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Development of RBL-STEM learning tools to enhance students' metaliteracy in identifying facial skin types using graceful color segmentation and Deep-CNN techniques

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Abstract

At present, possessing literacy skills alone is insufficient to address the challenges of the globalized world. The ability to reflect on one's cognitive processes when interacting with diverse sources of information is also required; therefore, a new concept known as *metaliteracy* has emerged. One model and approach that can be applied to enhance metaliteracy is Research-Based Learning integrated with Science, Technology, Engineering, and Mathematics (RBL-STEM). This study aims to identify RBL-STEM activities, to describe the processes and outcomes of developing RBL-STEM learning tools, and to examine improvements in students' metaliteracy. The study employed a Research and Development (R&D) methodology. The research products consisted of developed learning tools, including student assignment designs, student worksheets, and learning outcome tests. The development process resulted in a validity level of 94%. The trial involved 33 students, and the results indicated that the RBL-STEM approach was effective, achieving an effectiveness score of 94.7%, and practical, with a practicality score of 94.2%. In addition, students demonstrated positive responses to the learning experience and exhibited a high level of engagement. Students' metaliteracy improved after solving problems related to Deep Convolutional Neural Networks (Deep-CNN), as evidenced by the pretest and posttest results. The study also identified three levels of students' metaliteracy, namely high, medium, and low. The research findings were validated through statistical analysis using the SPSS application. Therefore, RBL-STEM has the potential to enhance students' metaliteracy in real-world contexts, such as the application of Deep-CNN with graceful color segmentation for identifying facial skin types.

Keywords: Metaliteracy; RBL-STEM; Deep-CNN; Graceful Coloring; Facial Skin Types

1. Introduction

UNESCO, as cited by the Indonesian Ministry of Education and Culture (Kemendikbud), defines literacy as an integrated set of abilities to use reading, writing, and numeracy skills in accordance with context, which are acquired and developed through learning processes and application in schools, families, communities, and other relevant situations [1]. However, at present, possessing literacy skills alone is still insufficient to address the challenges of the globalized world. The ability to reflect on one's thinking processes when interacting with diverse information is also required.

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Consequently, a new concept known as *metaliteracy* has emerged. Metaliteracy is defined as a comprehensive model of information literacy that aims to enhance critical thinking and reflective practices [2]. Therefore, educators are required to have the capability to design learning activities that effectively enhance students' metaliteracy. In line with this, student-centered learning designs must be maintained so that the improvement of students' metaliteracy can be integrated into the domains of attitudes, knowledge, and skills as learning outcomes to be achieved by students.

Research-Based Learning (RBL) is one learning model that actively involves students in exploring information. RBL provides opportunities for students to seek information, formulate hypotheses, collect data, and draw conclusions [3]. The STEM (Science, Technology, Engineering, and Mathematics) approach integrates multiple disciplines within a single learning activity. In practice, problem-solving often requires more than one field of knowledge. Through the STEM approach, students are encouraged to analyze, explain, and create products based on their learning outcomes [4]. One area of content that can effectively apply the STEM approach is digital image processing.

Digital image processing is a discipline that studies techniques for processing images (photographs or videos) digitally using computers. In this process, images need to undergo segmentation, which involves separating objects from their background so that further analysis can be performed. The segmentation technique employed in this study is *graceful coloring*, a technique derived from graph theory that assigns labels to graph elements according to specific rules to enable optimal distribution of label values. Subsequently, image processing is carried out using Deep Convolutional Neural Network techniques.

Deep Convolutional Neural Networks (Deep-CNN) are widely recognized as one of the deep learning architectures inspired by the human neural system. Deep-CNN consist of multiple layers of computational neurons with processing performed hierarchically, resulting in significant advancements in the field of computer vision research [5]. One of the primary advantages of Deep-CNN is their ability to automatically extract features from images without requiring manual feature extraction. This capability enables Deep-CNN to recognize complex patterns more efficiently.

