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The Development of RBL-STEM Learning Materials to improve Students' Combinatorial Thinking Skills in Solving DNA Protection Problems

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Students often face challenges in solving complex mathematical problems in real-world contexts due to low combinatorial thinking skills. To address this, the RBL-STEM learning method—a model that integrates Research-Based Learning (RBL) with the STEM approach (Science, Technology, Engineering, and Mathematics)—offers a research-oriented, practical framework for effective learning. This study aims to identify the syntax of the RBL-STEM learning method, describe the process and results of developing the material, and analyze students' combinatorial thinking skills. The research method used is research and development (R&D). The output of this research includes RBL-STEM learning materials such as semester learning plans, student assignments, worksheets, and learning outcomes tests. The results of material development showed a high level of validity with a score of 95%. The pilot test involved 40 students, and the implementation of these learning materials was rated as practical with a score of 92.5% and effective with a score of 90%. Students showed very positive engagement and responses to this learning method. Analysis of the pre-test and post-test results revealed that students' combinatorial thinking skills improved, particularly in solving problems related to irregular reflexive k-labeling. This study also identified three levels of combinatorial thinking skills: high, medium, and low. The results of the statistical analysis confirmed the improvement of these skills. Thus, the RBL-STEM learning method has significant potential to enhance students' combinatorial thinking skills in relevant fields like DNA protection.

Keywords: RBL-STEM, combinatorial thinking skill, irregular reflexive k-labeling, DNA protection, learning materials, thinking skill, protection problems

INTRODUCTION

In a constantly evolving world, the development of combinatorial thinking skills in mathematics, particularly through its integration into university curricula, is becoming

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increasingly crucial to equip students for the complex challenges of the modern age. The role of university lecturers is shifting from merely imparting knowledge to ensuring that students develop the creativity, critical thinking, intelligence, and problem-solving skills needed for the 21st century. As a result, the study of best practices, teaching methods, and classroom management strategies, particularly in mathematics education, has become a key focus in teacher education programs. A study on the factors influencing students' performance in mathematics at selected colleges of education in East Java Province, Indonesia, found that most lecturers commonly use an explanatory approach when teaching mathematics (Sucianto et. al, 2019). According to the survey, 80% of mathematics lecturers use the lecture method, 11% use the question-and-answer technique, and only 9% use the heuristic approach, which involves small group discussions and is considered the least effective teaching method.

Several studies have also noted that mathematics teachers in Indonesia primarily rely on traditional methods (Dini, 2019). These methods often result in passive learning environments, where students struggle to actively engage with the material or develop deeper understanding (Nazula, 2019). The Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia has reported that the low performance of mathematics subjects at the tertiary level stems from the inability of lecturers to apply effective teaching approaches (Ridlo et al., 2019). As a result, there is an urgent need for more dynamic and innovative learning models that address these shortcomings while preparing students to face interdisciplinary challenges. Among several innovative approaches, Research-Based Learning (RBL) has gained attention for its potential to actively involve students in the learning process and encourage them to explore, investigate, and apply concepts to real-world problems (Hastuti et al., 2019).

While various learning models exist, such as Problem-Based Learning (PBL), Inquiry-Based Learning (IBL), and Design-Based Learning (DBL), RBL stands out due to its emphasis on fostering deeper engagement with research processes. Unlike PBL, which primarily focuses on solving pre-defined problems, or IBL, which emphasizes curiosity-driven exploration, RBL integrates authentic research activities into the learning process, allowing students to not only solve problems but also generate new knowledge. This makes RBL particularly effective in developing advanced skills such as combinatorial thinking, which requires students to synthesize and apply complex information. Moreover, when integrated with the STEM (Science, Technology, Engineering, and Mathematics) approach, RBL becomes a powerful framework for addressing complex challenges that involve interdisciplinary thinking. By combining RBL with STEM, this study seeks to establish a learning model that prepares students to tackle advanced mathematical problems and bioinformatics challenges, such as DNA protection using irregular reflexive k-labeling.

The theory used in this study is research-based theory (Jenkins, 2004). Research-based theories that support combinatorial thinking skills include several multidisciplinary approaches that focus on understanding and developing how people solve complex problems by analyzing and synthesizing information. One of the most important theories is cooperative learning theory, which strongly supports the development of combinatorial thinking skills through a collaborative framework supported by numerous studies (Ridlo, 2020). In cooperative learning, students work in small groups where they must rely on each other to achieve a common goal. This approach requires students to interact, discuss, and formulate ideas together, which inherently involves combinatorial thinking processes (Maylisa, 2020). For example, when solving math problems or science projects in groups, students must combine different information and approaches to find effective solutions. Research shows that this type of group work facilitates knowledge sharing among group members, allows students to see problems from multiple perspectives, and enhances their ability to think critically and creatively (Wahyuni and Farisi, 2020). In addition, the group dynamics of cooperative learning often create a supportive environment in which students feel more comfortable taking intellectual risks. This is especially important in developing combinatorial thinking, where exploring unconventional solutions and creative approaches to problems is highly valued (Ridlo and Nugroho, 2020).

Applying research-based theory to cooperative learning also helps develop metacognitive skills, where students learn to reflect on their own thinking as well as that of their group as a whole (Kurniawati et. al., 2022). The ability to evaluate strategies and make adjustments is necessary for combinatorial thinking, especially when dealing with complex problems that require multiple approaches to solve. Thus, cooperative learning theory not only supports collaborative learning, but also helps students develop and strengthen their combinatorial thinking skills, which are extremely useful in a variety of academic disciplines and real-life contexts (Puji and Ridlo, 2023). These theories, when applied to teaching and learning, provide important insights into how to facilitate and enhance combinatorial thinking skills through innovative teaching and learning methods. These theories support the development of these skills not only in academic settings, but also in professional and everyday contexts where the ability to combine information from multiple sources is critical for problem solving and decision making. (Dafik, 2016) developed several strategies for integrating research into learning, including the following: 1) Enrich teaching materials with lecturers' research results, 2) Use the latest research and trace the history of its origins, 3) Enrich learning activities with current research questions, 4) Include research methodology materials in the learning process, 5) Enrich the learning process with small research activities, 6) Enrich the learning process by engaging students in activities, 7) Implement cooperative teaching and learning by encouraging students to actively interact, and 8) Enrich the learning process with values that researchers should possess.

The research-based cooperative learning theory should include interactive tactics such as hands-on and group activities in the classroom (Gita et. al., 2021). And one of the approaches that can support this is the STEM (Science, Technology, Engineering, and Mathematics) approach. The application of research-based cooperative learning theory to the development of combinatorial thinking skills through the STEM approach has several important implications. First, the small-group collaboration typical of cooperative learning allows students to combine expertise from different STEM disciplines, encouraging them to solve complex problems more effectively (A'yun et. al., 2023; Sumarno et al., 2024). In STEM contexts, students are often faced with challenges that require interdisciplinary thinking, where they must apply concepts and techniques from different fields to find innovative solutions. Second, group work facilitates a dynamic exchange of ideas and often leads to more creative solutions, which is the essence of combinatorial thinking. By working together, students learn how ideas from one discipline can be applied in another context, broadening their understanding of how knowledge is integrated in the real world. In addition, group discussions and interactions allow students to ask questions, critique assumptions, and refine their understanding, all of which reinforce the critical and analytical thinking skills essential to the STEM approach (Izza et. al., 2023).

