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Development of RBL-STEM Learning Materials to Improve Students' Computational Thinking Skills

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This study aims to develop a Research-Based Learning in Science, Technology, Engineering, and Mathematics (RBL-STEM) based learning material designed to improve students' computational thinking skills in solving Strong Rainbow Antimagic Coloring (SRAC) problems in river erosion. This learning material combines systematic research methods with the STEM approach, providing an immersive and applicable learning experience. The material development used the Research and Development (RnD) model to ensure its validity, effectiveness and practicality. The pilot test was conducted on Bachelor of Mathematics Education at one of the universities in Probolinggo, namely Zainul Hasan Genggong Islamic University. Data were collected through a validity sheet, learning implementation sheet, student activity observation sheet, questionnaire sheet, and pretest-posttest sheet of computational thinking skills. Furthermore, the effectiveness was analyzed using quantitative (t-test) and qualitative analysis (using Nvivo). The results showed that the use of this RBL-STEM material significantly improved students' computational thinking skills. The learning material showed 95% validity criteria, 92.5% practicality, and 90% effectiveness. Participating students demonstrated improved skills in data analysis, computer simulation, and complex problem solving related to river erosion using the SRAC concept. And, students also reported increased motivation and engagement in the learning process. The conclusion of this study is that the RBL-STEM material is effective and practical in developing students' computational thinking skills, while preparing them to face technical challenges in the real world. The wider implementation of this material is expected to support the development of a higher education curriculum that is more innovative and relevant to the needs of industry and the environment.

Keywords: RBL-STEM, computational thinking skills, SRAC, river erosion, thinking skills, learning materials, science, learning

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INTRODUCTION

Computational thinking skills are becoming increasingly important in today's digital era. In the midst of the rapid development of information and communication technology, humans are required to be able to think more computationally in solving problems and making decisions. These skills include the ability to decompose problems into steps that can be executed by computers, recognise patterns in data, and develop solutions using algorithms and programming. Computational thinking itself is an important 21st century skill that is crucial for developing students' critical and analytical thinking, as well as creativity and competence in problem solving (Saritepeci, 2020; Anggraini et al., 2023). In fact, computational thinking has also recently received considerable attention in educational policy initiatives (e.g., Aydeniz, 2018; Nordby et al., 2022). In addition, this ability is receiving increasing attention as technology evolves (e.g., Agbo et al., 2019; Liu et al., 2020; Menon et al., 2020). The output of this ability is to present solutions by processing information on computer algorithms and other technologies. Therefore, this computational ability is required in all other disciplines such as science, technology, engineering, mathematics, social sciences, and literacy, as digital and technological literacy is increasingly required in these disciplines (Yuan et al., 2021).

One of the things that can be done by lecturers to improve students' computational thinking skills is to choose the Research-Based Learning (RBL) model that is applied in learning. RBL engages students in practical experiences where they are actively involved in exploration, research and solving real problems. Through these experiences, students can develop their computational thinking skills by applying the concepts they learn in a real context (Cheng et al, 2023). RBL is a learning approach that emphasizes direct experience, exploration, and experimentation in understanding concepts and solving problems (Hidayatul et al., 2020). This approach encourages students to be actively involved in acquiring knowledge through the process of investigation and discovery. In Research-Based Learning (RBL), students act as researchers who seek answers and solutions to questions or tasks given to them. In essence, RBL encourages students to learn more deeply and meaningfully by engaging in exploring topics or issues that are interesting and relevant to them (Gita et al., 2022). This process will assist students in developing important skills such as data analysis, evidence-based decision-making, and the ability to present their findings clearly and logically. In an educational context, RBL also prepares students to be critical and innovative thinkers as they learn to formulate the right questions, search for reliable sources of information, and build arguments based on their findings (Hakim et al., 2021). In addition to memorisation, students are equipped to become independent researchers and are good at dealing with real-world challenges. There are at least seven stages of research-based learning, consisting of (1) problem posing, where open problems are identified in the research group; (2) learners are encouraged to develop problem-solving strategies; (3) data collection including orientation, tabulation, and hypothesis formulation; (4) data analysis, prediction process, and validation; (5) formulation of conjectures, conclusions, hypotheses/formulas, theorems, and generalizations; (6) discussion in the research group; and (7) RBL reporting (Dafik et al., 2019). So through these stages, RBL allows students to apply computational concepts in relevant contexts. For example, they can use computer programming, data analysis or simulation modeling to solve problems related to the STEM topics being studied. Through the application of these concepts, students can strengthen their understanding of computational thinking (Li et al., 2020).

Computational thinking emerges as students develop the concept of strong rainbow antimagic coloring and build the programming that supports it. They begin with problem decomposition, identifying the problem and breaking down the necessary information to find solutions. Next, they apply pattern recognition to determine and implement solution steps, then move to algorithmic thinking by mapping the problem into graphical representation, identifying labeling patterns, color weighting, and calculating the strong rainbow antimagic coloring value. Finally, through generalization and abstraction, they analyze the final result, link it with the initial hypothesis, and explain the broader relevance of the strong rainbow antimagic coloring concept. This process thoroughly and systematically hones students' computational thinking skills.

Building on this foundation, the research integrates computational thinking within a RBL-STEM framework to enhance students’ problem-solving abilities in mathematics. By embedding computational thinking steps into the RBL process, students develop skills not only in mathematical theory but also in applying these concepts to real-world STEM challenges. In this study, the Spatial Temporal Graph Neural Network (STGNN) programming approach serves as a critical tool, supporting students as they delve deeper into computational thinking processes and develop solutions to complex problems. This programming approach reinforces the RBL-STEM model, as it allows students to visualize and analyze mathematical patterns through computational simulations, effectively bridging theoretical understanding with practical applications. This synergy between computational thinking, RBL, and STEM methodologies provides a comprehensive learning experience, equipping students with skills essential for both academic and professional environments.

Globally, science, technology, engineering and mathematics (STEM) systems have become the focus of K-12 education, and the role of student learning attitudes in STEM education is also an important research agenda (Razali, 2021; Mariani, 2022; Arztmann et al., 2023; Jamali et al., 2023; Komaria, 2024). One of the main approaches in STEM education is to embed computational thinking elements in STEM topics (Sun et al., 2021). Meanwhile, computational thinking is a way of thinking that involves using the concept of mathematical algorithms to solve problems. It has recently been advocated as a skill that everyone should have, not just mathematical scientists (Kafai & Proctor, 2022). Even today some research is pointing towards integrating computational thinking into K-12 education (Merino-Armero et al., 2022; Ye et al., 2023). So based on this, to optimize the RBL learning model in improving students' computational thinking skills, researchers integrated it with the STEM approach.

