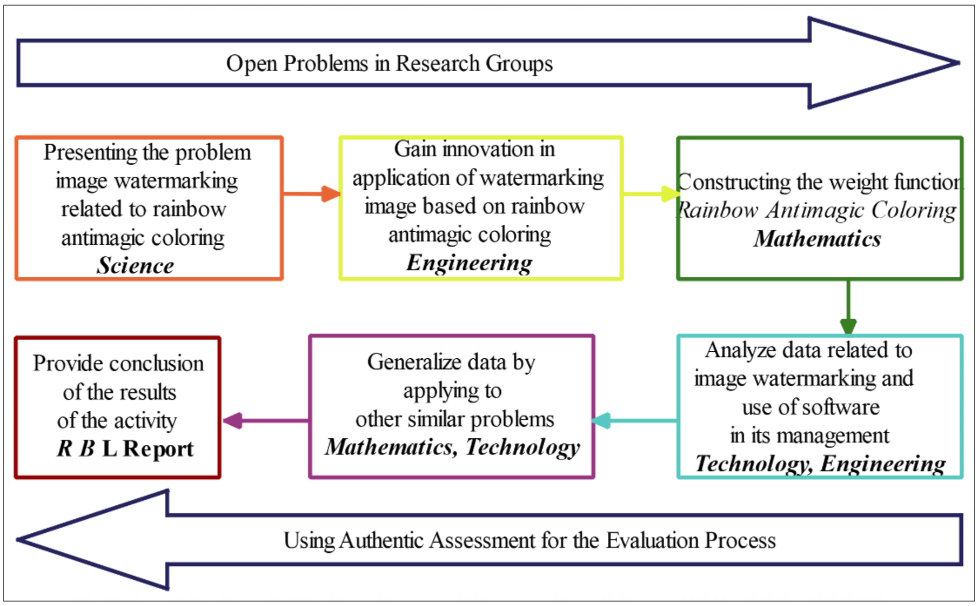

Figure 3 RBL-STEM Activity Framework for the RAC Problem

The first stage of the 4D model is to define, the purpose of this defining stage is to identify and define the learning needs by analyzing the objectives and limitations of the material to be provided. The defining stage is divided into four stages, namely beginning-end analysis, learner analysis, concept analysis and task analysis. The beginning-end analysis is conducted to identify the problems students face in learning, especially in understanding the concept of rainbow antimagic coloring, as a basis for developing learning devices. Student analysis was conducted to obtain data on the characteristics of undergraduate students of Mathematics Education, University of Jember. Concept analysis was conducted to identify, detail and systematically arrange the concepts learned by students on the concept of rainbow antimagic coloring. Task analysis aims to identify the main skills required in learning in accordance with the curriculum, namely identifying students' metaliteracy in accordance with the expected final ability.

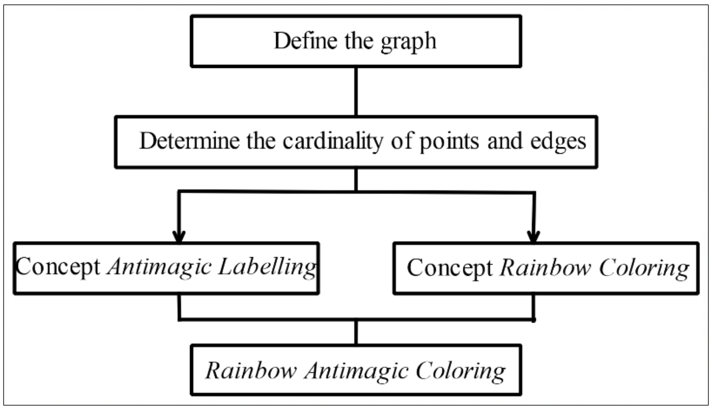

Figure 4 Rainbow Antimagic Color Theme Concept Map

The second stage, design, aims to design the learning devices to be used so that an initial design is obtained. At this stage, the design of the RBL-STEM device is carried out to determine the effect of learning devices on increasing students' metaliteracy on the concept of rainbow antimagic coloring. There are four steps in this phase, namely test preparation, media selection, format selection, and initial planning. The test preparation in this study is in the form of descriptions that include STEM and are related to the concept of rainbow antimagic coloring and image watermarking to maintain the authenticity of digital images by watermarking the images. The media selection process selected includes Power Point as a medium for delivering rainbow antimagic coloring material that can support student understanding and RBL-STEM MFIs that contain indicators of metaliteracy. The selection of this research format uses a learning model, namely research-based learning and the STEM approach with the learning stages in it selected as the learning format. The initial design is the overall design of learning tools that must be done before the study. The learning tools are in the form of Semester Learning Plan (RPS), Student Task Design (RTM), Student Worksheet (LKM) and Learning Outcome Test (THB). The visualization of the learning materials is shown in Figure 5.

