The analysis of students metaliteracy under the implementation of RBL-STEM in solving graph rainbow antimagic coloring problems

E Y Kurniawati, Dafik\textsuperscript{1,}\textsuperscript{*}, I H Agustin\textsuperscript{1,3} and I N Maylisa\textsuperscript{1}

\textsuperscript{1}CGANT Research Group, University of Jember, Indonesia
\textsuperscript{2}Department of Mathematics Education, University of Jember, Indonesia
\textsuperscript{3}Department of Mathematics, University of Jember, Indonesia

*Corresponding Author

Email: d.dafik@unej.ac.id

Abstract. Problem-solving can grow if students are trained to have metaliteracy. Metaliteracy is the ability to think that focuses on critical thinking skills and collaborative efforts. This study aims to determine the impact of the implementation of RBL-STEM to analyze the metaliteracy of students in solving rainbow antimagic coloring problems. The methods used in this study were a combination of quantitative and qualitative methods. This research used two classes, experimental and control. Both classes were given the same treatments with different experiment classes using LKM that have been developed with the RBL model. The analysis of the results of the homogeneity test on the pre-test items showed that the two classes were homogeneous with a significant value is ≥ 0.05, and the results of the independent sample t-test on post test result showed that the sig (2-tailed) value is 0.000 (\(p \leq 0.05\)) so its significant. It can be concluded that the RBL-STEM model can improve the metaliteracy level of the students in solving rainbow antimagic coloring.

1. Introduction

The thinking process is a conscious effort by each individual to solve a problem. The more often individuals do the thinking process, the better their ability to solve a problem. A thinking process is good has creative thinking that offers multi-variation to solve the problem. Problem-solving skills can grow if students are trained to have metaliteracy. Metaliteracy is the ability to think that focuses on critical thinking skills and collaborative efforts. With the knowledge of metaliteracy one can identify a problem and solve a problem collaboratively.

Based on Jacobson et al., metaliteracy is an overarching, self-referential and comprehensive framework that informs other literacy types. Information literacy is the metaliteracy for a digital age because it provides the higher order thinking required to relate with multiple document types through various media formats in collaborative environments [6]. Schematically, the metaliteracy indicators, according to Jacobson and Mackey, who have adopted the use of the Internet of Things, can be presented in Table 1. There are five leading indicators of metaliteracy, namely: produce, incorporate, use, share and collaborate. These five indicators can be explained as follows:
Table 1. Indicator dan sub-indicator of Metaliteracy.

| Indicator | Sub-Indicator |
|-----------|---------------|
| Produce   | (1a) Identifying the properties/characteristic of the problems, |
| (Level 1) | (1b) Obtain a breakthrough, |
|           | (1c) Develop or determine the stages, phases, syntax or algorithm |
| Incorporate| (2a) Identifying the pattern of the solution, |
| (Level 2) | (2b) Generalization, |
|           | (2c) Use the Internet of Things, such as software, platform, application, to integrate the results. |
| Use       | (3a) Testing/assessing the results, |
| (Level 3) | (3b) Analysing the results, |
|           | (3c) Interpreting the results, |
|           | (3d) Implementing the results |
| Share     | (4a) By using the Internet of Things (Social Media, OER, MOOCs, Teaching Platform), circulate the results, |
| (Level 4) | (4b) Have a reflection and evaluation toward a feedback, |
|           | (4c) Evaluate the number of participants responses, |
|           | (4d) Analyse the answer to read the trend by using some forecasting software. |
| Collaborate| (5a) Work with some other people by using IoT platforms, |
| (Level 5) | (5b) Enrich the product by requesting some suggestions from others, |
|           | (5c) Encourage people to do more to contributes the findings, |
|           | (5d) Obtain a joint work and development to publish, |
|           | (5e) Determine a joint future work for broader society |

To improve the metaliteracy, a good learning model is needed. One learning model that gives students freedom in building a knowledge based on research steps is a Research Based Learning (RBL) model. Dafik [8] explains that Research-Based Learning has advantages for learners, encompassing increased motivation to learn, improved ability to do meaningful work and enhanced problem-solving, especially when dealing with complex problems. What is more, RBL encourages students to be more active and thus skilled in solving complex problems, makes learning fun, and improves cooperation, interactivity, and mutual collaboration. The stages of the research-based learning model are formulate hypotheses, collect data to be used, analyze the data that has been obtained, make conclusions, then compile reports [1,7]. Research-based learning integrates theoretical knowledge with appropriateness in data collection and analytical procedures to examine, verify/study the phenomenon of a problem [9,10]. Research-based learning models have been studied by Wangguway et al. [13] to implement research-based learning to improve students' metacognition skills. Wardani [14] implemented research-based learning to enhance students' conjecturing skills.