More and more countries such as the United States, China, Australia, and Finland have issued policies to incorporate computational thinking skills into STEM education (Becnel, 2019; Lee et al., 2020). STEM has been a natural field to integrate computational thinking into the classroom. Therefore, it is clear that developing students' computational thinking has become one of the main goals of STEM education

(Lee et al., 2020). International studies have found that the STEM approach can be implemented with other learning methods (Sagala et al., 2019; Wahono et al., 2020). One of them is the Research Based Learning (RBL) method which also has the same characteristics that can develop critical thinking and problem solving skills (Ridlo et al., 2020).

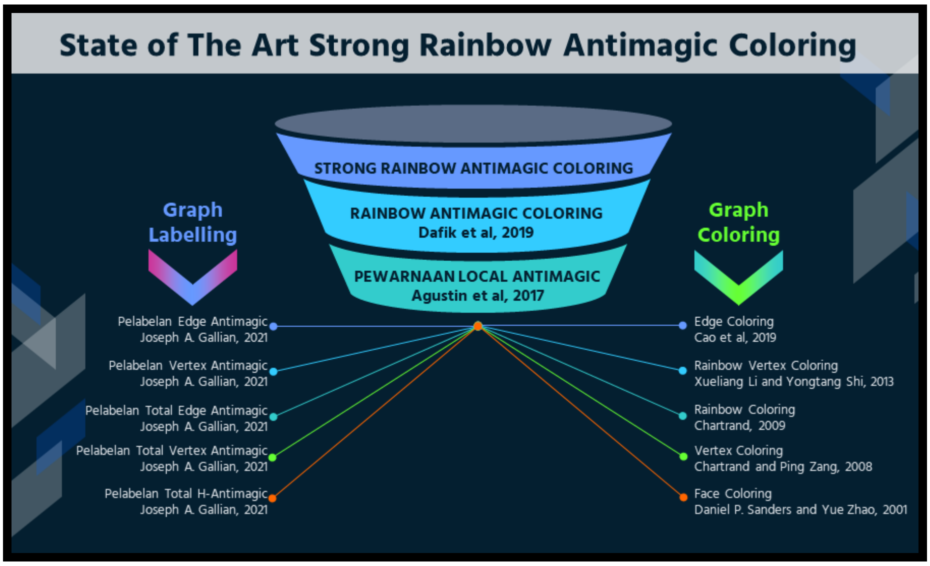

Figure 1
Strong rainbow antimagic coloring concept analysis

Not a few researchers have implemented the Research Based Learning model by integrating the STEM approach (Dafik et al., 2019; Hakim et al., 2021; Sumardi et al., 2023). However, there is still a lack of research on whether Research Based Learning (RBL) with the integration of STEM approaches will have a positive impact on students' computational thinking skills. Addressing this knowledge gap, this research will develop RBL-STEM based learning materials for students to improve their computational thinking skills. The development of specific RBL-STEM learning materials is essential, as existing resources are generally not designed to meet the complex needs of enhancing computational thinking skills, particularly in the context of studying relatively new material, namely the Strong Rainbow Antimagic Coloring (SRAC) in relation to river erosion. Available materials are often broad and lack the depth required to integrate a STEM approach that emphasizes research-based activities. The framework shown in Figure 2 is based on research-based learning theory, illustrating how the RBL-STEM approach can be applied effectively in graph application courses on SRAC material and river erosion problems. This approach is supported by the dimensions of research-based learning theory, including student-centered learning, interactive learning, collaboration, effective communication skills, and small group activities. We hypothesize that if lecturers adopt the RBL-STEM strategy for teaching mathematical concepts—particularly the SRAC topic related to river erosion in higher education—student outcomes in computational thinking skills will improve significantly.

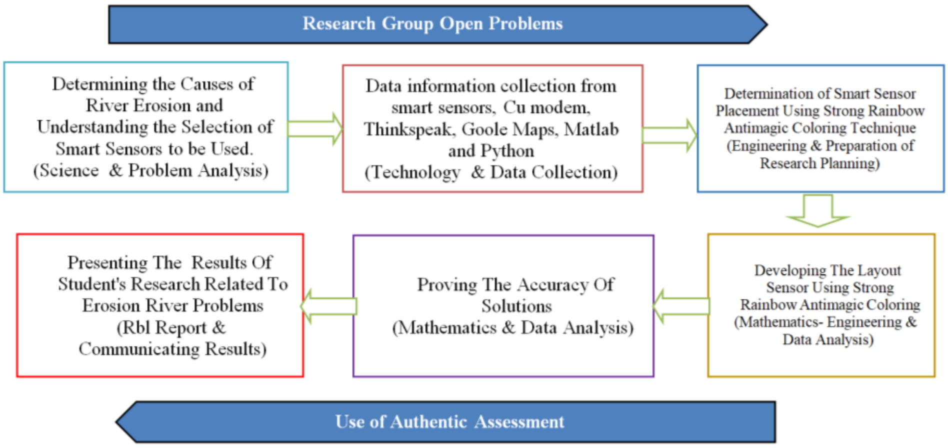

Figure 2
RBL-STEM frameworks

The learning materials developed are expected to provide an alternative in teaching Strong Rainbow Antimagic Coloring (SRAC) through RBL-STEM learning. Where the discussion of river erosion is considered important because it is included in the Sustainable Development Goals (SDGs) including the protection of terrestrial ecosystems and freshwater ecosystems at point 15. Especially for students, it is also necessary to introduce river erosion so that the river erosion management system is found through the RBL-STEM approach. Some relevant previous studies demonstrating the impact of river erosion on the environment, society, or Sustainable Development Goals (SDGs) can be found in (Hammad et al., 2006; Abu-Zreig, 2006; Auerswald et al., 2009; Cerdan et al., 2010). Therefore, this research will develop RBL-STEM-based learning materials that focus on river erosion problems that arise in each STEM element, a framework for solving River Erosion Problems using SRAC, and an assessment instrument for computational thinking skills in solving river erosion problems using SRAC. So in the following section, the RBL-STEM framework for the SRAC topic in the context of river erosion problems will be explained. There are six steps of RBL that have adopted the STEM approach.

