



## Students' Climate Change Literacy: Implementing RBL-STEM Makerspace Materials on Recycling Plastic Waste into Ecobricks

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### Abstract

Climate change is an increasingly significant concern due to rising sea levels and extreme weather events. This phenomenon has made specific regions uninhabitable or unsuitable for agriculture. In addition, promoting climate change literacy is one of the key factors in addressing the posed challenges. Therefore, this research aimed to analyze the implementation of Research-Based Learning with Science, Technology, Engineering, and Mathematics (RBL-STEM) materials to promote students' climate change literacy, using a mixed-methods design. This research employed a mixed-methods design. Quantitative methods were used to analyze climate change literacy, while qualitative methods examined learning activities and phase portraits under the implementation of the materials. The two classes used comprised a control class of 40 students and an experimental class of 42 students. Meanwhile, the instruments used were interviews, questionnaires, and students' climate change literacy tests. The results showed that there were differences between the control and experimental classes using an independent sample t-test with a sig value (2-tailed) of 0.0048 ( $<0.05$ ). In the context of this research, the implementation of the materials promoted students' climate change literacy in recycling plastic waste into ecobricks.

**Keywords:** Climate change literacy; RBL-STEM; Plastic waste; Ecobricks

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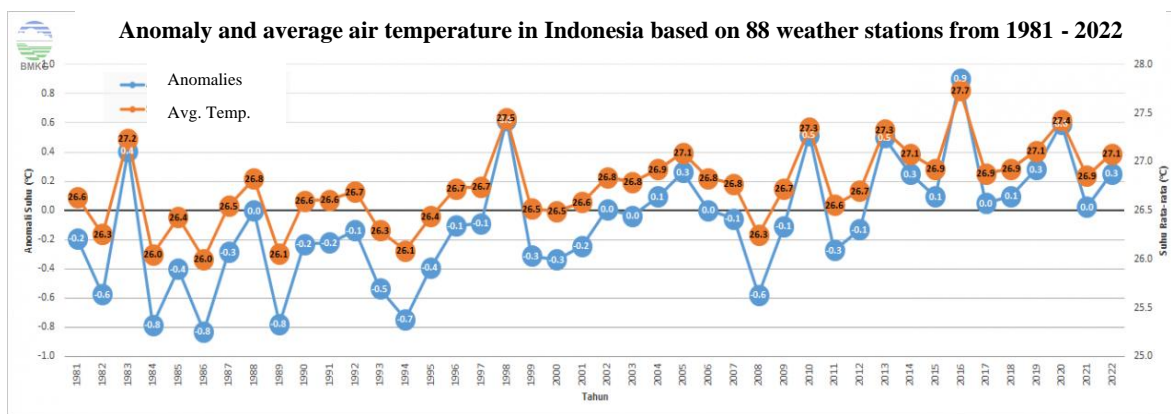
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## INTRODUCTION

Climate change has become one of the most urgent global challenges because its impacts are increasingly visible in the form of rising temperatures, extreme weather events, sea-level rise, and ecosystem disruption. These changes affect human life in many dimensions, including health, food security, water availability, and economic stability (IPCC, 2023). In Indonesia, climate-related changes have also become more apparent, as reflected in the long-term increase in average air temperature and climatic anomalies reported across recent decades. BMKG reported that 2024 was the warmest year in Indonesia during the 1981–2024 observation period, with a positive temperature anomaly of 0.8°C, indicating that climate change is no longer a distant issue but a real and contextual problem that requires public understanding and collective action (BMKG, 2025). Tackling climate change therefore requires not only awareness of the issue, but also a deeper understanding of its consequences and the capacity to develop innovative responses. Anomalies and average air temperature in Indonesia from 1981

to 2022 are shown in Figure 1. Therefore, education has an important role in preparing students to understand climate change and respond to it responsibly.



**Figure 1.** Anomalies and Average Air Temperature in Indonesia from 1981 to 2022

In this context, climate change literacy is an essential educational outcome. Climate literacy does not only refer to students' knowledge of the causes and impacts of climate change, but also to their ability to analyze problems, evaluate evidence, communicate ideas, and identify possible solutions. Recent studies emphasize that climate literacy should move beyond conceptual understanding toward action-oriented capacities that enable learners to make informed decisions and participate in adaptation and mitigation efforts (Leve et al., 2023; Hijazi et al., 2024). This means that climate-related learning should not be limited to conceptual explanation, but should also provide meaningful experiences that connect knowledge with authentic environmental problems. A recent scientometric review also shows that climate literacy research is expanding, but its pedagogical implementation remains uneven across educational contexts, especially when linked to interdisciplinary and practice-based learning designs (Ismail et al., 2024).