Third, the use of cooperative learning in STEM education also emphasizes the importance of the learning process in addition to the end result. The group process encourages students to participate in active experimentation, problem solving, and design projects that require not only theoretical knowledge but also practical application (Alpian et. al., 2023). Through these interactions, students develop skills such as leadership, negotiation, and conflict management, all of which are important in STEM careers. Finally, this approach promotes inclusive and supportive teaching, where all students, regardless of background or ability, are invited to contribute and feel valued in the learning process. This not only builds a sense of ownership and satisfaction in the learning process, but also increases students' motivation to engage in STEM, a field where collaboration and innovation remain key to long-term success (Waris et. l., 2024). Implementing collaborative approaches in STEM education not only improves combinatorial thinking skills, but also prepares students to be effective thinkers and problem solvers in the future.

The Research-Based Learning (RBL) learning model was first introduced by Alan Jenkins in 2004 (Jenkins, 2004). On the other hand, there is the STEM approach, which was first developed by Janet Marsden in 1995 (Marsden and Wilkinson, 1995). Then, in 2016, Dafik began to conduct further research on RBL for universities (Dafik, 2016). In 2021, Dafik and Gita began to integrate their research on RBL with STEM (Marsden and Wilkinson, 1995). In his research, Dafik identified seven main characteristics of RBL. The seven characteristics are 1) Students' ability to make decisions about a framework is developed; 2) The existence of problems or challenges proposed by students related to the research interests of the instructor, or open problems from the research umbrella of the instructor, can be proposed by students but elaborated with problems that develop in the research interests of the instructor; 3) The ability of students to design a process to determine solutions to the proposed problems or challenges; 4) The creation of collaborative student responsibility to access and manage information to solve problems with the latest methodologies; 5) The growing ability of students to communicate the results of their problem solving through various national and international media; 6) The evaluation process is carried out continuously through authentic assessment; and 7) The development of students' ability to reflect on the research-based learning activities that have been carried out.

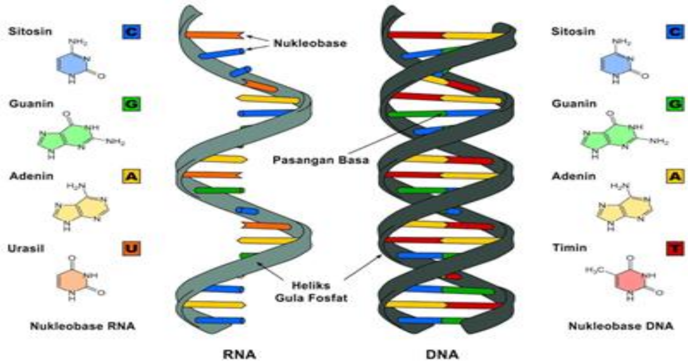

Figure 1
RNA and DNA composition

The integration of STEM (Science, Technology, Engineering, and Mathematics) and Research-Based Learning (RBL) has emerged as a transformative educational strategy with the primary goal of preparing students to face complex scientific and technological challenges in the modern era (Septory and Tirta, 2019). This research explores the combined application of RBL and STEM methods to improve combinatorial reasoning, an essential cognitive skill in mathematics and computer science, specifically in solving DNA protection problems using irregular reflexive k-labeling. These combinatorial skills are important in helping students solve advanced mathematical problems, allowing them to develop effective strategies for tackling complex problems (Anwarudin and Farisi, 2020). A practical application of these skills is in graph theory, where the irregular reflexive k-labeling problem plays an important role, with significant implications for network security and genetic sequencing (Agustin, et. al., 2023). This has particular relevance in bioinformatics, especially in the protection and analysis of DNA, providing a new perspective on how to understand and protect genetic information (Yenigun et. al., 2024). An example of the sequence of DNA starting from RNA is visualized in Figure 1. While the process of DNA construction can be seen in Figure 2.

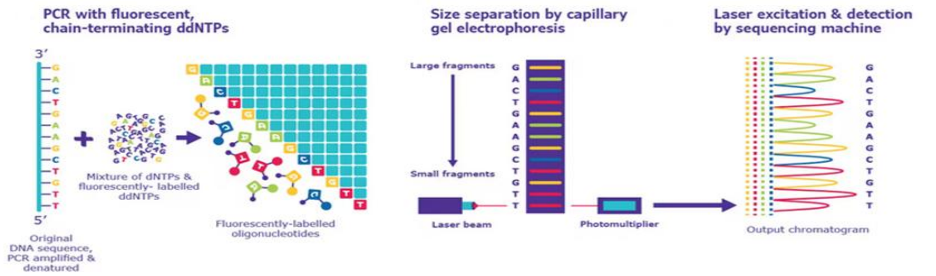

Figure 2
The process of DNA construction

Although there are many studies that separate RBL and STEM, it is still rare to find studies that integrate the two to strengthen combinatorial skills in solving advanced mathematical problems. As a result, this work is innovative in that it develops, implements, and evaluates an RBL-STEM learning model aimed at improving combinatorial reasoning skills, notably in the solution of DNA protection issues with irregular reflexive k-labeling. DNA protection with irregular reflexive k-labeling is a new breakthrough to build a key stream in cryptography so that it is not easily hacked (Salim et. al., 2024). In addition, this research is expected to make a significant contribution to the education of mathematics, graph theory, and bioinformatics by enabling students to be better prepared to face future challenges in science and technology (Marsidi et. al., 2023). The indicators and sub-indicators of combinatorial thinking skills (Maryati et. al., 2022) are as follows 1) Identify some cases, which has two sub-indicators: students are able to identify the characteristics of a problem and students are able to implement these characteristics into several cases. 2) Recognize patterns in all cases, which have two sub-indicators: students are able to identify patterns of case resolution and students are able to extend the pattern of the case solution obtained. 3) Apply patterns from all cases, which have three sub-indicators: students are able to determine point and side notation, students are able to calculate cardinality, and students can develop their algorithms. 4) Proving mathematically, which has five sub-indicators: students can perform argument calculation, students are able to test their algorithms, students are able to develop a function, students are able to validate the function, and students can apply inductive, deductive, and qualitative proofs? 5) Consider another combinatorial problem, which has four sub-indicators: students are able to interpret, students can propose open problems, students are able to identify new combinatorial problems, and students can find potential applications.