First Stage of RBL (*Science*)

The provision of previous research to bring up the problem of river erosion whose solution is possible in graph theory which assigns unique labels to each graph vertex so that each edge has a different color, which is useful in solving complex problems with unique structures. In the context of river erosion, it is possible to model river flow networks as graphs, where nodes represent important sensing points and edges represent water flow or sedimentation pathways. We can identify complex flow patterns, erosion-prone areas, and predict flow changes more systematically. Using the RBL-STEM method, students can develop computational and analytical thinking skills through projects that combine graph theory with real applications, such as river erosion, so that they learn to apply mathematical concepts in solving real-world environmental problems.

Therefore, the first stage of RBL-STEM in this study is fundamental problems related to river erosion. This stage is divided into 3 learning activities, namely 1) Lecturers provide previous research on river erosion problems, 2) Lecturers provide an overview of river erosion problems. Then ask students about their understanding of the problems proposed, 3) Students are asked to identify the background of river erosion analysis. This learning activity is a continuation of research that researchers have done before with SRAC where the theory has also been found by researchers (Lestari et al., 2024).

Second Stage of RBL (*Engineering*)

The second stage of the RBL-STEM activity was to develop innovative solutions using SRAC to improve students' computational thinking skills in dealing with river erosion problems. This stage involved three learning activities: 1) Lecturer guided students in discussing the solution to the given problem using SRAC, 2) Lecturers provide an explanation of river erosion and then ask students' understanding of the problem that has been proposed, 3) Students are asked to record relevant information related to the proposed problem.

Third Stage of RBL (*Technology*)

The third stage of RBL-STEM activities is using software or the use of technology in collecting and processing data related to river erosion problems at the Central Bureau of Statistics. At this stage, students are asked to carry out three learning activities, namely 1) Collecting simulation data on the internet through the Central Bureau of Statistics web page, 2) Students are asked to normalize the data using Microsoft Excel software, 3) Students are asked to forecast data using Python online from normalized data.

Fourth Stage of RBL (*Mathematics*)

The fourth stage of the RBL-STEM activity is to analyze the data by sketching an illustration of the river flow that will be passed by the river erosion detection sensor. Then represent it in the form of a graph that will be analyzed using the concept of strong rainbow antimagic coloring to determine the effective number of river erosion detection sensors that must be placed on the river flow. At this stage, five learning activities are required, namely 1) Students are asked to identify the set of nodes and edges, as well as the cardinality of nodes and edges in the graph formed from the illustration of the river flow map, 2) Students are asked to perform anti-magic point labeling by labeling the points in the graph with the number 1 up to the number of points in the graph, 3) Students are asked to calculate the edge weights obtained by adding up the point labels whose two points are connected, 4) Students are asked to analyze every two points in the graph have rainbow paths with different colors derived from the edge weights, 5) Students write the theorem based on the observations that have been made.

Fifth Stage of RBL (*Mathematics*)

The RBL-STEM activity in the fifth stage is to generalize by proving theorems related to strong rainbow antimagic coloring on other graphs. This stage requires five learning activities, namely: 1) Students are asked to identify the set of nodes and edges, as well as the cardinality of nodes and edges in other graphs, 2) Students are asked to perform anti-magic point labeling by labeling the points in the graph with the number 1 up to the number of points in the graph, 3) Students are asked to calculate the edge weights obtained by adding up the point labels whose two points are connected, 4) Students are asked to analyze every two points in the graph that have rainbow paths with different colors derived from the edge weights, 5) Students are asked to write the theorem based on the observations that have been made.

Sixth Stage of RBL (*Report*)

In the final stage of RBL-STEM activities, students are asked to convey and explain the results and conclusions of learning using the RBL-STEM method with the topic of strong rainbow antimagic coloring. The final form of this learning is a research report written and presented by students. The details of learning activities are as follows: 1) Students make a report on the use of strong rainbow antimagic coloring to solve river erosion problems, 2) Students make presentations on the reports that have been made, 3) Lecturers evaluate and provide feedback on the understanding gained by students during the research process, 4) Lecturers observe students' computational thinking skills.

The RBL-STEM strategy intervention and data collection took place over three meetings. The graph application course on the topic of strong rainbow antimagic coloring was designed and taught using the RBL-STEM method in accordance with the steps described by Dafik (2016) in implementing RBL. At the beginning of learning, RBL-STEM is guided by a carefully designed lesson plan to reflect the features of RBL-STEM, such as small group activities, interaction between group members, cooperation, student-centered learning, and development of computational thinking skills, all done interactively. The application of this method takes into account the characteristics already described by the researcher in section 2 on the overview of RBL-STEM. Thus, 1) Students are at the center of learning; 2) Learning is done in small groups; 3) Lecturers act as facilitators or guides; 4) Students are given previous research at the beginning of learning; 5) The problems used are taken from previous research to achieve learning objectives on the topic of strong rainbow antimagic coloring; and 6) Group learning is used to acquire new knowledge. Before starting each lesson, a pre-test was conducted to determine students' initial knowledge of the topic. Lesson delivery was conducted in such a way that the lecturer acted as a facilitator who encouraged students to take primary responsibility for group learning. At the end of learning the topic, a post-test was conducted to measure the improvement of computational thinking skills through teaching and learning the RBL-STEM method. At the end of the lesson, the RBL-STEM questionnaire was administered to the students to measure the effectiveness of the RBL-STEM material.

This study aims to investigate the validity, practicality, and effectiveness of RBL-STEM learning materials in improving students' computational thinking skills. The overall research question is: how valid, practical, and effective is the development of RBL-STEM materials developed to improve students' computational thinking skills in solving SRAC (Strong Rainbow Antimagic Coloring) on river erosion problems?

METHOD

Research Design

The research design used in this study is research and development (R&D), which refers to the development of Thiagarajan's 4D model, which includes the define stage, design stage, develop stage, and disseminate stage. This 4D model is shown in Figure 3.

Sampling

This research was conducted at the undergraduate study programme of Bachelor of Mathematics Education, Faculty of General Studies, Zainul Hasan Islamic University Genggong. This university is located in Probolinggo Regency, Indonesia, which includes coastal areas that are often found related to river erosion problems. A purposive sampling technique was used to select Zainul Hasan Islamic University Genggong as the research site. This selection was based on the university's specialization in Mathematics in addition to its general programmes. In addition, Zainul Hasan Genggong Islamic University serves as the central Islamic campus in the Probolinggo area. Therefore, the university has the necessary capabilities to ensure the credibility and success of the RBL-STEM intervention.