Research-Based Learning (RBL) learning model with STEM approach are two breakthroughs that will be studied in this study. RBL is a learning method that uses contextual learning, authentic learning, problem-solving, cooperative learning, inquiry discovery approach, and hand-on & mindeducation. RBL can develop the active participation of students in building their knowledge. It is realized because the learning process provides sufficient space for the development of student activities. While STEM education is an approach in learning that involves four areas of the interdisciplinary one learning process at once Science, Technology, Engineering, and Mathematics [11,12].

Mathematical problems, especially in graph theory, have an important role in solving problems in daily life. The application of graph theory itself can be used in subject scheduling, fingerprint recognition, social network analysis, city street morphology analysis to modeling a problem to facilitate problem solving. In general, graph theory is always. The purpose of this study is to determine the effectiveness of Research-Based Learning to identify students' metaliteracy. In this study, students were asked to complete the rainbow antimagical coloring of the graph.
Let \( G = (V, E) \) be a simple graph. Graph \( G \) is called antimagic if \( G \) has a label of antimagic [3]. A bijective function \( f: E \rightarrow \{1, 2, \ldots, |E|\} \) is called as an antimagic label if for \( u \in V(G) \) and weight \( w(u) = \sum_{e \in E(u)} f(e) \) where \( E(u) \) is an edge set that is incident to \( u \) by \( w(u) \neq w(v) \) for two different vertices of \( u \) and \( v \). For a bijective function \( f: V(G) \rightarrow \{1, 2, \ldots, |V(G)|\} \), the weight result from edge \( uv \in E(G) \) of \( f \) is \( w_f(uv) = f(u) + f(v) \). A path \( P \) of graph \( G \) which its vertex is labeled called as rainbow path if for each two edges \( uv, u'v' \in E(P) \), there is \( w_f(uv) \neq w_f(u'v') \). If for every two edges of \( u \) and \( v \) from \( G \), there is a rainbow path \( u - v \), then \( f \) is called as rainbow antimagic labeling of graph \( G \). The research about rainbow antimagic coloring can be seen in [2,4,5].

![Figure 1](image1.png)

**Figure 1.** The example of (a) rainbow coloring of \( Tb_7 \) and (b) rainbow antimagic coloring of \( Tb_7 \).

### 2. Research Methods

We applied the type of this research using a combination of qualitative and quantitative methods.

#### 2.1. Research Procedure

This research procedure is illustrated in Figure 2.

![Figure 2](image2.png)

**Figure 2.** Research procedure of the mixed method model.
2.2. Population

This research was undertaken in Mathematics Education, University of Jember, with the undergraduate students as the subjects. The samplingselected two classes randomly. The sample of this study consisted of two classes, namely the control class of 16 students and the experiment class of 14 students.

2.3. Students Task

To identify metaliteracy of students, we developed the instrument with a rainbow antimagic coloring problem. The example is a triangular book graph. A triangular bookgraph is a simple graph. This graph is denoted by $T_{bn}$, and has a set of vertices and edges, respectively, $V(T_{bn}) = n + 2$ and $E(T_{bn}) = 2n + 1$. Figure 3 illustrates the task to solve the rainbow antimagic coloring problem of the triangular book graph.

![Figure 3. Task about rainbow antimagic coloring of graph.](image)

According to [5], the rainbow antimagic connection number of the triangular book graph is $rac(T_{bn}) = n + 21$. Figure 3 represents the rainbow antimagic coloring on a triangular book graph with $n = 3$. The vertex labeling function $f : V(T_{bn}) \rightarrow \{1, 2, ..., n + 2\}$ is defined as follows $f(a) = 1$, $f(b) = 2$, $f(v_i) = i + 2$ and from that function the edge weight function as follows $w(ab) = 3; w(av_i) = i + 3, w(bv_i) = i + 4$, for $1 \leq i \leq n$.