This research aims to achieve three main objectives. First, it seeks to identify specific applications of the Research-Based Learning (RBL) and STEM approaches in the learning process, particularly in the context of solving DNA protection problems using irregular reflexive k-labeling. This includes exploring how these methods can effectively enhance students' combinatorial thinking and problem-solving abilities. Second, the study aims to outline and develop learning materials based on the RBL-STEM framework. These materials will be designed, implemented, and evaluated to ensure their validity, practicality, and effectiveness in supporting advanced learning outcomes. These materials are designed to enable students to identify patterns, apply mathematical algorithms, and propose solutions to combinatorial problems in a structured and methodical way. Third, the research intends to assess the impact of implementing RBL-STEM-based learning materials on improving students' combinatorial thinking skills, especially in solving advanced mathematical problems and cryptographic challenges related to DNA protection.

The study is guided by several hypotheses. It hypothesizes that integrating RBL-STEM into the learning process will significantly enhance students' understanding and application of combinatorial reasoning to solve complex problems. Additionally, it posits that learning materials developed through the RBL-STEM approach will meet the criteria of being valid, practical, and effective in fostering higher-order thinking skills. Finally, the study hypothesizes that implementing these learning materials will positively influence students' ability to tackle DNA protection problems and enhance their overall combinatorial thinking skills, preparing them for future challenges in science, mathematics, and technology.

METHOD

Research Design

The research design employed in this study refers to Thiagarajan's development, specifically the 4D model, which includes the define, design, develop, and disseminate stages. The 4D model is shown in Figure 3. The Bachelor of Mathematics Education Program, Faculty of Teacher Training and Education, University of Jember was used for this study. The university is located in Jember Regency, East Java Province, Indonesia, and is one of the 4 state universities responsible for mathematics education in East Java. A purposive sampling technique was used to select Jember University to conduct the study. This is because in addition to general programs, this university specializes in mathematics education. In addition, the University of Jember is the central campus for the entire Tapal Kuda or 6 eastern districts of East Java Province (Pasuruan, Situbondo, Bondowoso, Lumajang, Jember, and Banyuwangi districts). As a result, the institution has the ability to assure the legitimacy and success of the RBL-STEM initiative.

The mathematics education program at this university has 160 students and an average class size of 40. A simple random sample procedure was used to choose one class (the complete class) from four. The selected class of 40 students served as a case study for a further in-depth examination into the development of an RBL-STEM material to improve students' combinatorial thinking abilities on DNA protection challenges using irregular reflexive k-labeling. The students are 5th semester undergraduates who have taken Discrete Mathematics, which is a prerequisite for the Graph Applications course. The class is heterogeneous, with 24 females and 16 males.

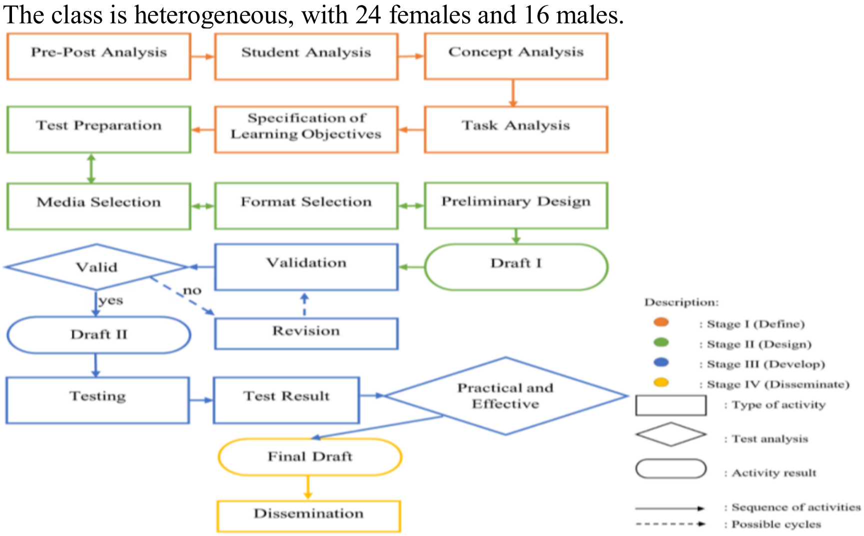

Figure 3
4-D Model design

Data Collection Instruments

The RBL-STEM strategy intervention and data collection took place in 3 face-to-face classroom meetings. The face-to-face meetings occurred once a week, so this study took 3 weeks in a month. The graph application course on the topic of irregular reflexive k-labeling was designed and taught using the RBL-STEM method, which follows the steps proposed by Dafik (2016) for implementing RBL. RBL-STEM learning begins with a well-developed lesson plan that embodies RBL-STEM qualities (small group activities, interaction among group members, collaboration among group members, student-centered, and combinatorial thinking abilities) in an interactive manner. Its implementation takes into account the characteristics identified by the researcher in section 2, the overview of RBL-STEM. Thus, 1) students are at the center of learning; 2) learning takes place in small groups of students; 3) teachers act as facilitators or guides; 4) students are given prior research at the beginning of learning; 5) the problems used are problems that arise from prior research to achieve learning objectives on the topic of irregular reflexive k-labeling; and 6) group learning is utilized to gain new information. Prior to the start of each lesson, a pretest was administered to determine the students' prior knowledge of the topic. The lectures were designed in such a manner that the researchers were viewed as facilitators, challenging the students to take main responsibility for group learning. At the end of learning the topic, a post-test was administered to measure the improvement of combinatorial thinking skills in 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.

The validity sheet, learning implementation sheet, student activity observation sheet, questionnaire, and student pretest-posttest were used to collect data for this study. In the validity sheet, learning implementation sheet, and student activity observation sheet, each dimension has a possible answer on a Likert scale from 1 to 4. While the questionnaire sheet uses a dichotomous scale, namely the answer options "yes" and "no". The student pretest-posttest is in the form of descriptive response questions with a maximum total value scale of 100. All data results from the material validity evaluation are computed by taking the average of each indicator value element, which is then utilized to determine the material validity criterion. The table of criteria for material validity is shown in Table 1.

Table 1
Criteria for learning materials validity

Score	Interpretation
$V_a = 4$	Very Valid
$3,25 \le V_a < 4$	Valid
$2,5 \le V_a < 3,25$	Fairly Valid
$1,75 \le V_a < 2,5$	Less Valid
$1 \le V_a < 1,75$	Not Valid

Data on the practicality of learning materials describes how the application of materials has been developed. This data is obtained through an observation sheet that contains the results of observations of the implementation of learning. Student activities can also be used to measure the effectiveness of learning materials. Student activities include all activities carried out during the teaching and learning process in the classroom. In addition, data from the student response questionnaire was analysed to find out students' responses to the implementation of the learning that has been done, and the results can be seen from the percentage of responses obtained. The criteria for the practicality of learning materials, student activity observation results, and student response questionnaires can be seen in Table 2 below.