The Bachelor of Mathematics Education at this university has a population of 160 students, with an average class size of 40 students. Using probability sampling techniques, 40 students were used as case studies to aid the investigation into the development of an RBL-STEM tool to improve students' computational thinking skills in the context of SRAC problems related to river erosion. The students were in the 5th semester and had completed the Discrete Mathematics course, which was a prerequisite for the Graph Applications course. The class was heterogeneous, consisting of 25 females and 15 males.

Data Collection Instruments

This study used several instruments to collect data, namely validity sheets, learning implementation sheets, student activity observation sheets, questionnaires, and student pretest-posttest. The validity sheet → tested the validity of the learning materials, the learning implementation sheet → assessed their practicality, and the student activity observation sheet, questionnaire, and pretest-posttest → evaluated their effectiveness. The validity sheet, learning implementation sheet, and student activity observation sheet all used a Likert scale from 1 to 4. A score of 1 → means an Operational Verb (OV) is not achieved, 2 → means an OV is less achieved, 3 → means moderately achieved, and 4 → means achieved. The questionnaire used a "yes" or "no" scale. The student pretest-posttest consisted of essay questions with a maximum score of 100.

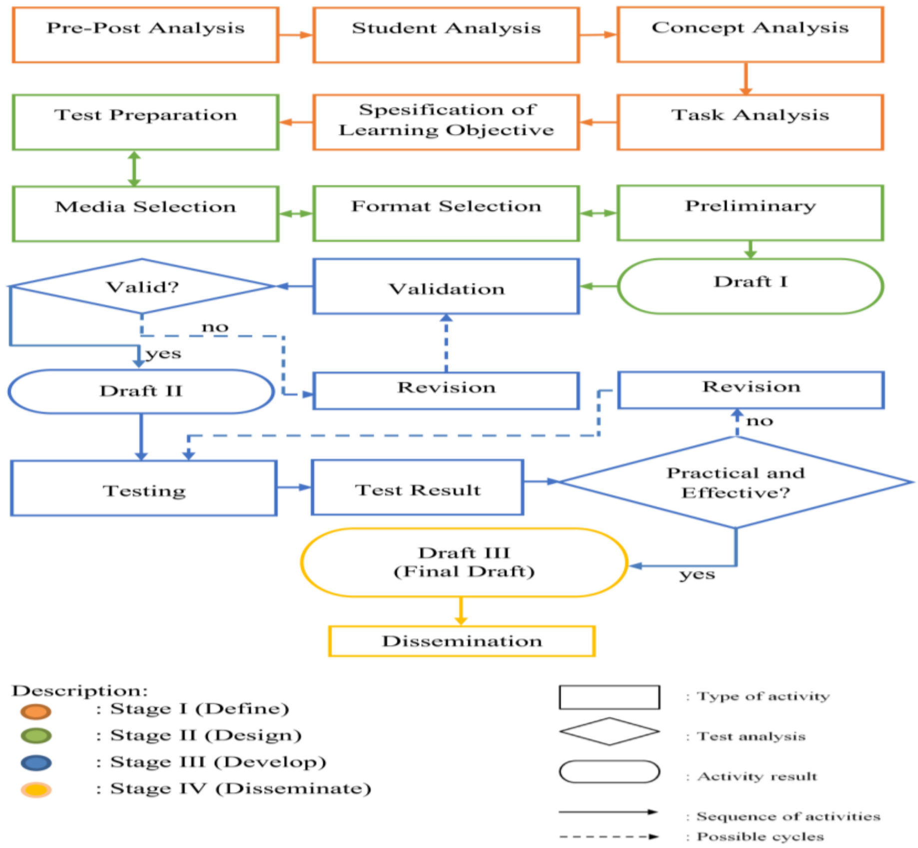

Figure 3
4-D model design

All data results of the material validity assessment are calculated based on the average of each aspect of the indicator value, which will then be used to determine the criteria for the validity of the learning material. In this study, Validity of learning materials is required $V_a \geq 3.25$. Data on the practicality of the material reflects the implementation of the learning material that has been developed. This data is obtained from the observation sheet, which is used to record the results of observations of learning implementation. The criteria for practicality of learning materials must reach $SR \geq 80\%$.

The effectiveness of learning materials is measured based on student activity data. Student activities include all forms of activities carried out in the classroom during the teaching and learning process. The criteria for the results of observations of student activity so that the learning device is said to be effective when the score $P \geq 80\%$. In addition, the effectiveness of the developed learning materials is seen from the questionnaire phase. Student response questionnaire data will be analyzed to find out how students respond to the implementation of learning that has been done. The results of student responses to learning materials can be seen from the percentage of responses obtained ($P_r \geq 60\%$).

Data Processing and Analysis

We used SPSS to analyze the effectiveness of the RBL-STEM material in improving students' computational thinking skills through pretest and posttest results. The statistical analysis used was paired sample t-test with SPSS software. This paired t-test compares two samples that are paired with each other with the same subject, but experiencing different treatments at two different times. Before doing this analysis, it is necessary to test the research data with the normality test as a prerequisite. The t test in this study aims to determine whetstine there is an increase in students' computational thinking ability after the application of the RBL-STEM method on SRAC for river erosion problems. The hypothesis is formulated in the form of null hypothesis (H0) and alternative hypothesis (H1). The assessment criteria are if the sig value > 0.05 then H0 is accepted, but if the sig value < 0.05 then H0 is rejected. The following hypothesis will be tested in this study.

H_0: there is no difference in students' computational thinking skill scores before and after learning with RBL-STEM materials in solving SRAC and river erosion problems with STGNN (Spatial Temporal Graph Neural Network)

H_1: there is a difference in students' computational thinking skill scores before and after learning with RBL-STEM materials in solving SRAC and river erosion problems with STGNN (Spatial Temporal Graph Neural Network)

FINDINGS

The study lasted for 6 months, from January to June 2024. During this time, the researcher conducted the entire R&D research process that refers to the development of the 4D model. This research uses materials with the RBL model and STEM approach to enable students to learn and develop skills in science, technology, engineering, and mathematics. This RBL-STEM method encourages students to be more active in learning through research. In this study, the application of the RBL-STEM material aims to improve students' computational thinking skills. In the initial stage, the syntax of this RBL-STEM method poses a problem derived from the open problem research group. An explanation of the STEM aspects in this study can be seen in Figure 4.