The application of Deep-CNN in the healthcare sector has also developed rapidly. Along with the increasing public awareness of skincare, numerous brands and skincare products have emerged to offer solutions, particularly for facial skin care. Understanding facial skin types is crucial, as each skin type requires different treatment approaches. The use of Deep-CNN to identify facial skin types can significantly assist in determining effective and efficient skincare treatments. In this context, the ability to read and understand information, as well as to evaluate and critically assess encountered information (metaliteracy), becomes essential. Such abilities help individuals filter relevant and accurate information and make more informed decisions regarding facial skincare.

Numerous studies have explored the application of Deep-CNN in the healthcare field. For instance, research conducted by Ekin Adhi Guna et al. utilized Deep-CNN for skincare-related recommendations and concluded that Deep-CNN, as a component of deep learning, demonstrate high performance across various applications, including the identification of acne severity levels on facial images [6]. Yudha and Wahyudi applied Deep-CNN for cataract detection and achieved an accuracy rate of 97% [7]. Meanwhile, Agung and Achmad reported an accuracy of 75% in predicting pneumonia disease using Deep-CNN [8].

Based on the discussion above, to support the successful enhancement of learning outcomes, this study focuses on the development of RBL-STEM–based learning tools aimed at improving students' metaliteracy in applying digital image processing using graceful color segmentation with Deep Convolutional Neural Network techniques. The learning tools developed include student assignment designs, student worksheets, and learning outcome tests. The problems addressed in this study are specifically related to facial skin type identification using Deep-CNN techniques, with datasets obtained from the Kaggle website. Therefore, the title of this study is *"Development of RBL-STEM Learning Tools to Enhance Students' Metaliteracy in Identifying Facial Skin Types Using Graceful Color Segmentation and Deep-CNN Techniques."* To determine the impact of RBL-STEM implementation on improving students' metaliteracy, a quantitative analysis was conducted on the results of the developed learning tools.

2. Material and methods

2.1. RBL - STEM

Research-Based Learning (RBL) can be simply defined as a learning approach that involves students, either individually or in groups, in research activities with the aim of developing a deeper understanding of a particular topic. Ulinsa, in her book, describes research-based learning as an instructional approach characterized by authentic learning, problem solving, cooperative learning, contextual learning, and inquiry-based strategies grounded in the philosophy of constructivism [9]. Ahdika reported that RBL designed to enhance students' quality, interest, and critical and analytical thinking skills demonstrated significant results, indicating that RBL effectively increases students' learning motivation in higher education settings [10]. A well-designed RBL learning environment has been shown to improve students' understanding and research skills, making it a highly recommended learning experience for university students [11]. Zainal Arifin, in his study, reported that RBL successfully enhances students' cognitive aspects, attitudes, and skills, particularly in content knowledge, critical and analytical thinking, and communication abilities [12]. Furthermore, RBL is highly effective when implemented in higher education, as it facilitates in-depth understanding of fundamental concepts and methodologies, fosters problem-solving skills, and develops students' abilities to regulate and evaluate their own thinking processes [13]. In addition, the presence of research groups plays a crucial role in RBL, as they provide students with direct opportunities to engage in research activities, thereby enabling them to actively contribute to the creation of new knowledge and to enrich their learning experiences [14].

The concept of STEM emerged as an approach to remove the boundaries among disciplines, enabling their integration into a cohesive curriculum. STEM education is considered an innovative instructional approach, as it is capable of addressing educational challenges in the Industry 4.0 era and supporting the development of four essential skills: critical thinking, creativity, communication, and collaboration. STEM empowers both students and educators to engage in research, dialogue, problem solving, and experiential learning [15]. The STEM approach is not limited to primary and secondary education but can also be implemented at the undergraduate, graduate, and even postdoctoral levels [16]. An article by Carter et al. emphasized that STEM approaches are highly necessary in higher education to equip students with relevant skills to meet global challenges; therefore, interdisciplinary approaches that allow collaboration across diverse disciplines by integrating multiple perspectives and methodologies are essential [17]

