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The development of RBL-STEM learning materials to improve students' environmental literacy in solving urban farming problems using locating metric coloring and STGNN

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Abstract

The development of environmental issues in the modern era emphasizes the importance of improving students' environmental literacy. 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' environmental literacy level. Research and development (RandD) 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 93.8%. The trial involved 35 students', and the use of the RBL-STEM learning resources was found to be effective with a 95.22% effectiveness criterion and practical with a 95.82% practicality criterion. In addition, students' responded positively to the learning experience and were highly engaged. Students' environmental literacy levels increased as they solved locating metric coloring problems, based on the pretest and posttest study. This study also identified three levels of environmental literacy proficiency: high, medium, and low. The research findings were validated using statistical analysis, image analysis, N-Vivo, and word cloud, all of which demonstrated an improvement in students' environmental literacy. Thus, RBL-STEM has the potential to enhance students' environmental literacy in real-world contexts, such as its application in urban farming.

Keywords: Environmental Literacy; Research Based Learning; STEM; Locating Metric Coloring; Urban Farming

1. Introduction

Education is one of the key factors in developing a nation's quality of life [1]. It has undergone significant transformation in response to global dynamics and technological advancements in the 21st century [2]. The increasingly complex environmental challenges have positioned education not merely as a medium for knowledge transfer, but also as a tool to raise ecological awareness within society [3]. One area of the curriculum that has begun to receive special attention is environmental education. The awareness and concern fostered through environmental education are expected to shape a generation that is cultured, environmentally conscious, and possesses strong environmental literacy [4].

Environmental literacy refers to an individual's awareness and responsiveness toward the environment, including the ability to act responsibly and sustainably [5]. It involves the capacity to understand, apply, and participate in addressing

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complex environmental issues by interpreting scientific information, while also developing awareness and sustainable actions to protect and preserve the environment [6]. Students can enhance their problem-solving skills in environments that support good environmental literacy [7]. This environmental literacy among students can be improved through the application of Research-Based Learning (RBL) integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach [8].

RBL is a research-based learning model that involves activities such as analysis, synthesis, and evaluation, and helps in deepening understanding and application of knowledge [9]. Additionally, RBL encourages the development of students' critical thinking and analytical skills, as it engages them in simple research projects that lead to self-discovery of concepts and knowledge. RBL requires relevant approaches to effectively support mathematics learning [10]. One such approach is STEM, which has proven effective in solving mathematical problems [10].

The STEM approach integrates science, technology, engineering, and mathematics into processes focused on solving real-world problems [11]. STEM prioritizes problem-solving through the integration of its four core elements [12]. STEM also helps students understand the role of mathematics in addressing environmental challenges, while strengthening their environmental literacy through hands-on activities involving direct engagement with real-world issues [13]. Implementing STEM in learning has been shown to improve mathematical creative thinking and problem-solving abilities [14]. One issue that can be addressed through STEM is the problem of urban farming.

Urban farming is the practice of cultivating plants in limited spaces within urban areas, such as in small or unused spaces [15]. It emerges as a solution to land scarcity in cities and the growing need for sustainable, healthy food. However, one of the main challenges in urban farming is optimizing resources like water and plant nutrients to boost productivity without harming the environment. These challenges can be addressed by applying the concept of locating metric coloring.

Locating metric coloring is a graph theory concept that combines vertex coloring with distance information to uniquely identify each vertex in a graph [12]. This approach focuses on assigning colors to vertices such that each vertex can be distinguished based on the distances and color combinations of its neighboring vertices. As a result, every point can be uniquely identified based on its colored neighbors, which is useful in various applications such as sensor networks, location identification, or other optimization problems. In urban farming, this concept allows each location in a farming area to be uniquely identified based on distance and relevant environmental parameters such as in medicinal plant cultivation. This technique also enables the division of land into optimized zones for specific crops; for example, ginger may require higher moisture levels compared to other medicinal plants. Such an approach helps improve the overall efficiency and productivity of urban farming through its application in conjunction with STGNN.

Spatio Temporal Graph Neural Networks (STGNN) in urban farming help analyze spatial and temporal relationships, thereby enhancing the efficiency of land and resource use. STGNN analyzes spatial-temporal data from sensors monitoring water and fertilizer needs at various points, enabling accurate predictions of where crops will grow optimally. Meanwhile, locating metric coloring helps identify optimal locations for various elements based on distance and environmental conditions, so that each point can be uniquely monitored and managed. This approach not only enhances urban farming outcomes but also contributes to improving environmental literacy.

