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(Research Article)

The development of RBL-stem learning materials to improve students' combinatorial thinking skills in solving *b*-coloring problems for companion farming

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Abstract

Research Based Learning can be packaged with STEM approach. In a RBL, students will find a problem that requires a solution, problem solving skills are very important in learning. One of these mathematical thinking skills is combinatorial thinking skills. *b*-coloring is one of the concepts of graph theory. *b*-Coloring is widely applied in various fields, one of which we can apply to companion farming precision agriculture The development of RBL-STEM learning tools to improve students' combinatorial thinking skills in this research meet the criteria of valid, practical, and effective. The validity scores was 3.87. The observation results of learning implementation were 3.83 with a percentage of 95.75%, and student responses were 96.5% positive so that they met practical criteria. Based on the test results, researchers found that 97.5% of students were complete so that they met the effective criteria. Quantitative analysis involves processing pretest and posttest data, where normality test and paired sample t-test are conducted. Based on the normality test, it can be concluded that the pretest and posttest scores have a normal distribution, because the p-value is greater than 0.05, namely 0.053 and 0.059. Furthermore, a paired sample t-test was conducted which showed a p-value of 0.000. These results show that there is a significant increase in students' combinatorial thinking skills after participating in the learning.

Keywords: Research Based Learning; Science Technology Engineering Mathematics; Combinatorial Thinking Skills

1. Introduction

Mathematics is one of the most important disciplines in higher education. To understand these mathematical concepts, good mathematics learning is needed. One approach that has been widely developed to improve the quality of education is the Science, Technology, Engineering, and Mathematic (STEM) based learning approach. STEM (Science, Technology, Engineering and Mathematics) has become an increasingly important policy imperative globally [1]. The application of STEM in learning can encourage students to design, develop and utilize technology, hone cognitive, affective, and apply knowledge. Two important attributes of STEM education addressed in the literature appeared infrequently across all contexts and role groups: students' use of technology and the potential of STEM-focused education to provide access and opportunities for all students' successful participation in STEM [2]. STEM (Science, technology, engineering and mathematics) is currently an alternative learning that can build a generation capable of facing the challenging 21st century.

STEM-based learning can be packaged in several learning models, one of which is the research-based learning model according to Salimi [3] Research Based Learning (RBL) is one of the student-centered learning (SCL) methods that integrates research in the learning process. By learning to use the research-based learning model, students will have the opportunity to be able to develop and build knowledge from the steps of a study such as seeking information,

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formulating hypotheses, collecting data, analyzing, making conclusions and compiling reports. On the research before, RBL and STEM-based mathematics learning on the topic of Rainbow Vertex Antimagic Coloring are useful [4]. In a Research Based Learning (RBL) learning, of course, students will find a problem that requires a solution, problem solving skills are very important in learning.

One of these mathematical thinking skills is combinatorial thinking skills. Combinatorial thinking is the process of obtaining multiple solutions for discrete problem solving [5]. Combinatorial thinking skills are needed to find solutions to mathematical problems. Students use combinatorial thinking skills to look for various possible solutions to the problem systematically and try to ensure that the results that have been obtained are correct and can be accounted for. On the research provides empirical evidence of the effectiveness of a STEM-based RBL model, educators, and curriculum developers are encouraged to incorporate approach into their instructional strategies for enhancing combinatorial thinking skills [6]. Dafik [7] has formulated five indicators of combinatorial thinking skills, namely identifying several cases, recognizing patterns from all cases, generalizing all cases, proving mathematically, and considering other combinatorial problems. Therefore, to support students' combinatorial skills, it is necessary to have a learning tool that can support the success of the learning process.

Graph theory is a field of discrete mathematics that studies the structure of graphs and the mathematical properties of graphs. Graphs were discovered in the 18th century by a Swiss mathematician named Leonhard Euler. He used graph theory to solve the Konigsberg bridge problem. A graph is a discrete structure consisting of a set of objects called vertices and a set of edges that connect existing vertices. One of the concepts of graph theory is b-Coloring. b-Coloring of graph G is vertex coloring where each color class contains at least one vertex that neighbors all other color classes [8]. b-Coloring is widely applied in various fields, one of which we can apply to companion farming precision agriculture.