Figure 5 Initial Design of RPS, RTM, MFI, THB

The third stage is the development stage, which consists of 4 stages, namely validity test, device test, practicality test and effectiveness test. Each device produced in the development stage is validated by the validator and revised according to the recommendations. After the device was declared valid, a trial was held in the Graf Application Course of Class B of the Mathematics Education Study Program at the University of Jember. The results of this development stage are as follows: Based on the evaluation and suggestions of two validators, revisions and improvements were made to the developed learning devices. Based on the evaluation of the two validators, the device is feasible to use with minor changes. Based on the results of the recapitulation of the validation of RBL-STEM devices and instruments in Table 1, the average score of the validation is 3.82 with a percentage of 95.5%. Based on the validity criteria, the prepared learning device meets the validity criteria because it meets the score of $3.82 \leq V_a < 4$.

Table 1 Recap of RBL-STEM Device Validation

Validation Result	**Average Score**	**Percentage**
Draft Student Assignment (RTM)	3.76	94%
Student Worksheet (LKM)	3.83	95.83%
Learning Outcome Test (THB)	3.85	96.25%
Student Activity Observation Sheet	3.82	95.42%
RBL-STEM Implementation Sheet	3.83	95.83%
Student Response Questionnaire	3.83	95.83%
Overall average score	**3.82**	**95.5%**

The revised and validated devices were tested on students. This trial was conducted in a class of 40 students. The experiment was supervised by observers. The eight observers were students of the Master of Mathematics Education, FKIP, University of Jember. Evaluations including observer ratings and student work were used to assess the practicality and effectiveness of the device. The practicality test of learning devices consists of 2 indicators, namely by analyzing the results of learning implementation in the classroom and the results of student response questionnaires. The analysis of the implementation of learning is based on the RBL-STEM implementation observation sheet, which is evaluated by 8 observers. Based on the average score of the overall learning implementation observation results is 3.91 with a percentage of 97.71%. Based on the criteria of practicality, the prepared learning device meets the criteria of very high practicality because it meets the score of 90%≤ SR≤100%. Based on the students' responses in the questionnaire sheet, the summary of the students' response scores is presented in Table 2. Overall, the average positive percentage is 92.85%. Based on the analysis of the 2 indicators of the practicality of the learning device, this device is practical to use.

Table 2 Summary of Data from Student Response Questionnaire Results

Assessed Aspects	Percentage
Enjoyment of the learning component	96.88%
Students' metaliteracy skills feel trained	87.81%
Learning components are new	89.38%
Students clearly understand the language used	91.88%
Students understand the meaning of each problem presented	93.13%
Students are attracted by the appearance	91.25%
Students are interested in learning	95%
Students enjoy discussing with group members	97.5%
Overall average score	**92.85%**

The effectiveness test of learning devices consists of 2 indicators, namely by analyzing student learning outcomes and student activity observation results. Student learning outcomes were obtained through a post-test conducted on Thursday, October 10, 2024. The research subjects were 40 students. Based on the posttest results, it was found that 35 students (88%) had scores above the minimum completeness, which means classically complete. The observations used were observation of the introduction, core activities, and conclusion. The analysis of student activity is based on the student activity observation sheets scored by 8 observers. Based on Table 3, the overall average score of student activity observation was 3.87 with a percentage of 96.77%. In addition, the observers' comments were mostly positive, so they did not change the overall learning tool. Based on the effectiveness criteria, the learning tools meet the criteria of effective very active because they meet the score of 90%≤ P≤100%.

Table 3 Recapitulation of Student Activity Observation Results

Assessed Aspects	Average Score	Percentage
Introduction	4	100%
Introduction	3.61	90.31%
Closing	4	100%
Overall average score	3.87	96.77%

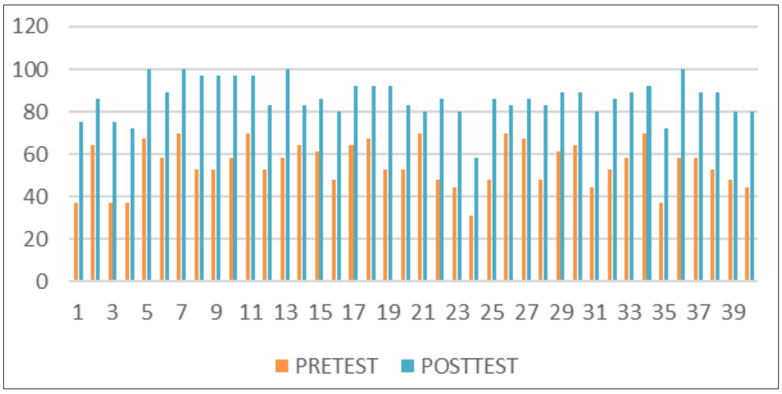

Figure 6 Graph of Distribution of Pretest and Posttest Scores

The final stage is the deployment stage, which involves the use of learning tools that have been developed on a larger scale, such as in untested classes or in study programs with similar courses. The goal is to find out if the developed tools work well in learning activities. In addition, we will use quantitative data analysis to analyze the improvement in students' information literacy skills. The following graph shows the distribution of students' pretest and posttest scores in Figure 6. While Figure 7 shows the percentage of students' metaliteracy level.