2.2. Metaliterasi

The concept of *metaliteracy* was developed by Thomas P. Mackey and Trudi E. Jacobson in response to the rapid growth of digital technologies and social media, which requires users to be more active and critical in utilizing information. Metaliteracy is a framework that integrates multiple forms of literacy into a comprehensive and unified model. It not only focuses on how individuals search for and evaluate information but also emphasizes how information is produced and shared within collaborative and participatory digital environments [18]. A core component of metaliteracy is the metacognitive dimension, which encourages continuous reflection on one's own thinking processes and literacy development within an increasingly connected and dynamic information environment [2]. According to Jacobson and Mackey, the key indicators of metaliteracy include *produce*, *incorporate*, *use*, *share*, and *collaborate*. The modified indicators and sub-indicators of metaliteracy applied in this study are presented in Table 1. The metaliteracy indicators *produce*, *incorporate*, and *use* were assessed based on students' performance in the pretest and posttest, whereas the indicators *share* and *collaborate* were evaluated through the learning process using student worksheets and interviews.

Table 1 Development of Metaliteracy Indicators

Indicators	Sub Indicators
Produce	Students are able to identify problems related to Deep-CNN
	Students are able to design technical steps to solve the identified problems.
	Students are able to generate solutions to problems in Deep-CNN applications
Incorporate	Students are able to repeat iterative processes in convolution operations within Deep-CNN
	Students are able to generalize convolution operation formulas in Deep-CNN
	Students are able to determine graceful coloring in a graph
	Students are able to utilize MATLAB software to solve problems
Use	Students are able to elaborate on other problems using the Python-based Google Colab online platform
	Students are able to generalize results to other problems.
	Students are able to apply the results to real-life contexts
Share	Students actively contribute ideas during group discussions
	Students demonstrate effective presentation skills in front of the class

Collaborate	Students demonstrate the ability to collaborate effectively in solving problems within groups
	Students are able to receive suggestions, feedback, and reflections from peers constructively

2.3. Research methods

The research procedure employed in this study refers to the development model proposed by Thiagarajan, commonly known as the 4D model. The stages of the 4D model consist of *define*, *design*, *develop*, and *disseminate*. A schematic diagram of the 4D model in the development of learning tools is presented in Figure 1. Data collection techniques in this study were based on research instruments that included learning tool validation, observation of learning implementation, collection of learning outcome data, observation of student activities, and response questionnaires. In this study, data analysis was conducted using quantitative data analysis, utilizing the SPSS application to perform statistical tests.

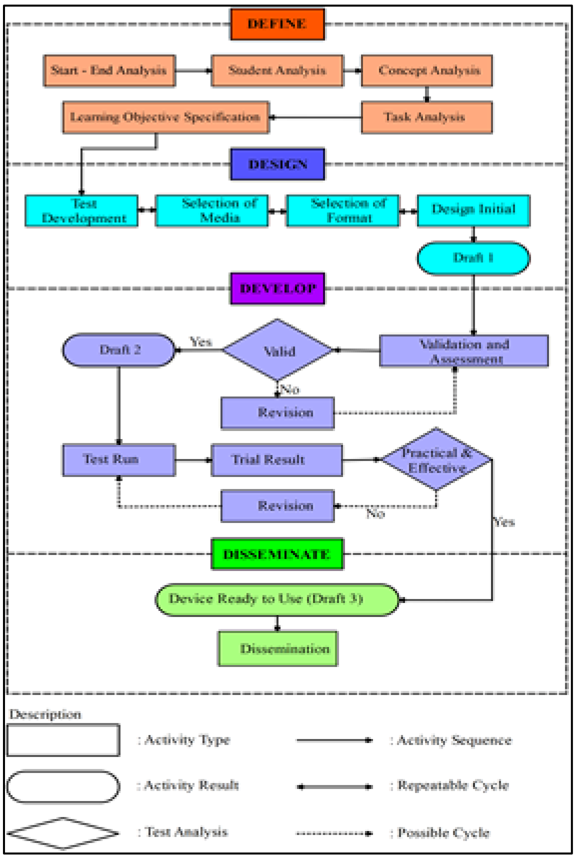

Figure 1 Stages of 4D-Model Learning Tool Development

3. Results and discussion

The RBL-STEM model can be integrated to enhance students' metaliteracy in addressing problems related to the application of graceful color segmentation and Deep Convolutional Neural Network (Deep-CNN) techniques for identifying facial skin types. The implementation of this model requires students' creativity, active participation, and metaliteracy skills in understanding and solving the given problems. In this context, the primary challenge involves training a machine to analyze digital images from various visual datasets of facial skin types using Deep-CNN techniques. Subsequently, students explore information from multiple sources to obtain relevant and reliable data.