Table 2
Criteria for practicality of learning material, student activity observation results, and student response questionnaires

Score	Interpretation
$90\% \leq SR, P, PR < 100\%$	Very Good
$80\% \leq SR, P, PR < 90\%$	Good
$70\% \leq SR, P, PR < 80\%$	Fairly Good
$40\% \leq SR, P, PR < 70\%$	Less Good
$0\% \leq SR, P, PR < 40\%$	Not Good

Data Processing and Analysis

We used SPSS to analyze the effectiveness of RBL-STEM materials in improving students' combinatorial thinking skills through pretest-posttest results and interviews. Quantitative analysis with statistics used is paired sample t-test using SPSS software. Paired sample t-test is a test that compares two paired samples involving the same subject but subjected to different treatments with two tests at different times. Before conducting this analysis, it is necessary to test the research data with a prerequisite test, namely the normality test. In this study, the t-test is used to see whether students' combinatorial thinking skills improve after the application of the RBL-STEM technique in solving DNA protection problems using irregular k-reflexive labeling. The hypothesis will be formulated in the form of null hypothesis (H0) and alternative hypothesis (H1). For the evaluation criteria, H0 is accepted if the significance value (sig) is greater than 0.05, and rejected if the significance value is less than 0.05.

The study employed qualitative analysis to evaluate the implementation of RBL-STEM teaching materials, using a thematic analysis approach to identify recurring patterns and insights into their effectiveness and practicality. Interviews were conducted with students to capture their perspectives, experiences, and challenges, with the data analyzed using NVivo, a qualitative analysis software that categorized responses, identified themes, and uncovered patterns related to combinatorial thinking processes. This approach provided a deeper understanding of how students engaged with the materials and developed their skills. The data were further triangulated with other sources to enhance reliability and explore the relationships between factors influencing students' skills. However, more detailed information about the specific interview questions, such as their focus on problem-solving experiences, perceptions of the materials' effectiveness, and their ability to apply combinatorial thinking, would provide greater clarity.

FINDINGS

The findings of this research are organized into three key sections that align with the study's objectives. The first section explores the implementation of RBL-STEM-based learning activities, providing insight into how these activities are integrated into the classroom setting and their influence on student engagement and learning outcomes. This section highlights the practical application of the RBL-STEM framework and its role in fostering an active learning environment. The second section delves into the development of learning materials tailored to the RBL-STEM approach, offering a comprehensive explanation of the components, structure, and the results of this developmental process. This part emphasizes the alignment of the materials with educational goals and their contribution to enhancing students' learning experiences. The third section presents a thorough analysis of data related to students' combinatorial thinking abilities, particularly in tackling complex problems such as irregular reflexive k-labeling. The analysis underscores the effectiveness of the RBL-STEM method in nurturing students' critical thinking, problem-solving, and creativity, providing a clear picture of how this approach strengthens these essential cognitive skills.

Data Processing and Analysis

RBL requires students to create their comprehension of a mathematical topic. Thus, teaching should not be viewed as a lecture or just communicating mathematical information. The RBL learning paradigm enables professors and students to develop critical thinking and make changes to traditional teaching methods. What is crucial in the RBL approach is how much students collaborate in small groups. This method stimulates and develops student's understanding of the material. Cooperation in small groups also improves students' ability to work in teams, which is a crucial skill in professional activity. This concept is consistent with the STEM approach to education, which emphasizes student-centeredness. This teaching technique requires students to actively create their knowledge and comprehension using STEM knowledge. Therefore, we construct new characteristics that are the result of integrating the STEM approach with the RBL learning model as follows:

a. Student Ability to Make Decisions about Frameworks: Integrate technology and engineering principles in making decisions to develop innovative and efficient frameworks, in accordance with STEM principles.
b. Problem or Challenge Submission by Students: Students are invited to identify and formulate challenges that are not only relevant to the lecturer's research interests but also utilize the latest technology and analytical methodologies in STEM to broaden the scope and depth of the research.
c. Students' ability to design processes for solutions: Apply engineering and mathematical methods in the design of research processes to ensure that the solutions produced are not only creative, but also optimal and reliable according to technical and scientific standards.
d. Student Collaborative Responsibility in Accessing and Managing Information: Students work collaboratively using digital materials and information technology

resources to collect, analyze, and manage data that will be used to solve problems with an innovative STEM approach.

e. Students' Ability to Communicate Results: Develop scientific and technical communication skills by presenting research findings in various scientific forums, both national and international, using digital media and online platforms to reach a broader audience.
f. Continuous evaluation process with authentic assessment: Implementing evaluation techniques that integrate STEM principles, such as statistical analysis and computerized scoring, to ensure more objective assessments and holistically measure student competencies and performance.
g. Student reflection on inquiry-based learning activities: Encouraging students to critically reflect on their learning process using digital research logs and collaborative platforms that enable continuous feedback integration and improvement based on educational technology.

By incorporating the STEM approach into the characteristics of RBL, educational programs not only enhance students' academic abilities, but also prepare them with the practical and technical skills necessary for success in competitive professional and academic environments. This study employs resources from the RBL model and the STEM method to help students acquire and build abilities in science, technology, engineering, and mathematics. The RBL-STEM method requires students to be more actively engaged in learning through inquiry. In this study, the implementation of RBL-STEM materials is aimed at improving students' combinatorial thinking skills. In the initial phase, the syntax of this RBL-STEM method presents problems derived from open problem research groups.

Research-based learning with a STEM approach, which aims to improve students' combinatorial thinking skills, is applied to the topic of irregular reflexive k-labeling in DNA protection problems. The framework in Figure 4 is supported by research-based theory in cooperative learning, which explains how RBL with a STEM approach occurs in the combinatorics course, specifically in the topic of irregular reflexive k-labeling and its problem in DNA protection. The researcher refers to dimensions of research-based theory, including student-centered learning, interactive learning, collaboration, effective communication skills, and small group activities. The researcher hypothesizes that if instructors adopt the RBL-STEM strategy in teaching mathematical concepts, especially on the topic of irregular reflexive k-labeling in DNA protection problems at the university level, students' learning outcomes in combinatorial thinking skills will improve.