Climate change literacy includes a comprehensive understanding of the causes and impacts of climate change, as well as initiatives aimed at diminishing greenhouse gas emissions. Additionally, it focuses on the development of analytical ability, critical thinking, effective communication, and exploration of innovative solutions (Eilam, 2022). Students possessing a strong foundation in climate change literacy are better equipped to identify related issues, actively participate in discussions and policymaking, and contribute meaningfully to tangible actions addressing the challenge. Therefore, the integration of climate change literacy into the educational curriculum becomes important. The next sections report the indicators and sub-indicators of climate change literacy, as shown in Table 1. The simplest way to promote students' climate change literacy is through recycling plastic waste (Ricoy & Sánchez, 2022). This is considered an excellent initiative that can be implemented at the school and university levels. Some strategies to encourage students to recycle plastic waste effectively are: i) Promoting self-awareness: this is achieved by educating students on the environmental impact of plastic waste and the importance of recycling; ii) Implementing a recycling program.

RBL stands for research-based learning, and the model encourages students to become active participants in the learning process (Safiati et al., 2021). Furthermore, conducting research can deepen understanding of the topic. This process helps students obtain a deeper understanding, explore different perspectives, and develop strong analytical abilities. Through research-based learning, students learn to collect data, analyze information, and make decisions based on facts and evidence (Mazidah et al., 2021; Hidayatul et al., 2020), thereby developing critical and analytical abilities in the world of work. These individuals also learn to evaluate the reliability of information sources and develop critical thinking ability (Lazuardi et al., 2021; Hakim et al., 2021). RBL prepares for real-world challenges by introducing students to a structured problem-solving process. Different problems have been encountered in identifying

possible solutions and testing the hypotheses. This leads to the development of effective and flexible problem-solving abilities (Dai et al., 2023; Maylisa et al., 2020). In RBL, teamwork is important for collecting and analyzing data and for promoting effective collaboration and communication. Students learn to share information, provide feedback, and present findings in a clear, structured manner (Anwarudin et al., 2021; Hastuti et al., 2019). The process of scientific discovery can also be experienced through RBL (Wahyuni et al., 2020), which promotes deep exploration of the field. RBL also introduces the best practices in a particular discipline and contributes to existing knowledge (Sulistiyono et al., 2020). Learning is a powerful educational method that enables students to develop important abilities, such as deep understanding, critical and analytical thinking, problem-solving, collaboration, and communication (Wangguway et al., 2020; Dafik et al., 2019).

**Table 1.** Indicators and Sub-Indicators of Climate Change Literacy

No	Indicators	Sub-Indicators
1	Basic understanding of climate change	Ability to explain how climate change occurs due to increased greenhouse gas emissions
2	Realizing the impact of climate change	Awareness of the increasing frequency of droughts and floods due to climate change
3	Ability to conduct research related to climate change	Ability to conduct research related to sustainable climate change solutions from simple to complex
4	Understanding the causes of climate change	Understanding some of the human activities that cause climate change to occur, such as deforestation, waste accumulation, land, water, air pollution, fossil fuels, etc
5	Understanding solutions to overcome climate change	The ability to address climate change, such as renewable energy, and sustainable agriculture. Biotechnology, waste management, clean environment, sanitation, flood prevention, etc
6	Ability to communicate related to climate change	Ability to explain the impact of climate change to others, related parties, and the agricultural community and then discuss to develop ways or policies to reduce the impact of climate

STEM (Science, Technology, Engineering, and Mathematics) education can be implemented at various levels of schooling, from elementary to higher education. This is often supported by hands-on experiments, projects, and activities that engage students, making learning more practical and applicable to real-life situations. The real-world problem this research addresses is the recycling of plastic waste into ecobricks. Furthermore, ecobricks, or bottle bricks, are a sustainable and creative solution for managing plastic waste. The solution includes stuffing used plastic bottles with non-recyclable materials and compacting them tightly to create a dense, sturdy brick-like structure. The tightly packed plastic bottles serve as building blocks used in construction projects. The concept behind ecobricks is to repurpose plastic waste that would end up in landfills or pollute the environment, providing an eco-friendly alternative to traditional building materials such as bricks and cement. By filling bottles with non-biodegradable waste, ecobricks keep the plastic out of the natural ecosystem, mitigating environmental pollution. These solutions are gaining popularity as an innovative way to address the plastic waste problem. Communities and individuals around the world are actively collecting and compacting waste to create eco-friendly building blocks. These compacted plastic bottles have various applications in construction, including building walls, benches, garden structures, and entire buildings. Ecobricks structures can be durable and strong when properly constructed.