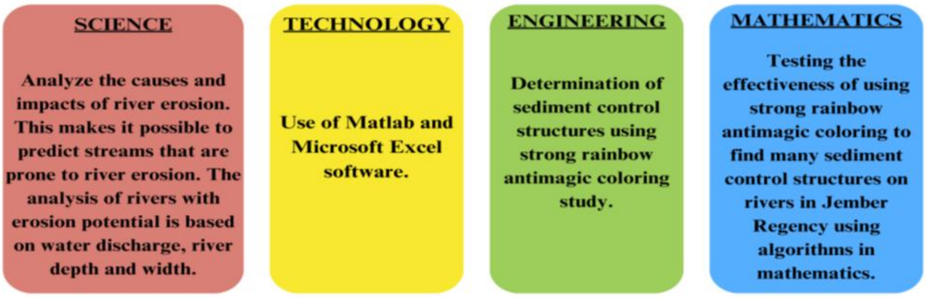

Figure 4
STEM aspects of the research

This research aims to solve the problem of river erosion by using the strong rainbow antimagic coloring technique. Therefore, the RBL-STEM method has the following activity framework, 1) the first stage that students must do is to understand previous research related to the basics of problems related to river erosion, 2) obtain a breakthrough in problem solving using strong rainbow antimagic coloring, 3) use software or the use of technology in collecting and processing data related to river erosion problems at the Central Bureau of Statistics, 4) analyze data by sketching illustrations of river flows that will be passed by river erosion detection sensors. Then represent it in the form of a graph that will be analyzed using the concept of strong rainbow antimagic coloring to determine the effective number of river erosion detection sensors that must be placed on the river flow, 5) generalize by proving the theorem related to strong rainbow antimagic coloring on other graphs, 6) finally, convey and explain the results and conclusions of learning activities using the RBL-STEM method with the use of the topic of strong rainbow antimagic coloring.

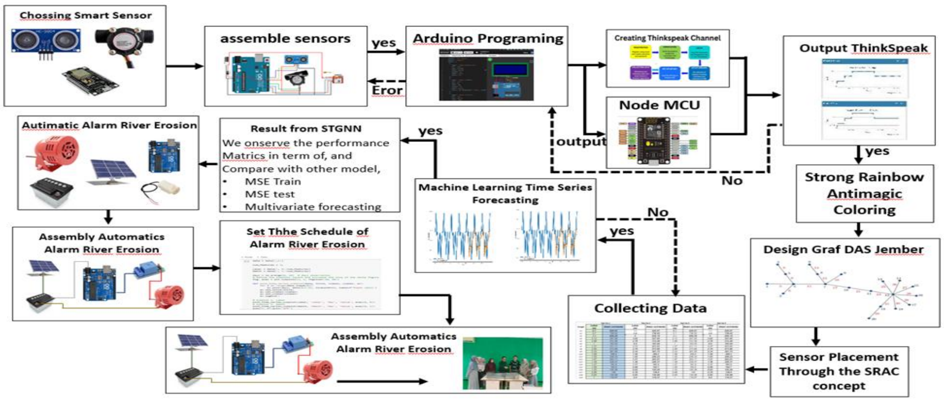

Figure 5
Prototype of sensor assembly

In this case, the technique used is to assemble sensors until data appears that can predict the state of river erosion. Of course, in this problem, students need to know the application of SRAC rules in a graph first. The concepts taught are 1) perform antimagic labeling on all points of the generated graph representation so that the point labels start from one to many points in a graph, 2) calculate edge weights by summing up the labels of the points connected to the edge to be calculated, 3) analyze rainbow trajectories in the graph with every two points in the graph having a rainbow trajectory, (4) if in one rainbow trajectory there is the same color (edge weight), then repeat the activity starting from the point labeling until every two points have a rainbow trajectory with a different color. After applying SRAC, the next step is to use the value of the anti-magic rainbow connection as a reference to determine the number of admins monitoring different watersheds. Since the graph representation in Figure 5 is already a tree graph, each watershed will have a different admin on its path. The function of the admin is to check the validity of a river erosion that occurs so that river erosion is not only determined by one party but there are admins who monitor river erosion from other watersheds who cross check. After the sensor circuit is ready, it is then integrated into the NodeMCU so that the data that appears on ThinkSpeak is obtained. So that the ThinkSpeak output data predicted through the Python Program can provide an alarm signal for river erosion that comes to be given rapid handling. It is hoped that through this activity, students can design as shown in Figure 5.

The first stage of the 4D model is defining, which aims to determine and define learning needs through analyzing the objectives and limitations of the material to be provided. This defining stage is divided into four parts: beginning-end analysis, student analysis, concept analysis, and task analysis. The beginning-end analysis is conducted to understand the basic problems faced by students in learning, as an illustration to determine how the learning materials will be developed. Student analysis aims to collect data on the characteristics of undergraduate students of Bachelor of Mathematics Education at Zainul Hasan Islamic University Genggong. Concept analysis is conducted to identify, detail, and arrange systematically the concepts that students have learned about strong rainbow antimagic coloring. Task analysis aims to identify the main abilities required in learning according to the curriculum.

The second stage is the design stage, which aims to design learning materials that will be used so as to produce an initial design. At this stage, the RBL-STEM material is designed to determine its effect on improving students' computational thinking skills on the concept of strong rainbow antimagic coloring. This stage includes four steps: test development, media selection, format selection, and initial design. Test preparation is based on predetermined learning indicators. Media selection was based on student analysis, concept analysis, and previous task analysis. The selected media include PowerPoint for the delivery of strong rainbow antimagic coloring material and RBL-STEM LKM which includes indicators of computational thinking ability. The choice of format in the development of teaching materials aims to formulate and determine the design of the model, approach, and learning resources to be used. The initial design is the overall design of learning materials that must be prepared before the trial. These learning materials include semester learning plans, student assignment designs, learning outcome tests, and student worksheets.

The third stage is the development stage, which consists of four stages: validity test, learning material test, practicality test, and effectiveness test. Each material produced at the development stage was validated by validators and revised according to their recommendations. The learning materials were validated by 1 lecturer of Mathematics Education Study Program of Jember University and 1 lecturer of Mathematics Education of Yogyakarta State University. The validators provided a validation assessment of the learning materials and tools. The assessment is in the form of a 1-4 Likert scale on each component of the validation form. Based on the assessment of both validators, the materials can be used with minor modifications. From the recapitulation of the validation results, the average validation score was 3.71 ($V_a \geq 3{,}25$) with a percentage of 92.75%. So based on these scores, the learning materials developed have met the validity criteria.