The RBL-STEM approach in mathematics courses enriches student learning by not only teaching graph theory but also applying it to solve real-world problems like urban farming. Several studies on RBL-STEM have shown its effectiveness in enhancing environmental literacy, as demonstrated by Kristiana et al. (2024) [9], Artika et al. (2023) [16], and Anggraini et al. (2022) [17]. Based on the RBL-STEM syntax used in previous studies to address mathematical problems, this study aims to develop RBL-STEM learning tools with the title: "Development of RBL-STEM Learning Tools to Improve University Students' Environmental Literacy in Solving Urban Farming Problems Using Locating Metric Coloring and STGNN."

2. Material and methods

2.1. RBL-STEM

Research-Based Learning (RBL) is an innovative educational model that enables students to acquire knowledge and skills through research processes such as information gathering, hypothesis formulation, data collection, analysis, and report writing [18]. RBL aims to create learning experiences that foster analysis, synthesis, and evaluation. Moreover, RBL seeks to enhance both students' and educators' abilities in applying knowledge [19]. This model encourages students to actively engage in research activities, such as formulating research questions, collecting and analyzing data, and presenting their findings [20].

The National Science Foundation (NSF) introduced a new educational innovation in the United States in 1990 known as STEM education, which stands for Science, Technology, Engineering, and Mathematics [21]. This approach emphasizes not only mastery of scientific concepts but also encourages students to think logically, critically, evaluatively, and creatively in solving problems and making decisions related to real-life issues through the use of technology and its application in everyday life [22]. In conclusion, RBL-STEM is a research-based learning approach that integrates the disciplines of Science, Technology, Engineering, and Mathematics (STEM) to foster students' development of critical, creative, and collaborative skills through the exploration of real-world problems that are relevant to scientific and technological contexts. This study will implement a Research-Based Learning (RBL) model with a STEM approach to enhance students' environmental literacy in solving urban farming problems using locating metric coloring and STGNN.

2.2. Environmental Literacy

Environmental literacy refers to the conscious attitude of maintaining environmental balance. This awareness is defined as environmental mindfulness, which not only involves possessing knowledge about the environment but also includes being responsive and capable of providing solutions to environmental issues [23]. The role of environmental literacy is crucial in developing students' problem-solving abilities, as a higher level of environmental literacy corresponds to a greater capacity to address environmental challenges effectively [7]. Therefore, environmental literacy is the ability of individuals to understand, analyze, and take action based on scientific knowledge to critically and sustainably solve environmental problems. The indicators used in this study are adopted from Utami et al. (2023) [24], which include knowledge, environmental affective attitude, cognitive skills, and behavior.