The task and interviews were validated by an expert of mathematics education and an expert of the graph.

This RBL-STEM learning will enable students to develop knowledge and skill in the following fields of Science, Technology, Engineering, and Mathematics.
**Table 2.** Applying STEM learning in the RBL model.

| Sciences | Technology | Engineering | Mathematics |
|----------|------------|-------------|-------------|
| Students are expected to: | Students are expected to: | Students are expected to: | Students are expected to: |
| - Understanding the problem of the rainbow antimagic coloring | - Use a web browser to identify the concept of rainbow antimagic coloring. | - Applying the rainbow antimagic coloring algorithm. | - Develop rainbow antimagic coloring function by using the functioning technique |
| - Analyze the situation and find the strategy to solve the problem. | - Use a researchgate site to find recent studies related to the rainbow antimagic color of the graph. | - Utilize the Geogebra Software for developing various types of graphs. | - Find the rainbow antimagic coloring chromatic number |

### 3. Research Finding

#### 3.1. The validity and reliability test

Before presenting the results of this research, we have tested the reliability and validity of the instrument that we have developed. Instruments that need to be tested for reliability and validity are pre-test and post-test assignments after testing, then analyzing the validity of the instrument using Pearson Correlation as shown in Table 3.

**Table 3.** The test result of the validity instrument correlations.

| Item1 | Item2 | Item3 | Item4 | Item5 | Total |
|-------|-------|-------|-------|-------|-------|
| Pearson Correlation | .213 | .479 | .145 | .139 | .535* |
| Sig. (2-tailed) | .464 | .083 | .621 | .636 | .049 |
| N | 14 | 14 | 14 | 14 | 14 |
| Pearson Correlation | .213 | 1 | .281 | .679** | .000 | .545* |
| Sig. (2-tailed) | .464 | .331 | .008 | 1.000 | .044 |
| N | 14 | 14 | 14 | 14 | 14 |
| Pearson Correlation | .479 | .281 | 1 | .636* | .549* | .900** |
| Sig. (2-tailed) | .083 | .331 | .014 | .042 | .000 |
| N | 14 | 14 | 14 | 14 | 14 |
| Pearson Correlation | .145 | .679** | .636* | 1 | .221 | .762** |
| Sig. (2-tailed) | .621 | .008 | .014 | .447 | .002 |
| N | 14 | 14 | 14 | 14 | 14 |
| Pearson Correlation | .139 | .000 | .549* | .221 | 1 | .645* |
| Sig. (2-tailed) | .636 | 1.000 | .042 | .447 | .013 |
| N | 14 | 14 | 14 | 14 | 14 |
| Pearson Correlation | .535* | .545* | .900** | .762** | .645* | 1 |
| Sig. (2-tailed) | .049 | .044 | .000 | .002 | .013 |
| N | 14 | 14 | 14 | 14 | 14 |

* Correlation is significant at the 0.05 level (2-tailed).  
** Correlation is significant at the 0.01 level (2-tailed).
Based on the instrument validity results, it is known that the values of $r_{count}$ are 0.535 (Item 1), 0.545 (Item 2), 0.900 (Item 3), 0.762 (Item 4), and 0.645 (Item 5). All items resulted for $N = 14$ and $r_{count} > r_{table}$. So it can be concluded that $r_{count}$ on item 1 until 5 > $r_{table}$ then all questions in that question are valid.

Table 4. The test result of the reliability question.

| Reliability Statistics | Cronbach's Alpha | N of Items |  |
|------------------------|-----------------|------------|---|
|                        | .715            | 5          |   |

Based on Table 4 above, the reliability value is 0.715 and $r_{table}$ from the 0.05 significant level with $dk = N - 2 = 12$, $r_{table} = 0.5324$. The conclusion is $r_{count} > r_{table}$ thus, the instrument can be said valid.

The next stage is to test the homogeneity of the control class and the experimental class using an independent t-test. Based on the results of the independent t-test presented in Table 5, the significance value is greater than 0.05, so it can be concluded that there is no difference in the mean of the pre-test data in the control class and the experimental class, that means the pre-test data obtained is homogeneous.