Table 1
Recapitulation of learning material validation

Validation Results	Average Value	Percentages
Learning Materials	3.65	91.25%
Observation Sheet of Student Activity	3.67	91.75%
Observation Sheet of RBL-STEM Implementation	3.69	92.25%
Students Response Questionnaire	3.79	94.75%
Questionnaire	3.72	93%
The overall average score	3.71	92.75%

After the learning materials were declared valid, the revised and validated materials were applied to students. This trial was conducted in a class of 40 students. After the practicality test of the learning materials was carried out, an analysis of the implementation of learning in the classroom was carried out. This analysis is based on the RBL-STEM implementation observation sheet evaluated by 8 observers. Based on Table 2, the average score of the overall learning implementation observation results is 3.95 with a percentage of 98.75% ($SR \geq 80\%$). So based on these scores, the learning tools developed have met the criteria of very high practicality.

Table 2
Recapitulation of learning implementation observation results

Assessed Aspects	Average Value	Percentages
Syntax	3.875	96.875%
Social Systems	4	100%
Principles of Reaction and Management	3.975	99.375%
The overall average score	3.95	98.75%

The effectiveness test of the learning material includes three indicators: analysis of student learning outcomes, student activity observation results, and student response questionnaire results. Based on the post-test results, 36 students (90%) scored above the minimum completeness, indicating classical completeness. Observations were made of the introduction, core activities, and closing. The score recapitulation results can be seen in Table 3. Based on Table 3, the average total score of student activity observation was 3.76 with a percentage of 94% ($P \geq 80\%$). So based on these scores, the learning tools developed meet the category of very high effectiveness.

Table 3
Recapitulation of student activity observation results

Assessed Aspects	Average Value	Percentages
Introduction	4	100%
Core Activities	3.96	99%
Closing	3.32	83%
The overall average score	3.76	94%

The third criterion was the student response survey. Student questionnaires were distributed in hardfile form. Based on the student response criteria, the recapitulation of student response scores is presented in Table 4. Overall, the average positive percentage

is 90.31% ($P_r \geq 60\%$). This shows that the learning materials have been effective because all three requirements are fulfilled.

Table 4
Data recapitulation of student response survey results

Assessed Aspects	Percentages
Enjoyment of the learning components	91.25%
Students' combinatorial thinking skills feel trained	90.55%
The learning components are new	86.875%
Students clearly understand the language used	87.5%
Students understand the meaning of each question presented	86.25%
Students are attracted by the appearance (text and images)	95%
Students are interested in learning	87.5%
Students enjoy discussing with group members	97.5%
The overall average score	90.31%

The final stage of the 4D model is the dissemination stage, which involves applying the developed learning materials on a larger scale, such as in untested classes or in other study programmes that have similar courses. The aim is to determine whether the developed materials are effective for learning activities.

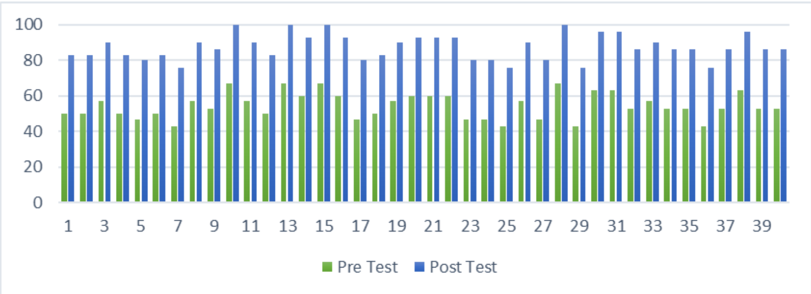

Figure 6
Student pretest and posttest score distribution

In addition, we will use quantitative data analysis to measure the improvement of students' computational thinking ability. The distribution graph of students' pretest and posttest scores can be seen in Figure 6. Meanwhile, Figure 8 shows the percentage level of students' computational thinking ability.

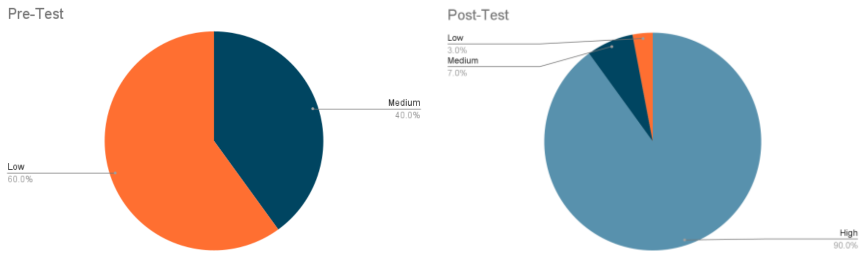

Figure 7
Percentage of students' computational thinking skills level

In the pre-test results, no students were categorized as having high-level computational thinking ability, 40% of students had medium-level computational thinking ability, and 60% of students had low-level computational thinking ability. However, in the post-test results, 90% of students were categorized as having high-level computational thinking ability, while students with moderate-level computational thinking ability decreased to 7%, and students with low-level computational thinking ability decreased to 3%. In addition, normality test was conducted as a prerequisite for paired sample t-test, using SPSS software.

Table 5
Results of normality test

One-Sample Kolmogorov-Smirnov		Pretest	Postest
N		40	40
Normal Parameters[a,b]	Mean	53.85	86.78
	Std. Deviation	4.216	3.059
Most Extreme Differences	Absolute	.136	.129
	Positive	.136	.068
	Negative	-.083	-.129
Test Statistic		.136	.129
Asymp. Sig. (2-tailed)		.061[e]	.090[e]

a. Test distribution is Normal.
b. Calculated from data.
c. Lilliefors Significance Correction.

Based on the results of the data normality test in Table 5, it shows that the pretest and posttest scores are normally distributed because the significance value Asymp. Sig. (2-tailed) > 0.05. Next, a homogeneity test was performed as shown in Table 6 below.

Table 6
Result of homogeneity test

Test of Homogeneity of Variances		Levene Statistic	dff	df2	Sig.
Score	Based on Mean	2.774	1	78	.100
	Based on Median	2.462	1	78	.121
	Based on Median and with adjusted df	2.462	1	67.753	.121
	Based on trimmed mean	2.716	1	78	.103

Based on the homogeneity test results in Table 6, it shows that the pretest and posttest scores are homogeneous because the significance value of Based on Mean is 0.10 > 0.05. Next, a paired samples t-test is performed as shown in Table 7 below.

Table 7
Correlation results of paired samples

Paired Samples Correlations		N	Correlation	Sig.
Pair 1	Pretest & Postest	40	.119	.486

The test results in Table 7 with a lot of data as much as 40, namely the correlation of pretest and posttest with a sig value of 0.466 > 0.05. This shows that the correlation or relationship between the two average pretest and posttest scores is significant.