2.3. Methods

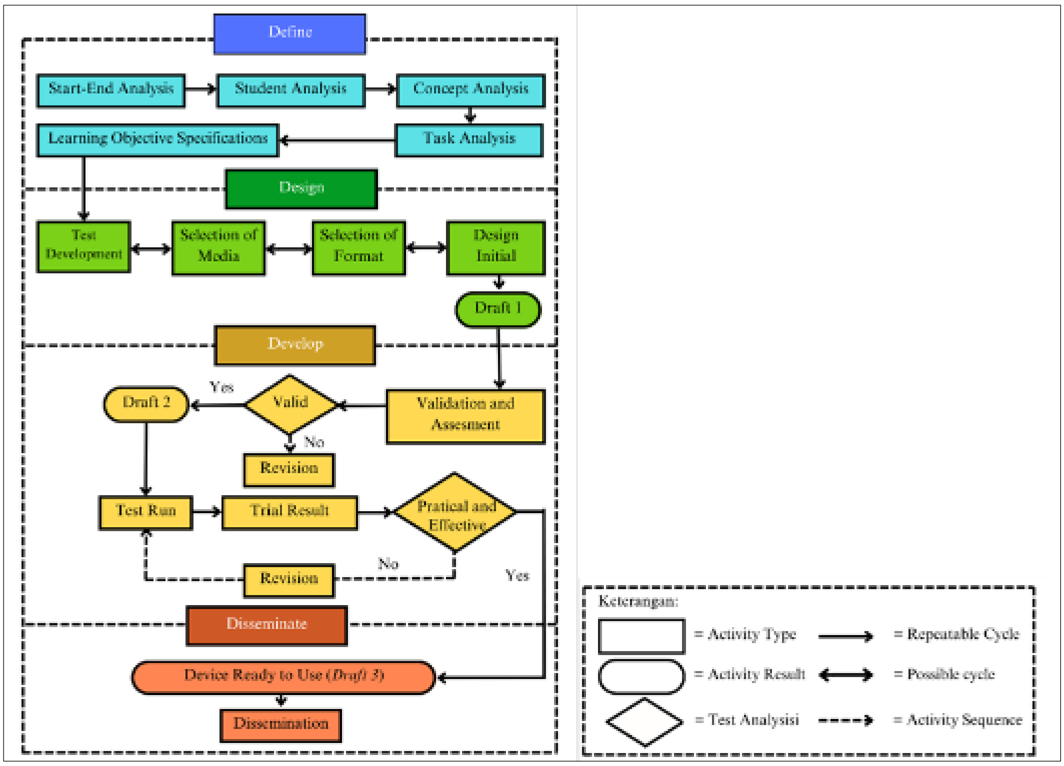

Figure 1 Stages of Learning Device Development 4-D Model

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-ended issues. The researchers consider the problem of urban farming as shown in Figure 2.

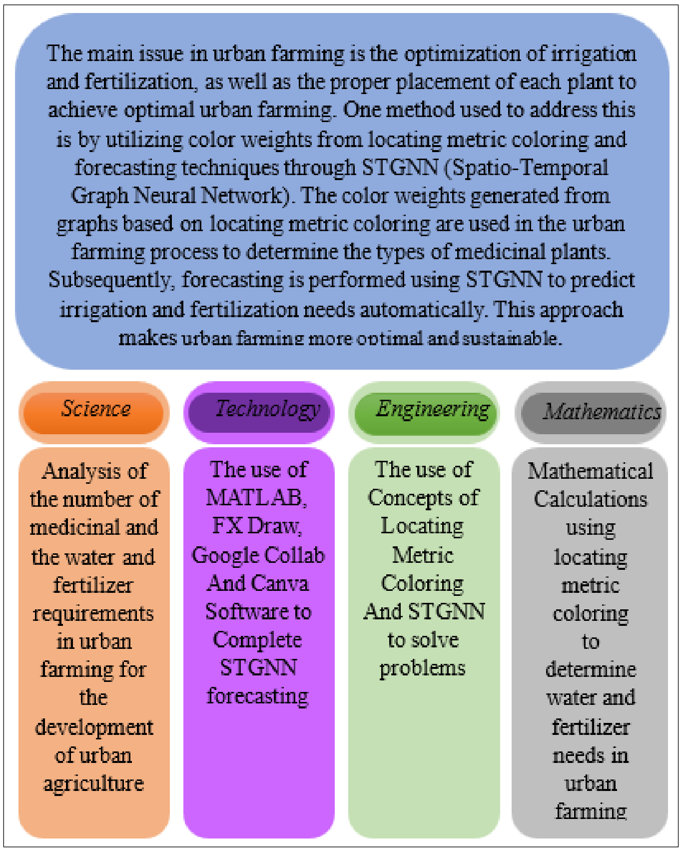

Figure 2 STEM elements of urban farming scheme

This research aims to solve the problem of urban farming using locating metric coloring and STGNN. Therefore, the RBL-STEM model has the following activity framework: 1) the first stage that students must carry out is to understand previous research related to urban farming using locating metric coloring, 2) obtain innovations in the application of urban farming based on locating metric coloring, 3) construct the coloring function of locating metric coloring, 4) analyze data related to urban farming and the use of software in its processing, 5) generalize the data by applying it to other similar problems, 6) draw conclusions from the results of the activities by presenting the findings related to solving urban farming problems using color weights from the concept of locating metric coloring and forecasting with STGNN.