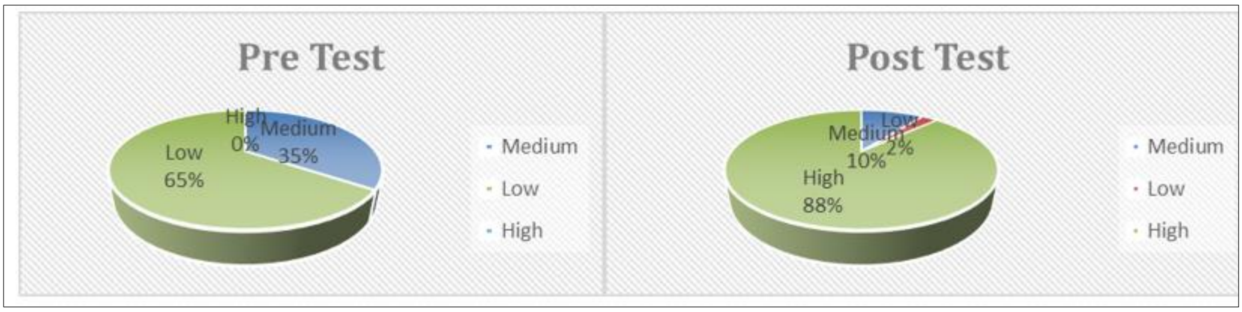

Figure 7 Percentage of Students' Metaliteracy Level

In the pretest results, there were no students who were categorized with high levels of metaliteracy, students with moderate levels of metaliteracy were 35%, and students with low levels of metaliteracy were 65%. While in the post-test results, students who were categorized with high levels of metaliteracy reached 88%, students with moderate levels of metaliteracy decreased to 10%, and students with low levels of metaliteracy skills decreased to 2%. In addition, a normality test was performed as a condition for the paired samples t-test. This statistical test was performed using SPSS software.

Table 4 Normality Test Results

Tests of Normality						
	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Pretest	0.111	40	0.200*	0.947	40	0.058
Posttest	0.115	40	0.195*	0.946	40	0.057

Based on the results of the data normality test in Table 4, it shows that the pretest and posttest scores are normally distributed because the significance value (Sig.) is > 0.05. Next, a paired samples t-test is performed as shown in Table 5.

Table 5 Paired Sample Statistics

Paired Samples Statistics					
		Mean	**N**	**Std. Deviation**	**Std. Error Mean**
Pair 1	Pretest	54.98	40	10.760	1.701
	Posttest	86.33	40	8.974	1.419

The test results in Table 5 show that the average posttest score is higher than the average pretest score. The average pretest score was 54.98 and then increased to 86.33 on the average posttest score. It can also be seen that the amount of data entered in the pretest and posttest is 40 data.

Table 6 Paired Sample Correlations

Paired Samples Correlations				
		N	**Correlation**	**Sig.**
Pair 1	Pretest & Posttest	40	0.693	0.000

The test results in Table 6 with a lot of data as much as 40, namely the pretest and posttest correlation value of 0.693> 0.05. This shows that the correlation or relationship between the two average pretest and posttest scores is strong and significant.

Table 7 Paired Sample Test

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	-31.350	7.899	1.249	-33.876	-28.824	-25.103	39	0.000

The test results in Table 7 are probability or Sig. (2-tailed) is equal to 0.000 <0.05. In conclusion, there are differences in the scores before and after learning using RBL-STEM devices on students' metaliteracy.

4. Conclusion

Based on the results of research conducted in the development of RBL-STEM learning tools to improve students' metaliteracy, the learning tools meet the criteria of valid, practical, and effective. Quantitative analysis includes pretest and posttest data processing, which is carried out normality test and paired samples t-test. Based on the normality test, it can be concluded that the pretest and posttest scores have a normal distribution because the significance value (Sig.) > 0.05. Furthermore, the paired sample t-test results show that the Sig. (2-tailed) is equal to 0.000 <0.05. That is, there is a difference in the value before and after learning with the RBL-STEM device on students' metaliteracy. This result shows that there is a significant increase in students' metaliteracy after participating in learning. The usefulness of this research can be used as a reference in making RBL-STEM devices to improve students' metaliteracy.

Compliance with ethical standards

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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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