Table 8
Paired sample t-test results

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 & Postest	-32.925	4.906	.776	-34.494	-31.356	-42.443	39	.000

The test result in Table 8 is the probability or Sig. (2-tailed) of 0.000 < 0.05. In conclusion, there is a difference in students' computational thinking skill scores before and after learning with RBL-STEM materials in solving SRAC and river erosion problems with STGNN. This study used NVivo software to qualitatively analyze variations in students' computational thinking skills. The researchers used specialized NVivo software called Word Frequency Query to monitor the frequency of certain words in the detailed interview transcripts with the students. This analysis resulted in a compilation of frequently occurring terms in the interview data, as illustrated in Figure 8.

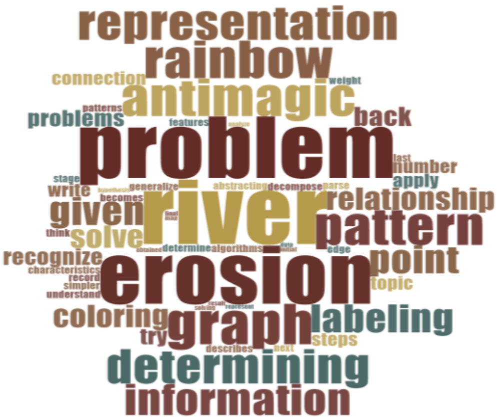

Figure 8
Word cloud student interviews

The second feature available in NVivo and used in this study is the Text Search Query. Obviously, this feature is used to interpret the meaning of the words that appear in the word cloud (Figure 8). The words that appeared came from the respondents selected for the interviews. The respondents selected for the interview came from a sample of categories of students with high, medium, and low computational thinking skills. One student was selected from each of these categories. Therefore, this study has 3 student respondents selected for an interview. In this study, the word "river erosion" was selected as one of the terms that appeared frequently in the interview data. Furthermore, the search results are shown in the form of a word tree in Figure 9. Figure 9 provides information that the RBL-STEM material helps students to understand the consequences of the decision to identify a river that has the potential to experience river erosion through the SRAC concept. Thus, this approach is effective in teaching river erosion management systems. In addition, another important piece of information is the importance of testing the effectiveness of using SRAC in helping students make decisions in determining sediment control structures to reduce river erosion potential. Therefore, RBL-STEM is a learning material to achieve this goal.

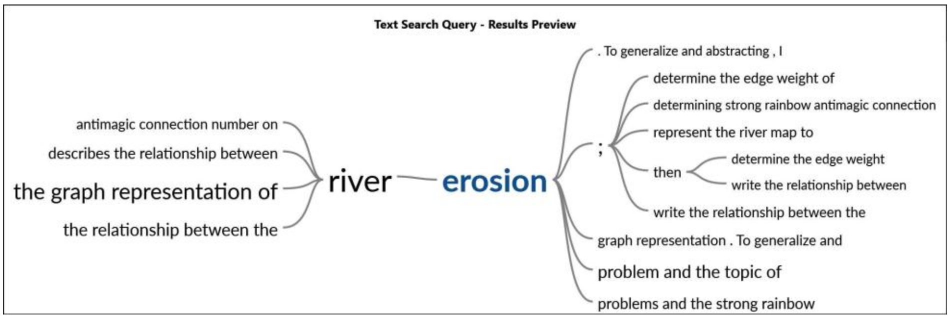

Figure 9
Word tree of the word “River Erosion”

Next, we will examine the comparative information provided by the three interviews. Comparative information is a useful feature of NVivo. In this section, computational thinking skills are divided into several indicators and sub-indicators. The first indicator is problem decomposition which has 2 sub indicators, namely identifying the given problem (DP1) and parsing information to solve the given problem (DP2). The second indicator is pattern recognition which has 2 sub indicators, namely determining the solution steps of the given problem (RP1) and applying the steps in solving the given problem (RP2). The third indicator is algorithmic thinking which has 4 sub-indicators, namely representing the river map to a graph (TA1), determining the point labeling pattern on the river erosion graph representation (TA2), determining the weight of the antimagic rainbow coloring side (TA3), and being able to determine the strong rainbow antimagic coloring number on the river erosion graph representation (TA4). The fourth indicator is generalization and abstraction which has three sub-indicators, namely analyzing the final result of the data or information that has been obtained with the initial hypothesis when solving the given problem (GA1), writing the relationship between the river erosion problem and the topic of strong rainbow antimagic coloring (GA2), and describing the relationship between the river erosion problem and the strong rainbow antimagic coloring number (GA3).

In Figure 10 (a), we observe differences in sub-indicators by M1 and M2. M1 are students with high computational thinking skills, M2 are students with medium computational thinking skills, and M3 are students with low computational thinking skills. In particular, the sub-indicator GA1 can only be achieved by M1, which is a differentiator between M1 and M2. Figure 14 (b) illustrates the specific sub-indicators that can be achieved by M2 compared to M3, where TA1 and TA4 can only be achieved by M2, while GA1 can only be achieved by M3. Similarly, Figure 14(c) shows the differences in sub-indicators achievable by M1 and M3. In particular, TA1 and TA4 are only achievable by M1.