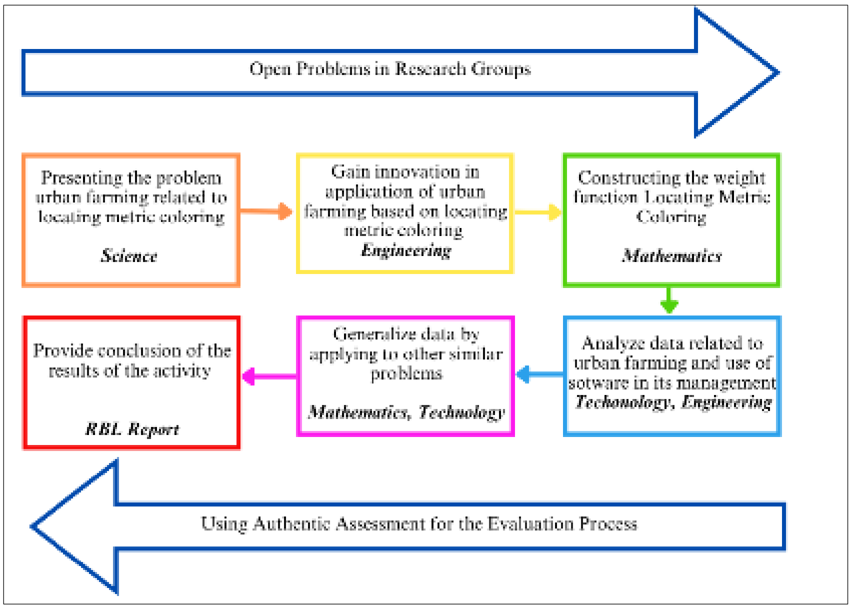

Figure 3 RBL-STEM Activity Framework for the LMC Problem

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 is divided into four phases: initial-final analysis, learner analysis, concept analysis, and task analysis. The initial-final analysis is conducted to identify the problems faced by students in learning, particularly in understanding the concept of locating metric coloring, as a foundation for developing learning tools. Learner analysis is carried out to obtain data on the characteristics of students in the Mathematics Education study program at the University of Jember. Concept analysis is conducted to identify, elaborate, and systematically organize the concepts that will be learned by students related to the concept of locating metric coloring. Task analysis aims to identify the key skills required in learning according to the curriculum, namely identifying students' environmental literacy in accordance with the expected final competencies.

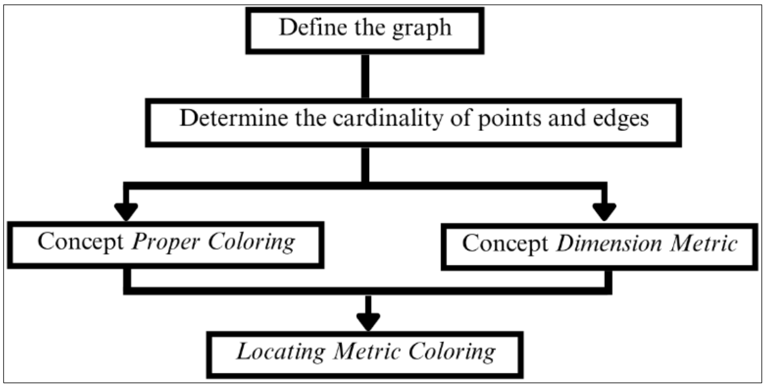

Figure 4 Locating Metric Coloring Theme Concept Map

The second stage, namely the design stage, aims to design the learning tools to be used, resulting in an initial design. In this stage, the design of the RBL-STEM learning tools is carried out to determine the effect of the learning devices on improving students' environmental literacy on the concept of locating metric coloring. There are four steps in this phase: test preparation, media selection, format selection, and initial planning. The test preparation in this study consists of descriptive questions that incorporate STEM elements and relate to the concept of locating metric coloring and urban farming, particularly in forecasting when automatic watering and fertilizing should be performed. The media selected includes PowerPoint as a medium for delivering the locating metric coloring material to support student understanding, and RBL-STEM MFI (Innovative Facilitator Module) containing indicators of environmental literacy. The format selection in this study uses the research-based learning model and the STEM approach, with their corresponding stages chosen as the learning format. The initial design refers to the complete plan of learning tools that must be prepared prior to conducting the research. These learning tools include the 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.