Some related research including RBL-STEM Learning Activities: Analysis of Transgenic Sugarcane Development Using Artificial Neural Networks in Improving Students' Combinatorial Thinking Skills [9], The Development of RBL-STEM Learning Materials to Improve Students’ Combinatorial Thinking Skills in Solving Local (a,d)-edge Antimagic Coloring Problems for Line Motif Batik Design [10], and The Implementation of RBL-STEM Learning Materials to Improve Students Historical Literacy in Designing the Indonesian Batik Motifs [11].

2. Material and methods

2.1. Research Based Learning

Research-based learning (RBL) was first developed at Griffith University in 2008 and is based on the philosophy of constructivism, which demands that students have an active role in learning. This means that the new concepts that students learn must be in accordance with students' pre-existing skills. This RBL adheres to student-centered learning which provides opportunities for students to learn by doing, so that learning is more meaningful [12]. The Research Based Learning (RBL) model is one of the new learning models that provides opportunities for students to learn and build knowledge from research steps such as having to seek information, formulate hypotheses, collect data, analyze, make conclusions and compile reports [13]. In general, RBL aims to create a learning process that leads to analysis, synthesis, and evaluation. In addition, it can improve the ability of students and teachers to apply knowledge [12].

2.2. Science, Technology, Engineering and Mathematics

STEM was introduced by the NSF (National Science Foundation) of the United States in 1990 which stands for Science, Technology, Engineering and Mathematics [14]. STEM is a learning approach that integrates science, technology, engineering and mathematics in solving problems in everyday life [15]. STEM-based learning methods apply knowledge and skills simultaneously to solve a case. This approach is stated as a 21st century learning approach in an effort to produce human resources with quality cognitive, psychomotor and affective.

2.3. Combinatorial Thinking Skills

Combinatorics is one part of mathematics related to calculations that can be implemented in real life. Combinatorial thinking is the process of obtaining multiple solutions for discrete problem solving [5]. Combinatorial thinking requires critical thinking procedures and convincing reasoning in the problem-solving process. Graumann [16] argues that students use combinatorial thinking to ensure that all possible solutions have been obtained to solve a geometry problem. The process of counting is a simple example of combinatorial thinking. Lockwood [17] has modeled combinatorial thinking skills which consists of three components: the counting process, the problem formulation, and the final result.

2.4. Methods

The stages that are used in this study refer to the development of the Thiagarajan 4-D Model which consists of the defining stage, the design stage, the development stage, and the dissemination stage. The data that was obtained from the observation of student activities during the learning process were statistically tested using parametric statistical tests. The statistical test in this study used SPSS. There are two variables in this study, namely the free variable and the bound variable. The free variables tested are research-based learning materials with STEM approach, while the bound variables are students' combinatorial skills. Furthermore, paired sample t test was carried out on pre-test and post-test results. The Thiagarajan 4-D model learning device development scheme can be seen in Figure 1.