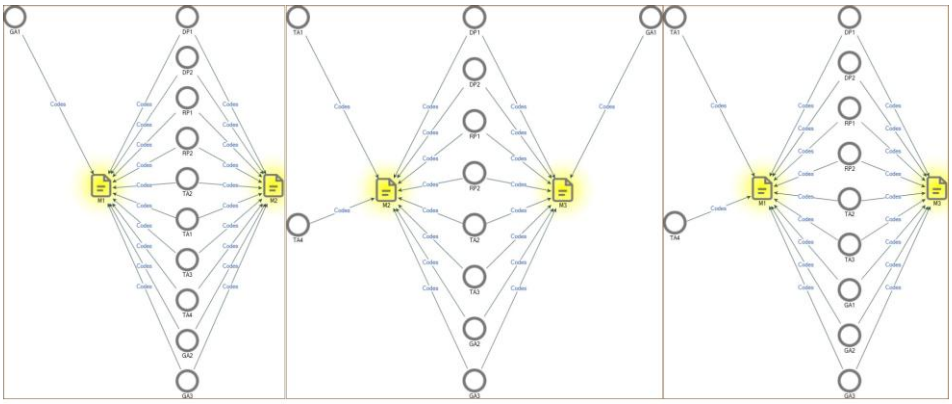

Figure 10
Comparison between (a) M1 and M2, (b) M2 and M3, (c) M1 and M3

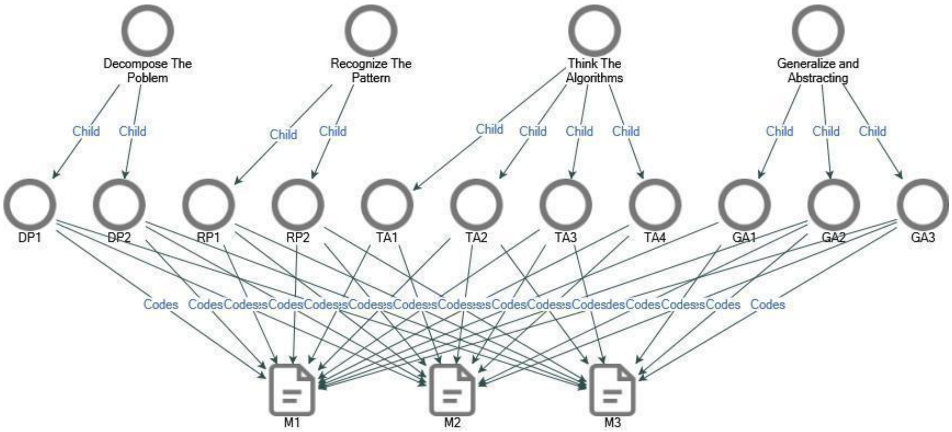

Figure 11
Project map of computational thinking skills in M1, M2, and M3

Finally, we analyze the overall student interview data and its relationship with the predefined categories. In addition, we will present the classification results from the interviews. Figure 11 displays the NVivo project map feature. This project map aligns with our previous analysis, which shows that M1 fulfills all sub-indicators, while M2 and M3 do not fulfill certain sub-indicators.

DISCUSSIONS

The learning materials with the RBL model and STEM approach developed have met the criteria of valid, practical, and effective. The validity is reflected based on the assessment of three validators, one of which assessed the appearance of the learning material product. The display of this material has been designed interactively in accordance with user characteristics. The interactive media design developed has been adjusted to the RBL-STEM aspect, which encourages students to learn more meaningfully by involving them in exploring topics or issues that are interesting and relevant to them (Sumarno et al., 2024). Through the Student Worksheet material, it is designed so that it helps students to solve problems from the given case. Through the appearance of the visualization of river erosion used, it is interesting and interactive so that it supports high interactivity in students.

The developed material has also fulfilled the practical aspect in this study. Through a score of 3.95 with a percentage of 98.75%, with very high criteria indicating the practicality of the RBL-STEM material that has been developed. Of course, this material plays an important role, by making it a guideline for analyzing data, making evidence-based decisions, and the ability to present their findings clearly and logically. So that the class becomes active in sharing opinions, discussing material in understanding difficult concepts. This is certainly contained in the RBL-STEM aspect where this approach encourages students to be actively involved in obtaining knowledge through the process of investigation and discovery (Gita et al., 2023).

Moreover, there is a problem that is relevant to them, namely the integration of SRAC in solving river erosion. Where river erosion is included in the focus of the Sustainable Development Goals (Moldovan et al., 2023), and many are found in coastal areas where the subjects of this study come from. So if used during learning, it will support their learning activities (Harris et al., 2023; Quintero-Angel et al., 2024).

The results of hypothesis testing also show that the developed material has met the effective criteria. This can be interpreted that there is an increase in students' computational thinking skills after the application of the RBL-STEM method on SRAC for river erosion problems. In Figure 5 it has been thoroughly explained that the material developed as a guide for students in learning about modeling, simulation, and decision making based on data. Through a series of activities this strengthens students' computational thinking skills (Peters-Burton et al., 2023; Zakwandi & Istiyono, 2023). Through the integration of computational thinking in STEM learning, students can see the direct application of what they learn in everyday life. This can increase student engagement as they see the value and relevance of what they are learning (Kong & Lai, 2023).

It is important to note that the effectiveness of the RBL-STEM Approach in computational thinking may depend on factors such as the quality of teaching, available resources, and support provided to students (Kerimbayev et al., 2023). Thus, through relevant problem content and the concept of systematic teaching flow in the developed RBL-STEM material, it has helped students develop computational thinking skills. This is evidenced based on qualitative data analysis which shows that the RBL-STEM material helps them understand the consequences of the decision to determine the river that has the potential for river erosion through the SRAC concept.

The findings of the results of this study add to the trend of the success of the RBL-STEM approach in a cognitive aspect (See Sumardi et al., 2023; Sumarno et al., 2024), namely mainly on improving computational thinking. Through STEM (Science, Technology, Engineering, and Mathematics) content with practical aspects in understanding river erosion problems, making it more relevant to students. Of course, this research adds a variation of the RBL-STEM approach in its integration of aspects of the Sustainable Development Goals (SDGs). In addition, this research shows how predicting river erosion can be applied in real-life situations, especially in the protection of terrestrial and freshwater ecosystems. This supports the idea of teaching students about river erosion management systems (Newson et al., 2023). This research validates the effectiveness of the RBL-STEM learning model. It contributes to the broader concept of a well-rounded STEM education that prepares students for the various challenges they may face in their future careers.

CONCLUSIONS

The results of the analysis of this RBL-STEM material meet the criteria of valid, practical, and effective. The average validation score is 3.71 with a percentage of 92.75%. Based on the validity criteria, the learning material meets the valid criteria because it reaches a score of $3.25 \leq Va < 4$. The average score of the overall learning implementation observation was 3.95 with a percentage of 98.75%. Based on the criteria of practicality, the learning material meets the criteria of very high practicality because it reaches a score of $90\% \leq SR < 100\%$. Furthermore, based on the post-test results, it was found that 36 students (90%) had scores above the minimum completeness, which means classically complete. The average score of the overall student activity observation was 3.76 with a percentage of 94%. Based on the results of student responses on the questionnaire sheet, the overall recapitulation of student response scores showed an average positive percentage of 90.31%. This shows that the teaching materials developed are effective because the three requirements for effective teaching materials are met.

The authors recommend more in-depth research into this teaching method, as three meetings may not be enough to study this phenomenon comprehensively. The study should also be repeated at other mathematics education colleges to strengthen the credibility and trustworthiness of the findings. In addition, this study was not compared to a recognised teaching method, so it cannot be determined whether this method is significant or not. Therefore, further studies are needed that allow for a fair comparison with other methods for better results.

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