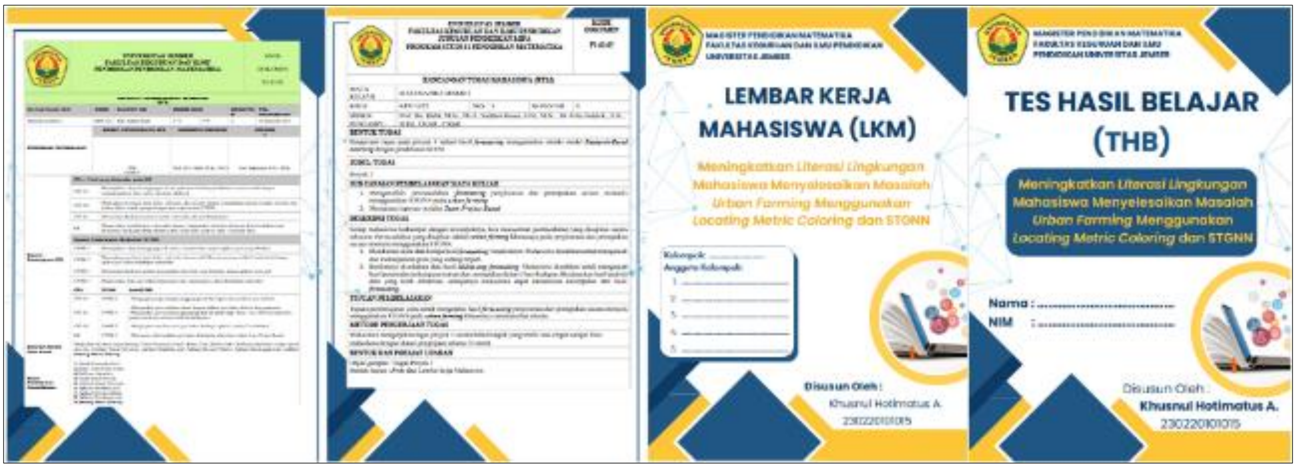

Figure 5 Initial Design of RPS, RTM, MFI, THB

The third stage is the development stage, which consists of four steps: validity test, device test, practicality test, and effectiveness test. Each device produced in the development stage is validated by experts and revised according to the recommendations provided. After the device is declared valid, a trial was conducted in the Discrete Mathematics course, Class C, Mathematics Education Study Program at the University of Jember. The results of this development stage are as follows: Based on the evaluation and suggestions from two validators, revisions and improvements were made to the developed learning tools. According to the evaluation from both validators, the device is considered feasible to use with minor revisions. Based on the results of the validation recapitulation of the RBL-STEM tools and instruments presented in Table 1, the average validation score is 3.75 with a percentage of 93.8%. According to the validity criteria, the developed learning device meets the criteria for validity, as it achieves a score in the range of $3.75 \leq Va < 4$.

Table 1 Recap of RBL-STEM Device Validation

Validation Result	Average Score	Percentage
Draft Student Assignments (RTM)	3.92	98%
Student Worksheet (LKM)	3.91	97.83%
Learning Outcome Test (THB)	3.92	98%
Student Activity Observation Sheet	3.54	88.54%
RBL-STEM Implementation Sheet	3.61	90.25%
Student Response Questionnaire	3.61	90.25%
Overall average score	3.75	93.8%

The revised and validated devices were tested on students. This trial was conducted in a class of 35 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 3.80 with a percentage of 95.22%. Based on the criteria of practicality, the prepared learning device meets the criteria of very high practicality because it meets the score of $90\% \leq SR \leq 100\%$. 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' environmental literacy 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, May 22, 2025. The research subjects were 35 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 3.80 with a percentage of 95.22%. 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 $90\% \leq P \leq 100\%$.

Table 3 Recapitulation of Student Activity Observation Results

Assessed Aspects	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 the use of learning tools that have been developed on a larger scale, such as in classes that have not been tested or in study programs with similar courses. The goal is to find out whether the developed tools work well in learning activities. In addition, quantitative data analysis will be used to analyze the improvement in students' environmental literacy. The following graph shows the distribution of students' pretest and posttest scores in Figure 6, while Figure 7 shows the percentage of students' environmental literacy levels.