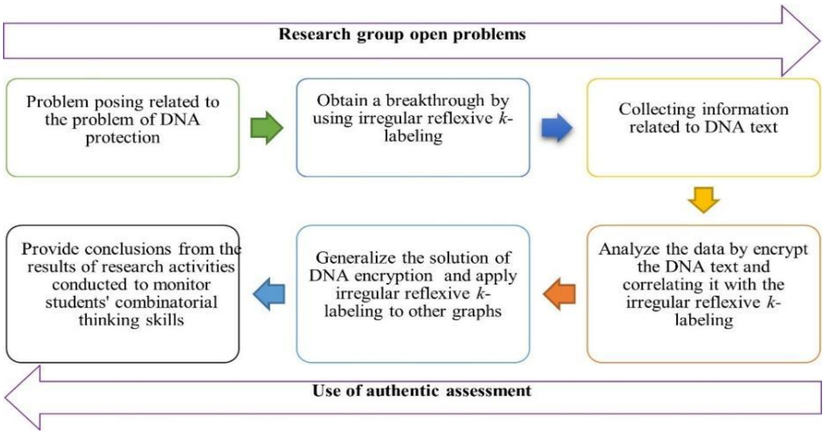

Figure 4
RBL-STEM syntax framework

The following section outlines the RBL-STEM framework for irregular reflexive k-labeling in DNA protection problems. There are 6 RBL steps that have adopted the STEM approach. The first step (Science) begins with the provision of previous research aimed at raising the issue of DNA protection. Through this learning, students are introduced to the concept of irregular reflexive k-labeling in graphs, which can be applied to the molecular structure of DNA. In this activity, students are asked to identify and understand the background of the DNA protection problem. The goal of this stage is to provide students with a scientific basis for the importance of DNA protection in the field of genetics.

In the second stage (Engineering), combinatorial thinking skills are developed through the application of irregular reflexive k-labeling to solve DNA protection problems. Active discussions and lecturer guidance encourage students to seek innovative solutions to these problems. This stage involves exploration of the DNA structure and the application of labeling concepts, with students required to record important information and develop relevant solutions. Next, in the third stage (Mathematics), students construct the irregular reflexive k-labeling function and calculate the matrix to create a key stream as part of the problem-solving process. This stage emphasizes mathematical analysis skills to construct the solution in detail.

The fourth stage (Technology) and the fifth stage (Mathematics) involve the use of technology in data collection and processing, including simulations using Python software. Students are tasked with collecting data from online sources, building encryption algorithms, and converting DNA data into a secure format. The fifth stage continues the process with the development of algorithms on other graphs. Finally, in the sixth stage (Report), students compile research reports and present their findings. The lecturer evaluates the students to measure the combinatorial thinking skills they have acquired, while also reinforcing the understanding gained throughout the learning process.

Development of RBL-STEM Learning Materials

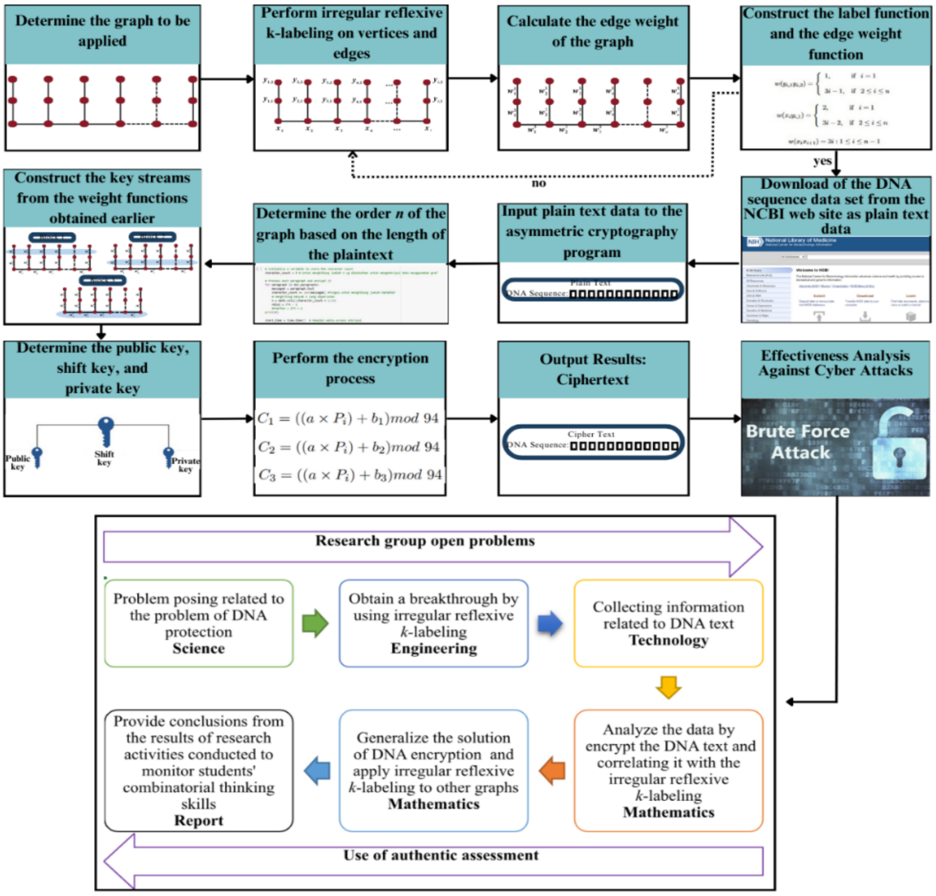

Figure 5
DNA protection prototype using asymmetric cryptography with irregular reflexive k −labelling

To support the RBL-STEM learning activities conceptualized by the researcher, learning materials were developed using the four stages of 4D. The first stage is definition, and the goal of this stage is to determine and define the learning needs by analyzing the objectives and limitations of the material to be delivered. The defining step is broken down into four parts: initial-final analysis, student analysis, idea analysis, and task analysis. The initial-final analysis is used to investigate the fundamental issues that students confront during learning and to influence the development of the learning content. The student analysis is used to collect information about the characteristics of students in the Mathematics Education program at the University of Jember. The concept analysis is used to methodically identify, describe, and arrange the ideas that students have learnt, particularly the issue of irregular reflexive k-labeling. The task analysis aims to identify the core competencies required for learning according to the curriculum.

The second stage is the design stage, which aims to design the learning materials that will be used so that an initial design is obtained. This initial design is preceded by a prototype in the DNA protection problem visualized in Figure 5. In this stage, the RBL-STEM materials are designed to evaluate the impact of the learning materials on improving students' combinatorial thinking skills in the concept of irregular reflexive k-labeling. There are four steps in this phase: test development, media selection, format selection, and initial design. Test development is based on the predetermined learning indicators. Media selection is based on past student, idea, and task analyses. PowerPoint was chosen to convey the irregular reflective k-labeling content, as well as RBL-STEM student worksheets providing markers of combinatorial thinking skills. The purpose of format selection in instructional material production is to define and determine the design model, method, and learning resources that will be employed. The original design is the comprehensive strategy of learning materials that must be completed prior to the trial. These learning resources comprise the semester learning plan, task design, learning result exams, and student worksheets. A visualization of the learning materials is shown in Figure 6.