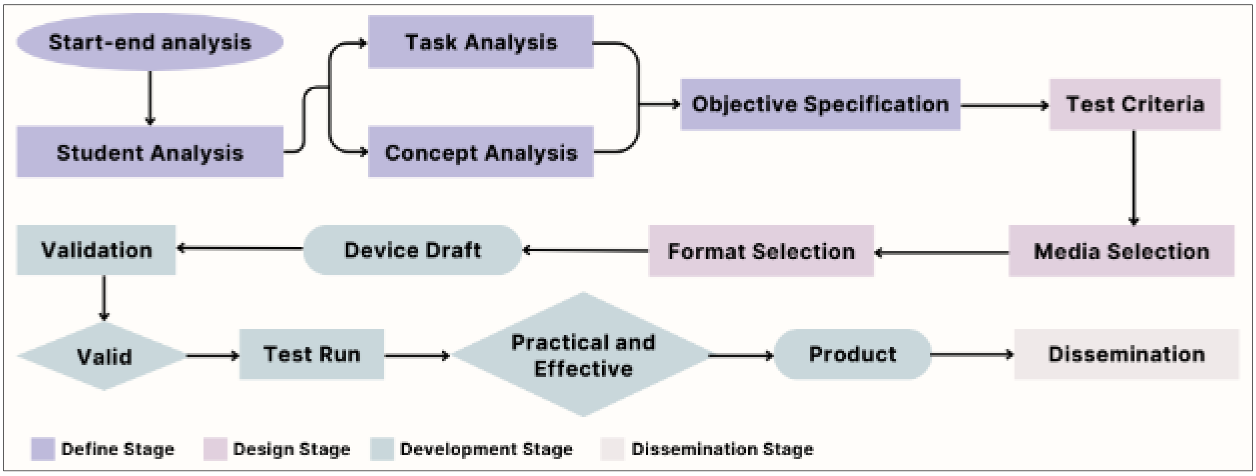
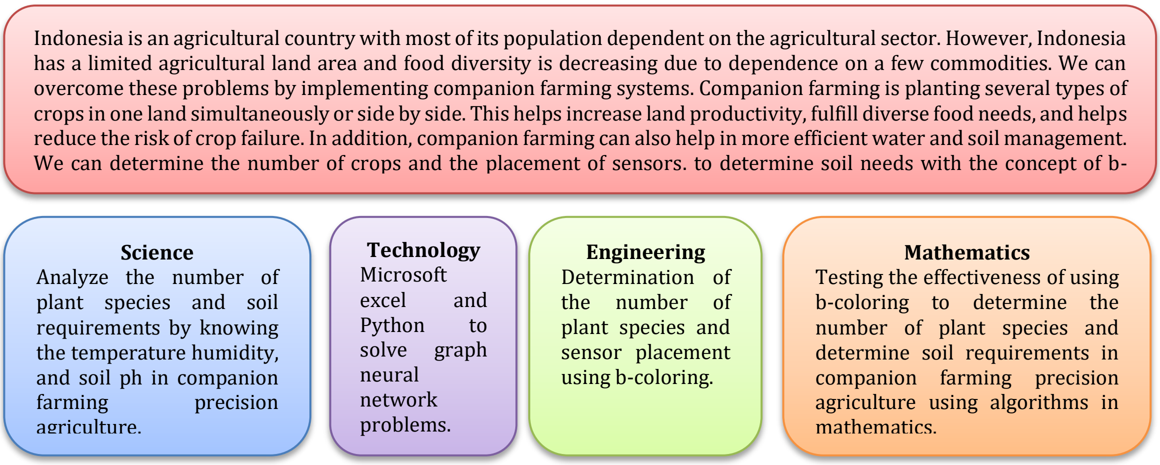


Figure 1 4-D model learning device development scheme

3. Results and discussion

To improve students' combinatorial understanding of the companion farming precision agriculture problem, the steps taken to integrate the RBL-STEM model are described below. In particular, the concept of *b*-coloring to determine the number of plant species in the companion farming system. This RBL model requires students to actively participate. Students must start by understanding the problem at hand and find the best way to solve it. Next, students will read the literature to get relevant information. In this case, the problem at hand is how to determine the number of plant species with the concept of *b*-coloring and knowing the soil requirements.


Indonesia is an agricultural country with most of its population dependent on the agricultural sector. However, Indonesia has a limited agricultural land area and food diversity is decreasing due to dependence on a few commodities. We can overcome these problems by implementing companion farming systems. Companion farming is planting several types of crops in one land simultaneously or side by side. This helps increase land productivity, fulfill diverse food needs, and helps reduce the risk of crop failure. In addition, companion farming can also help in more efficient water and soil management. We can determine the number of crops and the placement of sensors. to determine soil needs with the concept of b-

Science
Analyze the number of plant species and soil requirements by knowing the temperature humidity, and soil ph in companion farming precision agriculture.

Technology
Microsoft excel and Python to solve graph neural network problems.

Engineering
Determination of the number of plant species and sensor placement using b-coloring.

Mathematics
Testing the effectiveness of using b-coloring to determine the number of plant species and determine soil requirements in companion farming precision agriculture using algorithms in mathematics.