The research approach in this study consists of the following stages: (a) identifying facial skin types and determining methods for obtaining visual datasets; (b) developing a Deep-CNN model incorporating graceful color segmentation; (c) collecting visual data for Deep-CNN architectural modeling and analysis; (d) implementing the Deep-CNN model to identify facial skin types; (e) validating the general convolution formulas, performing iterations, evaluations, and model testing; and (f) presenting the results, preparing research reports, and observing the required aspects of students' metaliteracy. The instruments included in the developed learning tools consist of student assignment designs, student worksheets, and learning outcome tests in the form of pretests and posttests. The learning tools are considered feasible for use when they meet the criteria of validity, practicality, and efficiency.

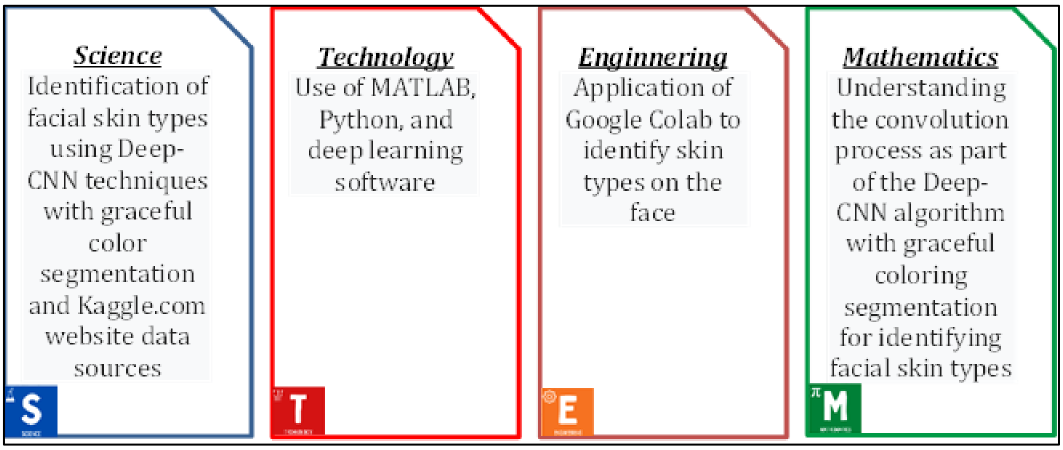

Figure 2 Aspects of RBL-STEM

The *define* stage aims to establish and define learning needs during the instructional process by analyzing learning objectives and the scope of the material to be delivered. This definition stage consists of five steps. An initial and final analysis is conducted to identify the fundamental problems to be addressed in the development of the learning tools. The selected topics include graceful coloring in graph theory and machine learning, particularly Deep Convolutional Neural Networks (Deep-CNN), which involve convolution operations.

Student analysis is carried out to examine the characteristics of undergraduate students in the Mathematics Education program, Faculty of Teacher Training and Education (FKIP), University of Jember, to ensure alignment with the design and development of the selected learning topics. Concept analysis is used to identify, elaborate, and structure the material concepts presented in the student worksheets (LKM) to be studied by students. The results of the concept analysis are illustrated in Figure 3. Task analysis aims to determine student assignments included in the LKM as well as in the learning outcome tests (THB), which are used to analyze students' metaliteracy. The specified learning objectives are utilized to achieve the target of improving students' metaliteracy.