Table 5. The homogeneity results in control class and experiment class.

| Test of Homogeneity of Variances | Levene Statistic | df1 | df2 | Sig. |
|----------------------------------|-----------------|-----|-----|------|
| Score Pretest                    |                 |     |     |      |
| Based on Mean                    | .029            | 1   | 28  | .865 |
| Based on Median                  | .063            | 1   | 28  | .804 |
| Based on Median and with adjusted df | .063       | 1   | 27.820 | .804 |
| Based on trimmed mean            | .040            | 1   | 28  | .843 |

Table 6. The normality results in control class and experiment class.

| One-Sample Kolmogorov-Smirnov Test | Unstandardized Residual |
|------------------------------------|-------------------------|
| N                                  | 14                      |
| Normal Parameters$^{ab}$            |                         |
| Mean                               | .0000000                |
| Std. Deviation                     | 2.17277648              |
| Most Extreme Differences           |                         |
| Absolute                           | .138                    |
| Positive                           | .138                    |
| Negative                           | -.133                   |
| Test Statistic                     | .138                    |
| Asymp. Sig. (2-tailed)             | .200$^{cd}$             |

a. Test distribution is Normal.
b. Calculated from data.
c. Lilliefors Significance Correction.
d. This is a lower bound of the true significance.
Table 6 shows the results of the normality test in the control class and the experimental class. Based on Table 6, the results of the post-test normality test score were normally distributed with a significance value of 0.200, which is more than 0.05. Table 7 shows that the average value obtained from the control class is 71.6250 and the experimental class is 80.7857, so it is found that the average value of the control class is lower than that of the experimental class.

Table 7. The Mean Results of the Post-test in the Control Class and Experiment Class.

| Group Statistics | Control Class | Experiment Class |
|------------------|---------------|------------------|
| N                | 16            | 14               |
| Mean             | 71.6250       | 80.7857          |
| Std. Deviation   | 5.16236       | 3.82660          |
| Std. Error Mean  | 1.29059       | 1.02270          |

Table 8 shows the independent test results from the post-test. Based on Table 8, it shows that the value of the independent sample t-test is sig. (2-tailed) is 0.000. Because the value of sig. (2-tailed) 0.000 < 0.05 it can be concluded that the post-test results in the control class and the experimental class differ significantly after the implementation of research-based learning with the STEM approach. Based on the results of normality, homogeneity, and independent t-test obtained using SPSS software, it can be concluded that there is no significant difference in the control and experimental classes. This means that $H_1$ is accepted, so it can be concluded that the control and experimental classes have significant differences in post-test results after the application of the worksheets in research-based learning.

Table 8. The independent test results of the post-test in control class and experiment class.

| Independent Samples Test | Levene's Test for Equality of Variances | t-test for Equality of Means | 95% Confidence Interval of the Difference |
|--------------------------|----------------------------------------|-------------------------------|-------------------------------------------|
|                          | F           | Sig.         | t     | df     | Mean Difference | Std. Error Difference | Lower | Upper |
| Score Posttest           | 2.08        | .160         | -5.453 | 28     | -.916071        | 1.68005                  | -12.60215 | -5.71928 |
| Equal variances assumed  | 2           | 2            |       |       |                |                          |                   |

3.2. The distribution of students metaliteracy based on pre-test

The next step the researcher did was give treatment to the experimental class and the control class. In the experimental class, student worksheet RBL-based was given, while problem-based learning was carried out in the control class. The distribution of the number of students based on indicator metaliteracy in the control class can be seen in Figure 4, and the experiment class can be seen in Figure 5.
Figure 4. The distribution of students metaliteracy based on their pre-test of the control class.

Based on distribution in Figure 4 above, we can see that the students in the control class met 4 levels of metaliteracy, namely level 1 (very low), level 2 (low), level 3 (fair), and level 4 (good), but there were no students who classified as level 5 (very good). Based on Figure 4, it can be seen that the highest percentage of students' metaliteracy is at level 2 (low), which is 50%. This shows that in the control class, the average student's metaliteracy are low. Furthermore, in Figure 5 we can see that students in the experimental class also meet 4 levels of metaliteracy, namely level 1 (very low), level 2 (low), level 3 (fair), level 4 (good), and no students are classified as level 5 (very good). Based on Figure 5, it can be seen that the highest percentage of students' metaliteracy is at level 2 (low), which is 43%. This shows that in the control class, the average student's metaliteracy are low. We can conclude that in the results of the pre-test in the control class and experimental class, students meet the metaliteracy at level 2 (low).