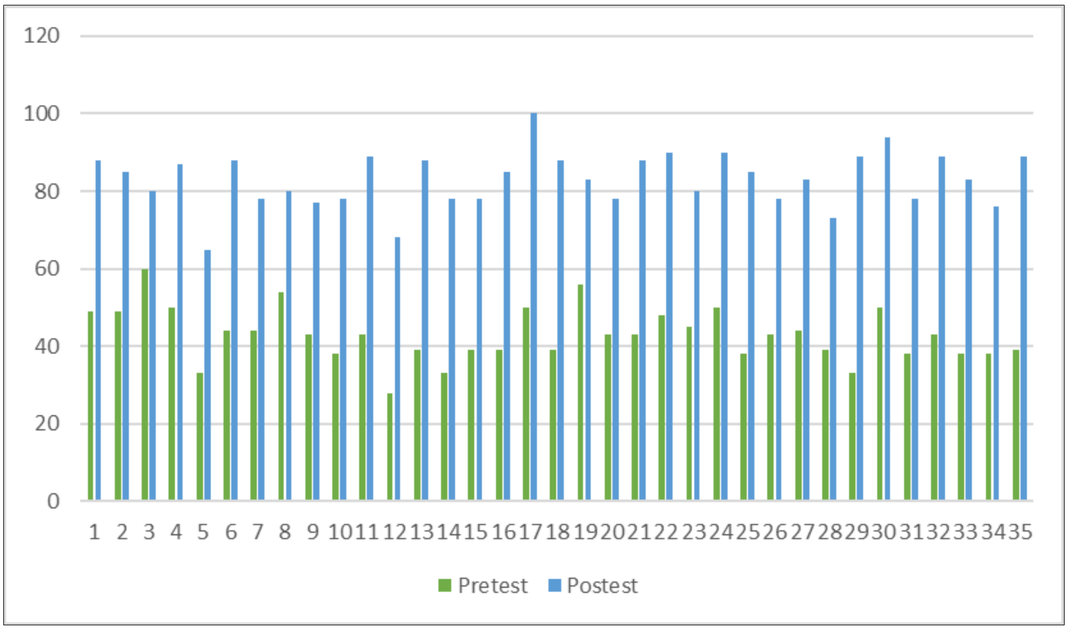

Figure 6 Graph of Distribution of Pretest and Posttest Scores

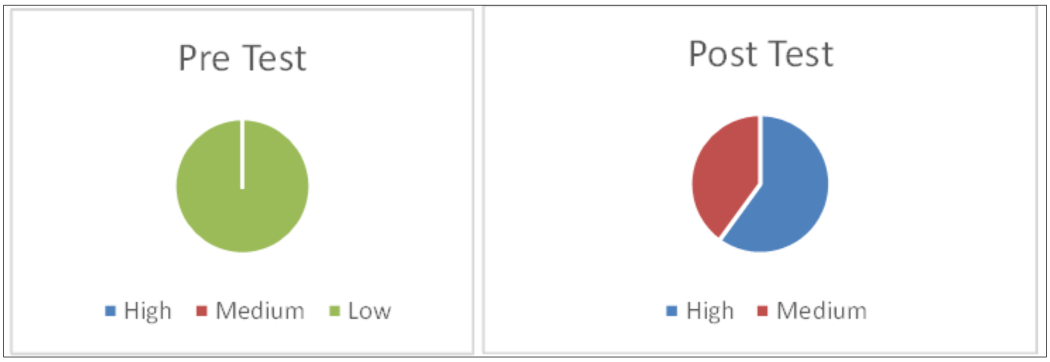

Figure 7 Percentage of Students' Environmental Literacy Level

In the pretest results, there were no students categorized as having a high level and moderate level of environmental literacy, students with a low level of environmental literacy were 100%. Meanwhile, in the posttest results, students categorized as having a high level of environmental literacy reached 60% and students with a moderate level decreased to 40%, In addition, a normality test was conducted as a prerequisite for the paired samples t-test. This statistical test was performed using SPSS software.

Table 4 Normality Test Results

Test of Normality						
	Kolmogorov-Smirnov²			**Shapiro-Wilk**		
	Statistic	**df**	**Sig.**	**Statistic**	**df**	**Sig.**
Pretest	0.143	35	0.068	0.966	35	0.335
Posttest	0.128	35	0.160	0.957	35	0.191

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	42.91	35	6.913	1.168
	Posttest	83.03	35	7.156	1.210

The test results in Table 5 show that the average posttest score is higher than the average pretest score. The average pretest score was 42.91 and then increased to 83.03 on the average posttest score. It can also be seen that the amount of data entered in the pretest and posttest is 35 data.

Table 6 Paired Sample Correlations

Paired Samples Correlations				
		N	**Corelation**	**Sig.**
Pair 1	Pretest and Posttest	35	0.427	0.011

The test results in Table 6 with a lot of data as much as 35, namely the pretest and posttest correlation value of 0.427>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	-40.114	7.533	1.273	-42.702	-37.526	-31.503	34	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' environmental literacy.

4. Conclusion

Based on the results of the research conducted in the development of RBL-STEM learning devices to improve students' environmental literacy, the learning devices meet the criteria of validity, practicality, and effectiveness. The quantitative analysis includes processing pretest and posttest data using normality tests and paired samples t-tests. Based on the normality test, it can be concluded that the pretest and posttest scores are normally distributed because the significance value (Sig.) > 0.05. Furthermore, the results of the paired samples t-test show that the Sig. (2-tailed) is 0.000 < 0.05. This means there is a difference in scores before and after learning with the RBL-STEM device on students' environmental literacy. These results indicate a significant improvement in students' environmental literacy after participating in the learning. The benefits of this research can be used as a reference in developing RBL-STEM devices to enhance students' environmental literacy.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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