Figure 2 STEM aspect in research

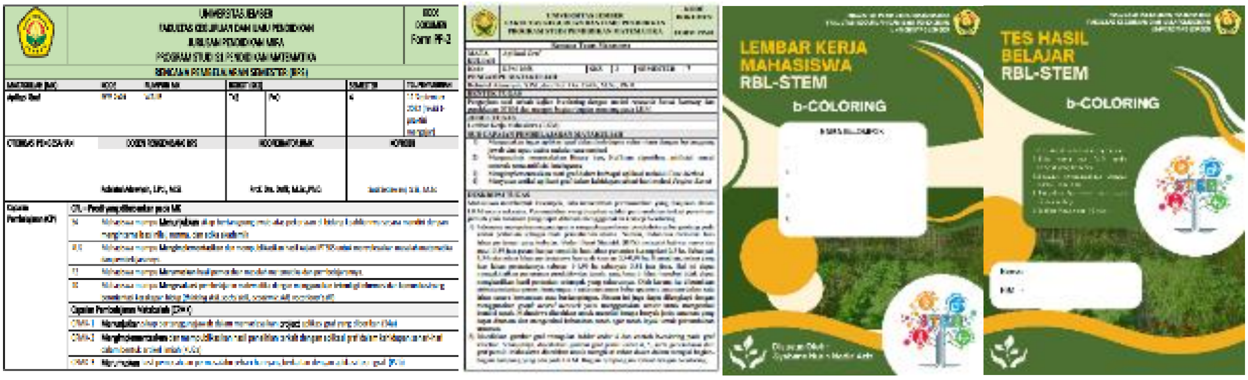
This research to solve the problem of companion farming precision agriculture by using the concept of *b*-coloring and graph neural network. The expected result is the determination of the number of types of plants that can be planted in companion farming and the placement of sensors including soil moisture, temperature, and soil pH to determine the needs of the soil. The RBL-STEM model in this study includes the stages of (a) Identifying the problem of determining the number of types of plants and laying sensors to determine soil needs; (b) Getting a breakthrough using a graph neural network with the concept of *b*-coloring; (c) Collecting data that will be used in solving the problem of determining the number of types of plants determined as much as possible using the concept of *b*-coloring and laying sensors to determine soil needs with graph neural networks; (d) Development of the number of types of plants and the placement of sensors in companion farming based on the concept of *b*-coloring; (e) Testing the number of types of plants that have been found; (f) Preparation of research reports and observation of students' combinatorial thinking skills.

Table 1 RBL-STEM activity framework

Phase	**Description**
Science	Providing problems about companion farming precision agriculture whose solutions are related to the concept of *b*-coloring and graph neural network
Engineering	Planning solutions to problems related to *b*-coloring
Technology	Gathering information related to the problem and things that will form the solution
Mathematics-Engineering	Generate theorems about *b*-coloring of some graphs and analyze the solution of the given problem
Mathematics	Proving that the theorem is reliable to solve the problem of companion farming precision agriculture
RBL Report	Presenting the results obtained regarding the solution of the problem and the *b*-coloring theorem obtained

The instruments included Student Assignment Designs, Student Worksheets, and Learning Outcome Tests that were used as pretests and posttests. As part of the Thiagarajan (4D) model, this development process consists of defining, designing, developing, and disseminating stages. The purpose of this defining stage is to establish and define learning needs by analyzing the objectives and limitations of the material to be provided. This stage consists of five stages, namely: (a) beginning-end analysis is conducted to determine the problems that occur in learning activities and the development of learning devices. It is expected that this device will help students who are hampered in classroom learning because they find it difficult to understand the concept of *b*-coloring (b) student analysis, data on the characteristics of Mathematics Education students at FKIP University of Jember were collected through student analysis. Students must have the ability to work together in groups and be directly involved in the learning process. (c) concept analysis, this process is carried out to identify, detail, and arrange the concept of *b*-coloring that will be learned by students (d) task analysis, researchers set tasks in the MFI in the form of overlapping parts and in the combinatorial thinking skills test in the form of questions about *b*-coloring in the real world (e) Specification of learning objectives, the purpose of this activity is to identify students' combinatorial skills according to the expected final ability.

At the design stage, RBL-STEM tools are being carried out to find out how learning tools affect students' combinatorial abilities in *b*-coloring material. The initial design of the learning device as in Figure 3. Student Worksheet is made with the concept of *b*-coloring using the RBL-STEM learning model. In accordance with the learning indicators to be achieved, this Student Worksheet focuses on solving *b*-coloring problems in companion farming precision agriculture that has been adapted to the RBL-STEM syntax. The Learning Outcome Test was used to measure students' combinatorial thinking skills. This test was used for both pretest and posttest which consisted of *b*-coloring and graph neural network materials. Pretest and posttest were conducted individually to determine the ability before and after student learning. Validation was conducted before the tests were tested.