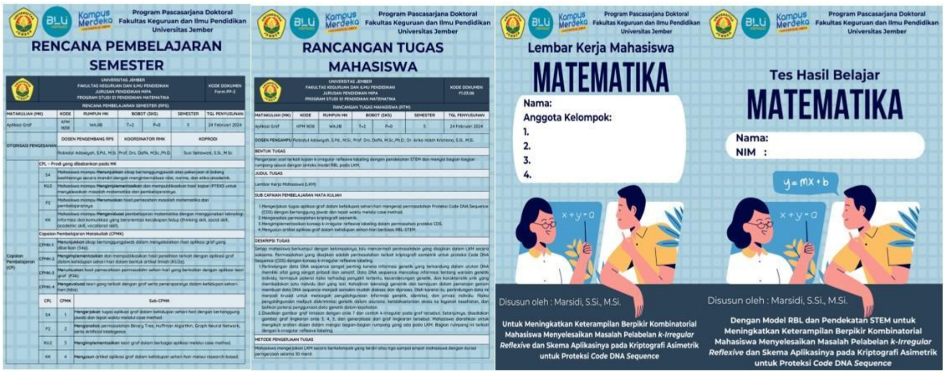

Figure 6
Preliminary design of learning materials

The third stage is the development stage, which is divided into four phases: validity testing, learning material testing, practicality testing, and effectiveness testing. Each material developed in this stage is validated by validators and revised according to their recommendations. The learning materials were validated by three validators who are lecturers in the Mathematics Education Program at the University of Jember. According to the evaluation of the three validators, the materials can be used with minor modifications. Based on the results of the validation summary of the RBL-STEM materials and instruments in Table 3, the average validation score was 3.71, with a percentage of 92.75%. According to the validity criteria in Table 1, the developed learning materials meet the validity criteria as they achieved a score of 3.25 < Va < 4.

Table 3
Recapitulation of learning materials validation

Validation Results	Average Score	Percentage
Learning Materials	3.65	91.25%
Student Activity Observation Sheets	3.67	91.75%
RBL-STEM Implementation Sheets	3.69	92.25%
Student Response Surveys	3.79	94.75%
Questionnaire	3.72	93%
Overall average score	3.71	92.75%

After the learning materials were deemed valid, the revised and validated materials were implemented with students. This trial was conducted in a class of 40 students. After the practicality testing of the learning materials, an analysis of the learning implementation in the classroom was conducted. The analysis was based on the RBL-STEM implementation observation sheets, which were evaluated by 8 observers. According to Table 4, the average score from the observation of total learning implementation was 3.95, representing 98.75%. Based on the practicality criteria in Table 2, the developed learning materials meet the criteria for very high practicality as they achieved a score of 90% < SR < 100%.

Table 4
Recapitulation of learning implementation observation results

Assessed Aspects	Average Score	Percentage
Syntax	3.875	96.875%
Social System	4	100%
Principles of Reaction and Management	3.975	99.375%
Overall average score	3.95	98.75%

The effectiveness test of the learning materials consists of three indicators, namely the analysis of student learning outcomes, the observation of student activities, and the results of the student response questionnaire. Based on the post-test results, it was found that 36 students (90%) had scores above the minimum passing grade, which means they achieved classical completeness. The observations made included the introduction, core activities, and conclusion. The summary of the scores can be seen in Table 2. According to Table 5, the average total observation score for student activities was 3.76, with a percentage of 94%. Based on the effectiveness criteria in Table 2, the learning materials meet the criteria for highly active effectiveness as they achieved a score of 90% < P < 100%.

Table 5
Recapitulation of student activity observation results

Assessed Aspects	Average Score	Percentage
Introduction	4	100%
Main Activities	3.96	99%
Closing	3.32	83%
Overall average score	3.76	94%

The third criterion is the student survey. The student questionnaire was distributed in paper form. Based on the student response criteria in Table 2, the summary of the student response scores is presented in Table 6. Overall, the average positive percentage was 90.31%. This indicates that the learning materials were effective because all three conditions were met.

Table 6
Data recapitulation of student response survey results

Assessed Aspects	Percentage
Enjoyment of learning components	91.25%
Students' combinatorial thinking skills feel trained	90.55%
Learning components are new	86.875%
Students clearly understand the language used	87.5%
Students understand the meaning of each problem 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%
Overall average score	90.31%

The 4D model's last stage is the dissemination stage, which entails using the produced learning materials on a bigger scale, such as in classes that have not yet been tested or in programs with similar courses. The goal is to determine whether the developed materials work effectively for learning activities.

Data Analysis

After conducting research in the classroom, the next step taken by researchers is to analyze the data obtained. The researcher used quantitative data analysis to analyze the improvement of students' combinatorial thinking skills. The following is a graph of the distribution of students‘ pretest and posttest scores which can be seen in Figure 7. Meanwhile, Figure 8 shows the percentage level of students’ combinatorial thinking ability.

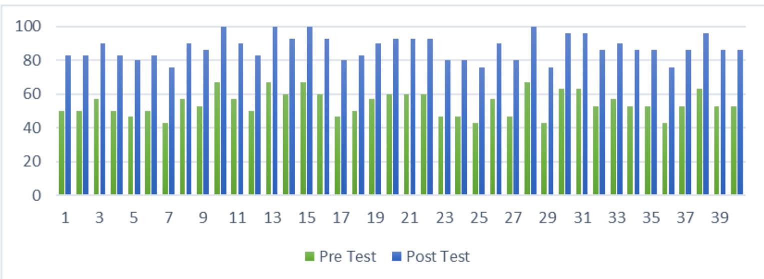

Figure 7
Distribution of students' pretest and posttest scores

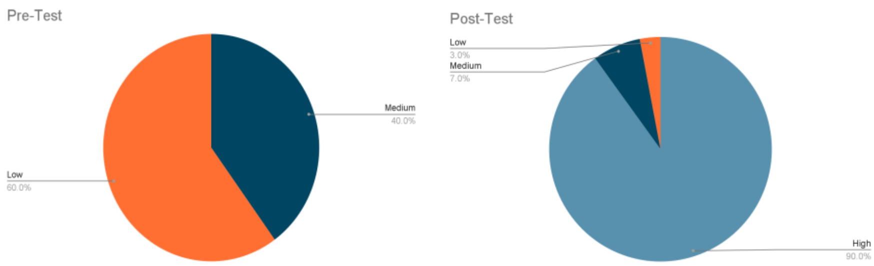

Figure 8
Percentage of students' combinatorial thinking skill level

Table 7
Normality test results

Tests of Normality						
	Kolmogorov-Sminov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Pretest	.128	40	.095	.948	40	.065
Posttest	.129	40	.090	.949	40	.070

a. Lilliefors Significance Correction

In the pre-test findings, no students were classified as possessing high-level combinatorial thinking ability, students with medium-level combinatorial thinking skills were 40%, and students with low-level combinatorial thinking skills were 60%. Meanwhile, in the post-test results, students categorized with high-level combinatorial thinking ability reached 90%, students with medium-level combinatorial thinking ability decreased to 7%, and students with low-level combinatorial thinking ability decreased to 3%. In addition, normality test was conducted as a requirement for paired sample t-test. This statistical test was conducted using SPSS software.