Figure 5. The distribution of students metaliteracy Based on their pre-test of the experiment class.
3.3. The distribution of the level of students metaliteracy of the experiment class and control class after implementation RBL-STEM

After giving treatment RBL-STEM in the experiment class and control class, the researcher gave the students a post-test to identify the metaliteracy of the student. In the experiment class, the researcher gave treatment RBL-STEM model with LKM. However, in the control class without the LKM. Figure 6 shows the post-test results of the control class students, and Figure 7 shows the post-test results of the experimental class. Based on Figure 6, the percentage of post-test results from 16 students in control class have found four levels of metaliteracy, namely level 1 (very low) is 25%, level 2 (low) is 31%, level 3 (fair) is 38%, and level 4 (good) is 6%. Meanwhile, the percentage of the pre-test results from 14 students in the experimental class have found five levels of metaliteracy, namely level 1 (very low) is 14%, level 2 (low) is 29%, level 3 (fair) is 36%, level 4 (good) is 14%, and level 5 (very good) is 7%.

Figure 6. The distribution of students metaliteracy based on their post-test of the control class.

Figure 7. The distribution of students metaliteracy based on their post-test of the experiment class.
Based on the pre-test and post-test results carried out in the control class and experimental class, the metaliteracy level of experiment class and control class, is presented in Table 6.

**Table 9. The metaliteracy level of experiment class and control class.**

| Experiment Class | Control Class |
|------------------|--------------|
| **Pre-test**     |              |
| Level 1 = 4 students | Level 1 = 5 students |
| Level 2 = 6 students     | Level 2 = 8 students    |
| Level 3 = 3 students     | Level 3 = 2 students    |
| Level 4 = 1 students     | Level 4 = 1 students    |
| Level 5 = 0 students     | Level 5 = 0 students    |
| **Post-test**        |              |
| Level 1 = 2 students     | Level 1 = 4 students    |
| Level 2 = 4 students     | Level 2 = 5 students    |
| Level 3 = 5 students     | Level 3 = 6 students    |
| Level 4 = 2 students     | Level 4 = 1 students    |
| Level 5 = 1 students     | Level 5 = 0 students    |

This study uses the RBL-STEM implementation to improve students' metaliteracy, and it is proven that this model has an effect on students' learning processes. Before using RBL-STEM, students had difficulty finding ideas and class lectures. However, now that after RBL-STEM, students are actively looking for solutions to solve the problem of antimagic rainbow coloring. This study was conducted to analyze metaliteracy under the implementation RBL-STEM.

4. Discussion
After the implementation RBL-STEM model in the experiment class, we can analyze the metaliteracy of the student. In this section, we will identify the answers of students in solving the rainbow antimagic coloring problem. Next, we analyze the results of student work with metaliteracy level 1, level 2, level 3, level 4, and level 5.

4.1. Students worksheet result of S01 in solving rainbow antimagic coloring problem
The results of S1’s work are presented in Figure 8. The results of the work show that S01 can create a graph and provide notation at every point on graph $G$. It can also be seen that S01 is able to determine the cardinality of vertices and edges correctly. However, S01 does not provide a troubleshooting solution. S01 cannot solve rainbow antimagic coloring problems correctly. Therefore, S1 enters at level 1, which means very low and only meets the indicators at Level 1.

**Figure 8. The answer is S01 to solving the rainbow antimagic coloring problem.**
4.2. **Students worksheet result of S02 in solving rainbow antimagic coloring problem**

The results of S02's work are presented in Figure 9, it can be seen that S02 can create a graph and provide notation at every vertex on $G$. It can also be seen that S2 is able to vertex label with a bijective function correctly. From the results of S02's work, it can be seen that S02 can understand the definition of antimagic labeling and determine the edge weights correctly. However, S02 does not determine the cardinality of vertices and edges in graph $G$. Therefore, S02 is entered at level 2, which means it is low and qualifies the indicators at Level 2.