LEMBAR KERJA MAHASISWA
RBL-STEM
b-COLORING

TES HASIL BELAJAR
RBL-STEM
b-COLORING

Figure 3 The initial design of the learning materials

Next is the development stage. Each device made at the development stage was validated by validators and changed according to recommendations. Two validators, both of whom are lecturers of the Mathematics Education study program at FKIP University of Jember, began the validation process, the validators were given learning devices, assessment instruments, and validation sheets. In addition to providing an assessment, the validators also provided comments and recommendations on the learning devices made. According to the evaluation of both validators, the device can be used with minor changes. All suggestions from validators are used to revise learning devices to ensure that the developed devices are feasible to use in learning. Based on the results of the validation of learning devices that can be seen in Table 2, the average score of all aspects is 3.87. The device is considered valid if it receives a score of $3.25 \leq V_a \leq 4$. Thus it can be concluded that the learning device made is valid.

Table 2 Learning materials validation recapitulation results

Assessed aspect	**Average Score**	**Average percentage**
Format	4.00	100%
Content	3.78	94.50%
Language and Writing	3.83	95.83%
Overall aspect average score	3.87	96.75%

The validated and modified device was tested on students. The trial was conducted in the Graf Application class of the Mathematics Education Study Program, FKIP, University of Jember. This trial was conducted on a class of 29 students. The researcher started the learning by giving a pretest with a duration of forty minutes. After that, the researcher gave a little incentive about the idea of b-coloring and its application to companion farming precision agriculture. The second meeting, students were divided into seven groups each with one observer. Each student discussed with their group. The observer helped guide the group if there were problems in working on the Student Worksheet. Each group was given the opportunity to make a presentation on what they had learned during the discussion. In the third meeting, the researcher gave a posttest to be answered, and a response questionnaire given until the end of the lecture time.

Data collected from the pilot test included student activity data, implementation observation data, student response questionnaire, and pretest and posttest results. The analysis of the learning enactment sheet shows whether the learning device is practical. The recapitulation results of the device practicality test are presented in the appendix, which shows that the learning implementation observation sheet received an average score of 3.83 with a percentage of 95.75%. By considering the criteria for device practicality, it can be concluded that the learning devices that have been made meet the criteria very well. Analysis of student completeness in the combinatorial thinking skills test, the results of observations of student activities during learning activities, and the results of student response questionnaires about learning are all indicators that can determine whether the learning device is effective or not.

Based on the response of students' answers in the combinatorial thinking skills test, we can conclude that there are 26 students who get scores above 70. In addition, considering the criteria for passing the learning test, it can be said that all students have achieved overall completeness. In this case, one of the three requirements to assess the effectiveness of a learning tool has been met. Analysis of student activity observation data was obtained from the results of observations made. The recapitulation of the student activity observation sheet showed that the sheet received an average score of 3.90 with a percentage of 97.5%. This shows that two of the three criteria needed to consider a learning tool effective have been met. Student response data was obtained from student response questionnaires distributed through printouts. The recapitulation of the student response questionnaire shows that the average positive percentage is about 96.5%, indicating that the learning tool has been considered effective because the three requirements have been met.

For the dissemination stage, this research will be delivered to Mathematics Education lecturers and on the internet, including social media. The aim is to find out whether the tools that have been developed work well for learning activities. In addition, it also wants to get input, corrections, suggestions, and assessments to improve this learning tool.

The following is a graph of the distribution of students' pretest and posttest scores and the percentage of students' combinatorial skill levels can be seen in Figure 4. In the pretest results, students who were categorized as students with combinatorial thinking skills at the moderate level were 10% and low level were 90%. Meanwhile, in the posttest results, students who were categorized as students with combinatorial skills at a high level reached 83%, students at a moderate level 14%, and students at a low level 3%.