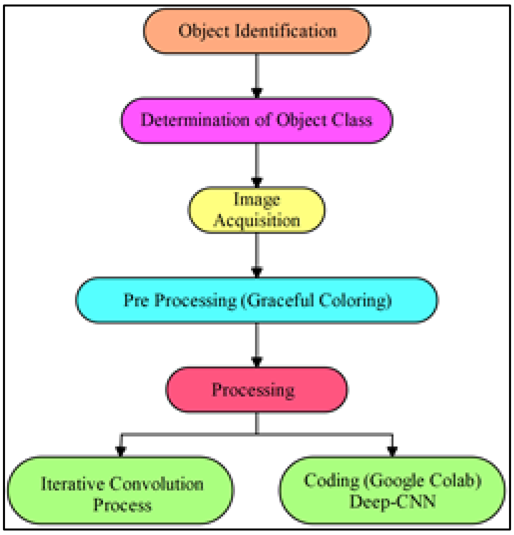

Figure 3 Concept Map

The *design* stage focuses on developing RBL-STEM learning tools based on the results of the definition stage, with the objective of enhancing students' metaliteracy in identifying facial skin types using Deep-CNN techniques with graceful color segmentation. The steps in this stage include: (1) designing student assignments aligned with the learning objectives; (2) developing student worksheets (LKM) containing problem topics, learning materials, and answer keys; and (3) constructing learning outcome tests (THB), which are administered as pretests and posttests. Figure 4 presents the initial design of the developed learning tools.

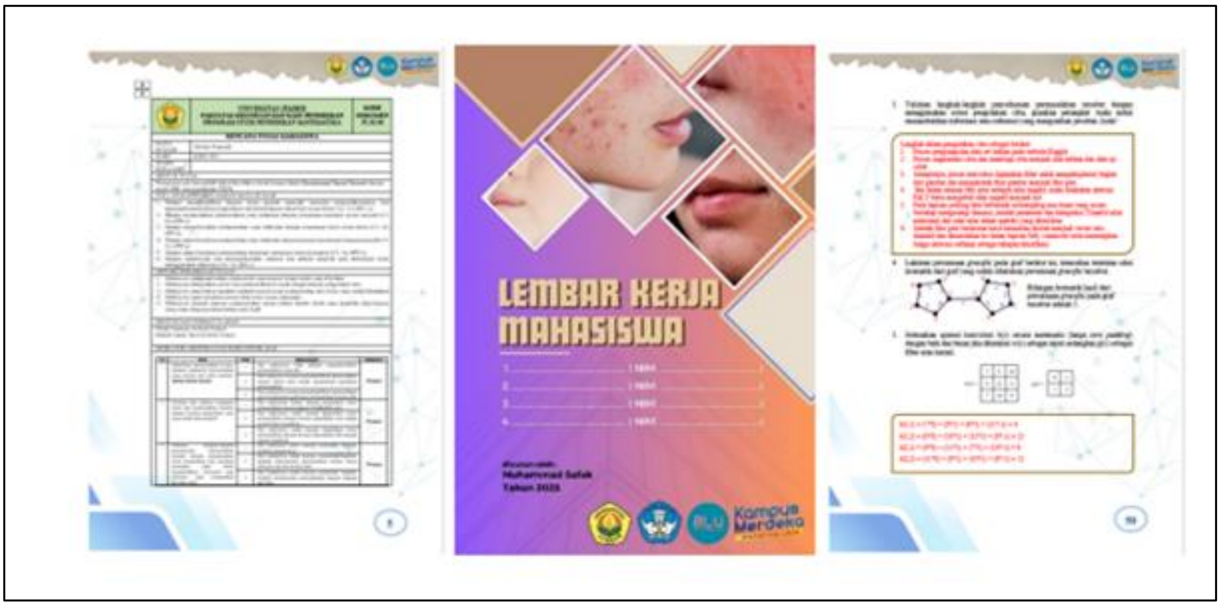

Figure 4 Initial design of RTM, LKM, and THB

At the *develop* stage, the learning tools that had been designed were validated by expert validators and revised according to their recommendations. At this stage, a classroom trial was also conducted in the Combinatorics course of the Mathematics Education Study Program, Faculty of Teacher Training and Education (FKIP), University of Jember, after the learning tools were declared valid. The evaluation of the learning tools was carried out by two validators. The validation process involved all learning tools, student activity observation sheets, RBL-STEM implementation observation sheets, and student response questionnaires, using assessment instruments and validation sheets.