Based on the results of the data normality test in Table 7, it shows that the pretest and posttest scores are normally distributed because the significance value (Sig.) > 0.05. More importantly, the paired samples t-test was performed, as seen in Table 8 below.

Table 8
Paired samples correlations results

Paired Samples Correlations				
		N	Correlation	Sig.
Pair 1	Pretest & Posttest	40	.983	.000

The test results in Table 8, with a sample size of 40, show that the correlation between the pretest and the posttest, with a significance value of 0.000 > 0.05, indicates that the correlation or relationship between the two average scores of the pretest and the posttest is significant.

Table 9
Paired samples test results

Paired Samples Test									
Paired Differences									
					95% Confidence Interval of the Differences				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	t	df	Sig. (2-tailed)
Pair 1	Pretest-Posttest	-30.725	1.648	.261	-31.252	-30.198	-117.883	39	.000

The test results in Table 9 show a probability or Sig. (2-tailed) of 0.000 < 0.05. The conclusion is that there is a significant difference in students' combinatorial thinking skills before and after learning with the RBL-STEM materials. In addition, this study used NVivo software to qualitatively analyze the change in students' combinatorial thinking skills. The researchers used a special NVivo material called Word Frequency Query to monitor the frequency of certain words in detailed interview transcripts with the students. This analysis resulted in a compilation of frequently occurring terms in the interview data, as shown in Figure 9.

Figure 9
Word cloud from student interviews

Next, we will examine the comparative information provided by the three students interviewed. Comparative information is a useful feature of NVivo. In this section, combinatorial thinking skills are divided into several indicators and sub-indicators. The first indicator is analyzing a problem, which has two sub-indicators: correlating previous research on DNA protection issues (IC1) and analyzing the background of DNA protection analysis (IC2). The second indicator is establishing patterns from a problem, which also has two sub-indicators: developing a solution to the DNA protection problem using the concept of k-irregular reflexive edge labeling and asymmetric cryptography (RP1) and analyzing the solution to the DNA protection problem using the concept of k-irregular reflexive edge labeling and asymmetric cryptography (RP2). The third indicator is to establish patterns from a problem, which has two sub-indicators: formulating a theorem based on the observations made (AP1) and establishing a key stream based on the k-irregular reflexive edge labeling function obtained (AP2). The fourth indicator is mathematical proof, which has four sub-indicators: collecting DNA data from the Internet (PM1), developing a key stream algorithm that generates a sequence of characters and combines it with the original data to convert the information into a secure format (PM2), developing the original DNA data into an encrypted form (PM3), and exploring the decryption process, which is the reverse of encryption (PM4). The fifth indicator is considering other combinatorial problems, which also has four sub-indicators: formulating the cardinality of vertices and edges on another graph (CP1), developing a k-irregular reflexive edge labeling function on that graph (CP2), constructing a matrix and key stream based on the k-irregular reflexive edge labeling function obtained on that graph (CP3), and developing the original DNA data into an encrypted form from the previously built key stream algorithm (CP4).

In Figure 10 (a), we observe the differences in the sub-indicators between M1 and M2. M1 is a student with high combinatorial thinking skills, M2 is a student with moderate combinatorial thinking skills, and M3 is a student with low combinatorial thinking skills. In particular, the sub-indicators AP2 and CP1 can only be achieved by M1, which distinguishes M1 from M2. Figure 10 (b) illustrates the specific sub-indicators that can be achieved by M2 compared to M3, where RP1 and CP2 can only be achieved by M2, while GA1 can only be achieved by M3. Similarly, Figure 10 (c) shows the differences in the sub-indicators that can be achieved by M1 and M3. Specifically, RP1, AP2, CP1, and CP2 can only be achieved by M1.

Finally, we analyzed the overall student interview data and its relationship to the predetermined categories. In addition, we will present the classification results from the interviews. Figure 11 shows the NVivo Project Map function. This project map is consistent with our previous analysis and indicates that M1 meets all sub-indicators, while M2 and M3 do not meet certain sub-indicators.

The learning materials created using the RBL model and STEM methodology satisfied the requirements of validity, practicality, and effectiveness. The RBL-STEM method is recommended for educational implementation to foster higher student motivation, improve student learning outcomes, and enable the application of what is learned in daily life. The results of implementing the RBL-STEM material development have been proven to significantly improve students' combinatorial thinking skills. This is evident from the quantitative data analysis, where the paired sample t-test between pre-test and post-test scores shows an effect in terms of improved student learning outcomes. In addition, the qualitative data analysis using NVivo indicates differences in the achievement of sub-indicators between students M1, M2, and M3.