![Figure 9](image.png)

**Figure 9.** The answer is S02 to solving the rainbow antimagic coloring problem.

4.3. **Students worksheet result of S03 in solving rainbow antimagic coloring problem**

The results of S03's work are presented in Figure 10, in the results of the work it can be seen that S3 can create a graph and give a name the graph, namely a ladder graph with $n = 5$ denoted by $L_5$. S03 also provides notation at every vertex correctly and can arrange the cardinality of vertices and edges well. It is also seen that S03 is fluent and works in an appropriate way. S3 is able to label each vertex with a bijective function correctly. Then S3 determines the edge weights and assigns colors to the edges of the path according to the obtained edge weights. S03 is also able to determine the rainbow antimagic chromatic numbers of $L_5$ is $\text{rac}(L_5) = 5$. From the results of S03's work, it can be seen that S03 can understand the definition of the rainbow antimagic coloring study on the graph and can solve the problem well. However, S3 is only able to solve for graph $L_5$ but is not yet able to solve for graph $L_n$. Because S3 has not been able to generalize to a graph with vertices expanded by $n$, then S3 is entered at level 3, which means it is fair and qualified the indicators at Level 3.

![Figure 10](image.png)

**Figure 10.** The answer S3 to solving the rainbow antimagic coloring problem.
4.4. Students worksheet result of S04 in solving rainbow antimagic coloring problem

The results of S4's work are presented in Figure 11, in the results of the work it can be seen that S4 can create a graph and give the graph a name, namely the grid graph $G_{n}^{3}$. S4 also provides notation at each point correctly and can arrange the cardinality of vertices and edges well. It is also seen that the S4 is fluent and works in an appropriate way. The S4 is able to vertex labels with a bijective function correctly. Then S4 correctly determine the edge weights. S4 also assigns a color to the edge weights on the path according to the rainbow antimagic coloring rule. S4 is also able to determine the rainbow antimagic chromatic numbers of the graph $G_{n}^{3}$ is $\text{rac}(G_{n}^{3}) = n + 1$.

![Figure 11](image11.png)

Figure 11. The answer is S4 to solving the rainbow antimagic coloring problem.

From the results of S4's, it can be seen that S4 can understand the definition of the rainbow antimagic coloring study on a graph and can provide a good solution to the problem. Because S4 has not been able to generalize by compiling the vertex label function and the edge weight function, then S4 is entered at level 4, which means good and qualify the indicators at Level 4.

4.5. Students worksheet result of S05 in solving rainbow antimagic coloring problem

![Figure 12](image12.png)

Figure 12. The answer is S5 to solving the rainbow antimagic coloring problem.
The results of S5's work are presented in Figure 12. In the results of the work, it can be seen that S5 can create a graph and give the name graph, namely a triangular ladder graph ($T_{ln}$). S5 also provides notation at each vertex correctly and can arrange the cardinality of vertices and edges are well. It also looks like S5 is fluent and works in an appropriate manner. The S5 is able to vertex label with a bijective function correctly. Then S5 accurately determines the edge weights. S5 also assigns a color to the edge weights on the path according to the rainbow antimagic coloring rule. S5 is also able to determine the rainbow antimagic chromatic number of the graph $T_{ln}$ is $\text{rac}(T_{ln}) = n + 2$. From the results of S5's work, it can be seen that S5 can understand the definition of the study of rainbow antimagic coloring on a graph and can provide an excellent solution to the problem. Because S5 is able to generalize by compiling the point label function and the side weight function, then S5 enters level 5 which means very good and meets the indicators at Level 5.

5. Conclusion
Based on the research conducted, applying the Research-Based Learning (RBL) learning model with the STEM approach can improve students' metaliteracy. This can be seen from the increasing level of Metaliteracy after the implementation of RBL-STEM in the experimental class at the time of the Pre-test at Level 2 then the Post-test increased to Level 3. Likewise, in the control class, there was also an increase in level metaliteracy in students. In the experimental class, initially, none of the students met the Level 5 indicator. After the RBL-STEM learning model was implemented with the RBL-based Rainbow Antimagic Coloring LKM, one person met the Level 5 indicator. It can be concluded that the RBL-STEM learning model can improve metaliteracy of students. The further researcher can develop the study in the other topic or the other of mathematics problem.

Acknowledgment
We thankfully acknowledge the support from CGANT Research Group, University of Jember of the year 2022.

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