Table 2 Recapitulation Results of RBL-STEM Device Validation

Validation Results	**Average**	**Percentage**
Learning Tools	3.76	94%
Student activity observation sheet	3.72	93%
RBL-STEM implementation observation sheet	3.77	94.4%
Student response questionnaire	3.86	96.5%
Overall average score	3.77	94%

Based on the evaluations of both validators, the learning tools were deemed suitable for use with minor revisions in accordance with the validators' suggestions. The results of the validation conducted by the two validators indicate that the learning tools and RBL-STEM instruments achieved an average score of 3.77 across all assessed aspects, corresponding to a validity percentage of 94%. According to the validity criteria, the developed learning tools met the valid category, as they satisfied the criterion of $3.25 \leq V_a < 4$.

After being declared valid, the learning tools were tested with students. The trial was conducted in a combinatorics class consisting of 33 students. The implementation was supervised by several instructors and observers, including eight observers who were graduate students from the Master's Program in Mathematics Education, FKIP, University of Jember. The assessment results, which consisted of observer evaluations and students' work, were used to determine the practicality and effectiveness of the learning tools. The data collected during the trial included student activity data, observations of learning implementation completed by observers, student response questionnaires, and pretest–posttest results of the learning outcome tests. The results of these analyses were used to consider revisions to the learning tools until they were ready for classroom implementation. The practicality test of the learning tools was based on two indicators: analysis of learning implementation in the classroom and analysis of student response questionnaires. The analysis of learning implementation was based on the RBL-STEM implementation observation sheets assessed by eight observers. The overall average score of learning implementation was 3.77, with a percentage of 94.2%. According to the practicality criteria, the developed learning tools met the *very practical* category, as they satisfied the criterion of 90% < $SR \leq$ 100%.

In addition, the recapitulation of student response questionnaire results indicates that, based on the student response criteria, the developed learning tools received a *very positive* response, as they met the criterion of 80% $\leq P_r \leq$ 100%, with an overall average percentage of 97.31%. The analysis of learning implementation based on the RBL-STEM observation sheets fulfilled the practicality criteria and received positive evaluations. Likewise, the analysis of student response questionnaires demonstrated positive responses from students. Therefore, based on the results of both practicality indicators, it can be concluded that the developed learning tools are practical for classroom use.

Table 3 Recap of Student Response Questionnaire Data Results

Rated aspect	**Percentage**
Enjoyment of learning components	100%
Students' metaliteracy feels trained	97%
The learning components are considered new	90%
Understand clearly the language used	98.5%
Understand the meaning of each question/problem presented	96%
Interest in device design	97%
Interested in taking part in learning	100%
Discuss with other members	100%
Average score of all aspects	97.31%

Two indicators were used to examine the effectiveness of the learning tools. The first indicator was the analysis of students' learning outcomes, while the second was the observation of student activities. Students' learning outcomes were obtained through the posttest. Based on the posttest results measuring students' metaliteracy, 31 out of 33 students (93.94%) achieved mastery. Considering the mastery criterion that at least 80% of the total number of students must achieve mastery, it can be concluded that the combinatorics class achieved classical mastery. Student activity observations during the learning process were conducted across three stages: introductory, core, and closing activities. The recapitulation of student activity observation scores, assessed by eight observers, indicates that the overall average score of student activity was

Table 4 Recapitulation of Observation Results of Student Activities

Rated Aspect	**Average**	**Percentage**
Preliminary activities	3.68	92%
Core activities	3.81	95.3%
Closing activities	3.87	96.7%
Average score of all aspects	3.78	94.7%

Based on two indicators: students' learning outcomes and observations of student activities, the effectiveness of the developed learning tools can be determined. The results indicate that the developed learning tools meet the criteria of being *highly effective and very active*, as they achieved a score within the range of $90\% \leq P \leq 100\%$.

Figure 5. presents a graphical distribution of the pretest and posttest scores of the 33 students. The graph clearly shows an increase from pretest scores to posttest scores. Figure 6. illustrates the percentage distribution of students' metaliteracy levels. In the pretest results, no students were categorized as having high or medium metaliteracy levels, while 100% of the students were classified as having a low level of metaliteracy. In contrast, the posttest results show that 66.7% of students achieved a high level of metaliteracy, 27.3% reached a medium level, and only 6% remained at a low level. These findings are further illustrated in the accompanying diagram.