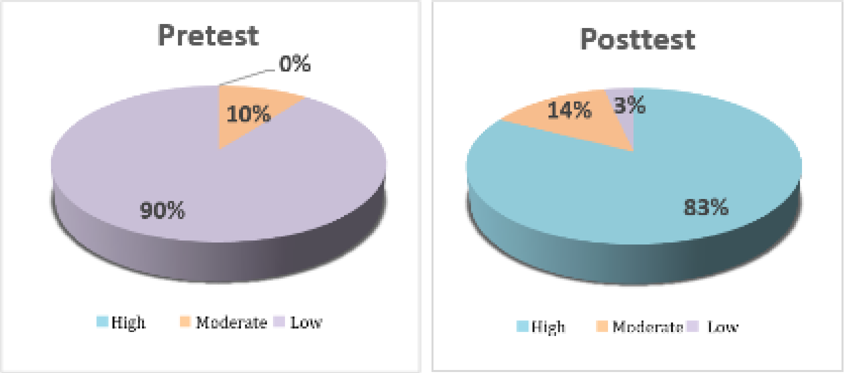
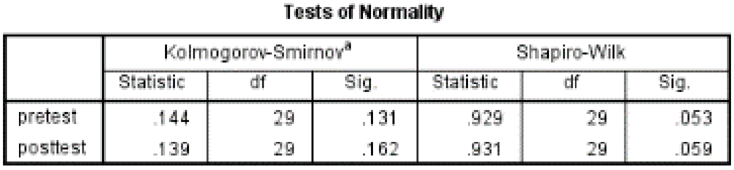


Figure 4 The percentage of students' combinatorial skill levels

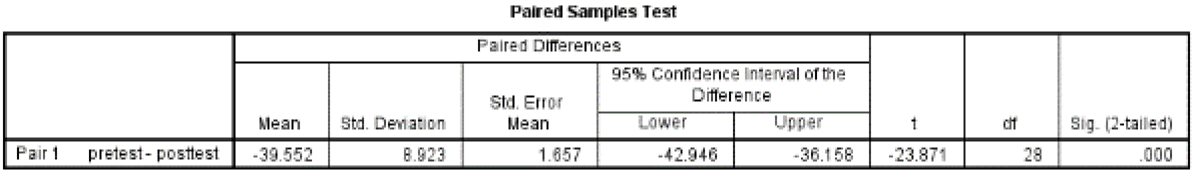
Furthermore, a normality test was carried out as a condition for the paired sample t test to be carried out. This statistical test was carried out using SPSS. The results of the data normality test are presented in Figure 5. Based on the results of the data normality test, it shows that the pretest and posttest values are normally distributed because the p-value on the pretest is 0.053> 0.05 and on the posttest is 0.059> 0.05. The last test is the paired sample t test which is presented in Figure 6.



Tests of Normality

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
pretest	.144	29	.131	.929	29	.053
posttest	.139	29	.162	.931	29	.059

Figure 5 Normality test results



Paired Samples Test

	Paired Differences					t	df	Sig. (2-tailed)
				95% Confidence Interval of the Difference				
	Mean	Std. Deviation	Std. Error Mean	Lower	Upper			
Pair 1 pretest - posttest	-39.552	8.923	1.657	-42.946	-36.158	-23.871	28	.000

Figure 6 Paired sample t test results

The results of the paired sample t test yielded a p-value of less than 0.05 which is 0.000 < 0.05, indicating that the improvement in combinatorial thinking skills between the two data groups is not random, but a statistically significant improvement. There is strong enough evidence to suggest that the observed improvement between the two groups of data is not caused by random variables but the improvement may have significant meaning. Thus, it can be concluded that there is an increase in students' combinatorial thinking skills.

4. Conclusion

Based on the research that has been carried out in the development of RBL-STEM learning tools to improve students' combinatorial thinking skills, it can be concluded that the tools meet the criteria of valid, practical, and effective. Quantitative analysis involves processing pretest and posttest data, where normality test and paired sample t-test are conducted. Based on the normality test, it can be concluded that the pretest and posttest scores have a normal distribution, because the p-value is greater than 0.05, namely 0.053 and 0.059. Furthermore, a paired sample t-test was conducted which showed a p-value of 0.000. These results show that there is a significant increase in students' combinatorial thinking skills after participating in the learning.

Compliance with ethical standards

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Disclosure of conflict of interest

I would like to disclose that I am the author responsible for this research, collaborating with other authors as a team. Although I will strive to remain objective throughout the article preparation process, I feel it is important to disclose my relationship with the other authors.

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