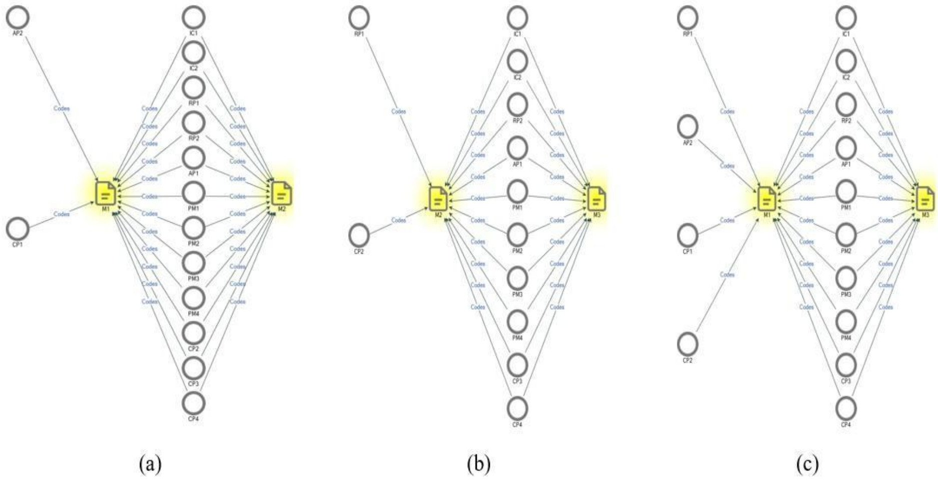

Figure 10
Comparison between (a) M1 and M2, (b) M2 and M3, (c) M1 and M3

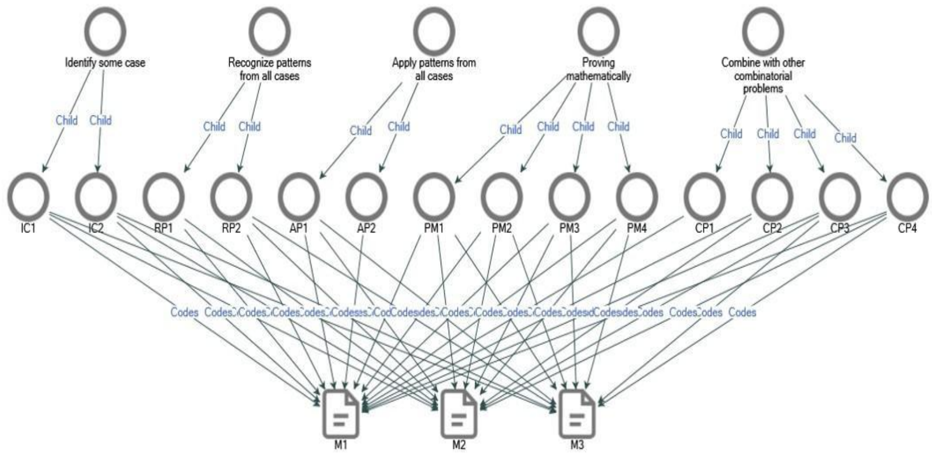

Figure 11
Comparison between (a) M1 and M2, (b) M2 and M3, (c) M1 and M3

DISCUSSIONS

This study aims to develop RBL-STEM-based teaching materials that enhance students' combinatorial thinking skills, specifically in solving DNA protection problems using irregular reflexive k-labeling. By integrating research-based learning approaches and STEM principles, the study builds upon and extends previous research, highlighting the effectiveness of these methods in addressing complex problems in mathematics, biology, and technology.

Several studies have emphasized the benefits of research-based learning and STEM integration in enhancing students' problem-solving skills. For example, Komaria et al. (2022) demonstrated that STEM-based learning activities, such as cascara fermentation with magnetic fields to produce herbal tea, foster a deeper understanding of scientific processes. Similarly, this study emphasizes active student exploration, enabling learners to engage directly in solving a complex biological problem, such as DNA protection, through novel mathematical approaches. However, unlike Komaria et al., this study introduces an advanced combinatorial method, irregular reflexive k-labeling, which further highlights the interdisciplinary nature of STEM in addressing real-world issues.

Research by Adawiyah et al. (2023) focused on improving students' combinatorial thinking skills using STEM-based approaches, particularly in solving Graceful Coloring problems for ATM placement optimization. This aligns with our study's objectives, as both research efforts aim to develop students' mathematical modeling skills to solve practical problems. While Adawiyah et al. concentrated on logistical optimization, our study extends the application to biological contexts, demonstrating how combinatorial thinking can bridge mathematical concepts and biological applications.

Priantari et al. (2023) showcased the integration of STEM in understanding real-world phenomena, such as the coffee roasting process. Their study revealed how science, technology, and mathematics can enhance students' analytical and problem-solving skills. Similarly, our research employs STEM-based teaching to prepare students for addressing complex biological challenges. However, this study goes a step further by applying these skills to the domain of DNA protection, introducing interdisciplinary problem-solving that combines mathematical theories with biological applications.

Jannah et al. (2024) explored the development of RBL-STEM teaching materials to improve students' information literacy in solving the Rainbow Antimagic Coloring problem in ETLE technology. Their work demonstrated the potential of research-based learning to equip students with mathematical and critical thinking skills for addressing technological challenges. In comparison, our study focuses on applying similar methods to biological challenges, thereby extending the scope of RBL-STEM to interdisciplinary fields. This highlights the adaptability and versatility of research-based learning in equipping students to solve diverse real-world problems.

Beyond these studies, the present research confirms the effectiveness of RBL-STEM in fostering critical thinking, problem-solving, and interdisciplinary learning. It extends previous findings by demonstrating how combinatorial thinking skills can be applied to DNA protection, a relatively unexplored area in the context of STEM education. Additionally, this study integrates irregular reflexive k-labeling, a novel mathematical approach, to emphasize the importance of advanced combinatorial methods in addressing biological and technological challenges.

Unlike earlier works, this study provides a comprehensive framework for integrating mathematical modeling into STEM-based learning, with a specific focus on solving DNA-related problems. It confirms the findings of earlier research on the efficacy of research-based learning while extending the application of these methodologies to new and emerging fields. The results contribute to existing literature by demonstrating the potential of RBL-STEM to not only improve mathematical and scientific literacy but also address pressing challenges in bioinformatics and network security (Agustin et al., 2023; Salim et al., 2024; Marsidi et al., 2024).

In conclusion, this study complements existing research on RBL-STEM by introducing novel applications and extending the scope of these approaches. By focusing on DNA protection using irregular reflexive k-labeling, it bridges mathematical theories with biological applications, offering new insights into interdisciplinary education and providing a robust foundation for future studies. This work reinforces the growing consensus on the value of research-based learning and STEM integration in preparing students for the challenges of the modern era.

Despite its contributions, this study has certain limitations that should be acknowledged. First, the application of irregular reflexive k-labeling in the context of DNA protection, while innovative, is still theoretical and requires further empirical validation to assess its practical feasibility in real-world biological systems. Finally, the study does not explore alternative combinatorial methods that could complement or enhance the effectiveness of irregular reflexive k-labeling, leaving room for future research to investigate these possibilities. Addressing these limitations could further strengthen the applicability and impact of this research in STEM education and interdisciplinary problem-solving.

CONCLUSIONS

The study utilized various data collection instruments to evaluate the validity, practicability, and effectiveness of the RBL-STEM teaching materials. These instruments included validation sheets, observation checklists, post-test assessments, and student response questionnaires, each designed to provide a comprehensive understanding of the materials' performance. The validation sheets were employed to assess the content, construct, and pedagogical validity of the developed materials. The results revealed an average validation score of 3.71 (92.75%), meeting the validity criteria of $3.25 \leq Va < 4$. This indicates that the materials are valid. However, the inclusion of external experts from diverse educational backgrounds in the validation process could enhance the robustness and reliability of this evaluation. Observation checklists were used during the implementation phase to measure the practical application of the materials in the classroom. With an average score of 3.95 (98.75%), the materials demonstrated very high practicability. To strengthen the validity of these observations, incorporating video recordings or involving external observers could provide additional perspectives and mitigate potential biases.

Post-test assessments were conducted to evaluate student learning outcomes and comprehension. The findings showed that 90% of students scored above the minimum threshold for completeness, indicating that the materials effectively supported learning. For a more robust evaluation, a pre-test/post-test experimental design could be implemented to compare the progress of students more definitively. Student response questionnaires provided insights into student perceptions of the teaching materials. With a positive response rate of 90.31%, the materials were well-received by students. However, adding open-ended questions or conducting focus group discussions could provide richer qualitative data and a deeper understanding of student experiences and preferences.

While the instruments used in this study were effective in capturing key aspects, there are opportunities to enhance data collection further. The use of interviews with students and teachers, longitudinal tracking of student performance, and comparative studies with other teaching methods could provide deeper insights. Additionally, incorporating technology-based tools such as learning analytics or real-time response systems could improve data precision and offer a broader understanding of how students interact with the materials. These enhancements would address the current study's limitations and provide a more comprehensive framework for evaluating the effectiveness of RBL-STEM teaching materials.

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