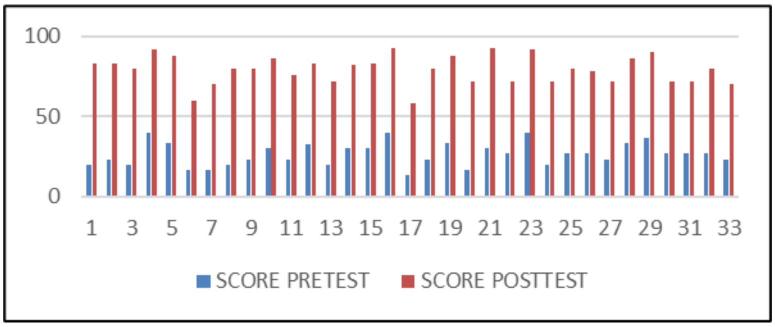

Figure 5 Distribution graph of pretest and posttest scores

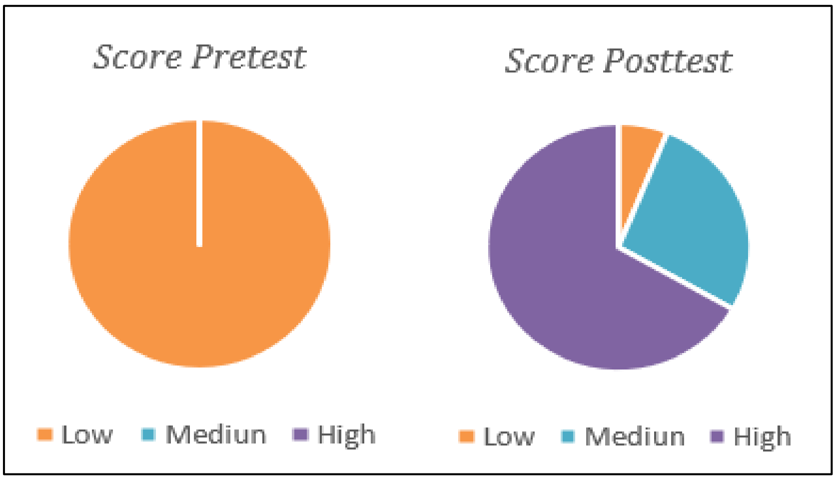

Figure 6 Percentage of Student Metaliteracy Level

Subsequently, a normality test was conducted as a prerequisite for performing a paired-sample *t*-test. The paired-sample *t*-test was employed to examine the relationship between pretest and posttest scores. All statistical analyses were conducted using SPSS software.

Table 5 Normality Test Results

Tests of Normality						
	Kolmogorov-Smirnov[a]			**Shapiro-Wilk**		
	Statistic	**Df**	**Sig.**	**Statistic**	**Df**	**Sig.**
pretest	0.141	33	0.093	0.957	33	0.215
posttest	0.136	33	0.126	0.949	33	0.122
a. Lilliefors Significance Correction						

The results indicate that the significance value of the pretest was 0.093, while the significance value of the posttest was 0.126. Since both significance values exceeded 0.05, the pretest and posttest data were determined to be normally distributed. Having met the normality assumption, a paired-sample *t*-test was subsequently performed to examine the relationship between the two scores and to determine whether a statistically significant difference existed between them.

Table 6 Statistics on Paired Samples

Paired Samples Statistics					
		Mean	**N**	**Std. Deviation**	**Std. Error Mean**
Pair 1	Pretest	26.4545	33	7.10234	1.23636
	Posttest	79.3333	33	8.84473	1.53967

Table 7 Paired Sample Test Statistics

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	pretest - posttest	-52.87879	5.07911	.88416	-54.67976	-51.07781	-59.807	32	.000

The results presented in Table 6 indicate that the mean posttest score was higher than the mean pretest score. Specifically, the average pretest score was 26.45, which increased substantially to 79.33 in the posttest. Furthermore, Table 7 shows that the significance value (Sig) was 0.000 (Sig < 0.05), indicating a statistically significant difference between the pretest and posttest scores. These results demonstrate that the learning strategy implemented to enhance students' metaliteracy was effective.

Table 8 Correlation Statistics for Paired Samples

Paired Samples Correlations				
		N	**Correlation**	**Sig.**
Pair 1	pretest & posttest	33	0.819	0.000

Additionally, the results presented in Table 8, based on a sample size of 33 students, indicate that the correlation significance value between the pretest and posttest scores was 0.000 (< 0.05). This finding suggests that the correlation between the mean pretest and posttest scores was strong and statistically significant. After establishing the effectiveness of the learning strategy, a further analysis was conducted to determine the magnitude of its effectiveness. Cohen's *d* effect size test was employed to quantify the strength of the observed effect. The effect size calculation was performed using the *Effect Size Cohen's d Calculator for T-Test* available at

https://www.socscistatistics.com/effectsize/default3.aspx.

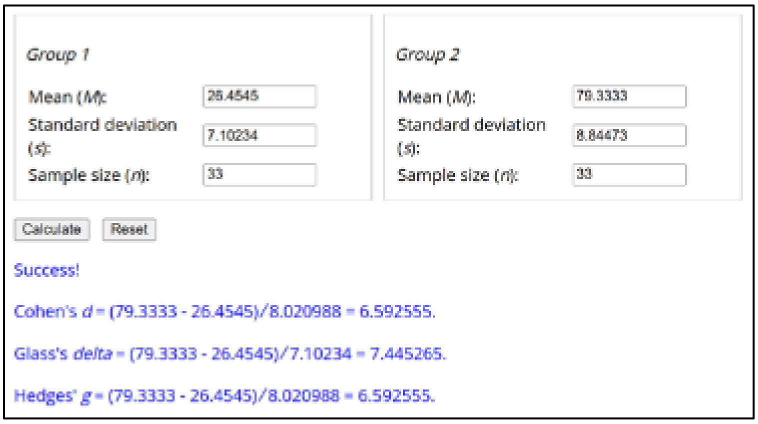

Figure 7 Effect Size Results of Cohen's d Calculator for T-Test

Based on the results shown in Figure 7, a *d*-value of 6.59255 was obtained. This value exceeds 0.8, which is categorized as a large effect size. Therefore, the results indicate a very large effect size, suggesting that the difference between the pretest and posttest scores is strong and meaningful rather than a result of statistical chance. Consequently, the applied learning strategy is highly effective and can be recommended for broader implementation.

The final stage of the development process is the *disseminate* stage. At this stage, the developed learning tools were shared with lecturers in the Mathematics Education program and disseminated through social media platforms. The purpose of dissemination was to further examine the effectiveness of the learning tools and to obtain feedback, corrections, suggestions, and evaluations for the refinement and improvement of the learning tools.

4. Conclusion

The process of developing the learning tools and the resulting products involved several stages. The first stage was the *define* stage, which included initial–final analysis, student analysis, concept analysis, and task analysis. This was followed by the second stage, the *design* stage, which involved test construction, media selection, format selection, and initial design development. The third stage was the *develop* stage, during which validity testing, field trials, practicality testing, and effectiveness testing were conducted. The final stage was the *disseminate* stage, which involved distributing the developed learning tools to lecturers in the Mathematics Education program. The results of the development analysis indicate that the learning tools met the criteria of validity, practicality, and effectiveness. Quantitative analysis was conducted using pretest and posttest data, which were analyzed through normality testing and paired-sample *t*-tests. Based on the normality test results, both pretest and posttest scores were normally distributed, as the significance values (Sig.) were greater than 0.05. Furthermore, the paired-sample *t*-test results showed a Sig. (2-tailed) value of 0.000, which is less than 0.05. These findings indicate a statistically significant difference between students' scores before and after the implementation of RBL-STEM learning tools, demonstrating that the use of RBL-STEM effectively improved students' metaliteracy.

Compliance with ethical standards

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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