This study introduces a novel integration of Research-Based Learning (RBL) and STEM pedagogies within a makerspace setting to promote students' climate change literacy through the practical activity of recycling plastic waste into ecobricks. Unlike previous research that

primarily addresses theoretical knowledge or isolated STEM interventions, this approach combines hands-on, inquiry-based, and collaborative learning, enabling students to actively engage in problem-solving and innovation while addressing a real-world environmental issue. The study not only investigates the development and implementation of the RBL-STEM makerspace materials but also examines its impact on students' cognitive, analytical, and practical competencies related to climate change mitigation, providing empirical evidence on the effectiveness of an applied, multidisciplinary educational approach in fostering sustainability literacy. RBL-STEM makerspace materials are integrated into learning activities focused on recycling plastic waste into ecobricks. Implementing the materials in education can inspire students to engage in hands-on activities, inquiry-based learning, and collaborative projects in a makerspace. Therefore, this research problem was (a) How to develop the learning design and materials on RBL-STEM makerspace materials on recycling plastic waste into ecobricks? (b) Does implementing the materials on recycling plastic waste into ecobricks promote students' climate change literacy? (c) What is the phase portrait of students' climate change literacy?

## METHOD

### Research Approach

This research used a mixed-methods design, combining qualitative and quantitative methods. According to Creswell (2014), this method is important in understanding problems. In the qualitative design, R&D methods are used. The ADDIE framework is used for developing learning materials, with five stages: analysis, design, development, implementation, and evaluation. The process of evaluating the learning materials includes testing for validity, specifically, content, construct, and language validity, as well as practicality and effectiveness. These assessments use observation rubrics through a Likert scale ranging from 1 to 5. The results of the qualitative analysis aimed to answer the first research problem.

After the development of the learning materials, the quantitative design is conducted in the form of a quasi-experiment, NVIVO, phase portrait, and SmartPLS analysis. The quasi-experiment analysis uses a pretest-posttest nonequivalent groups design with experimental and control classes, each receiving different treatments. The experimental class receives specialized attention, incorporating RBL-STEM makerspace materials. Meanwhile, the control class receives a conventional instruction. The quasi-experimental research design comprising two groups is shown in Table 2. The results of the quantitative analysis aimed to answer the first and second research problems.

**Table 2.** Research Design of Quasi-Experiment

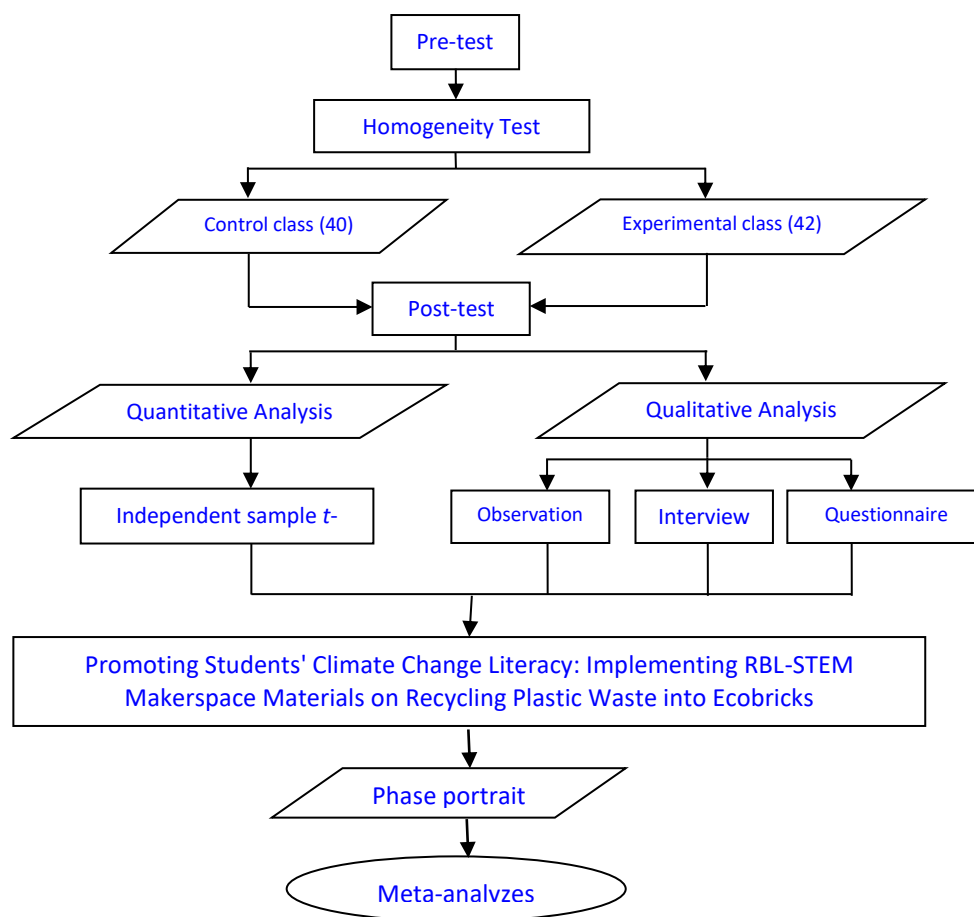
Class	Pre-Test	Treatment	Post-Test
Experiment class of 42 students	$O_1$	X	$O_2$
Control class of 40 students	$O_3$		$O_4$

Description:

$O_1, O_3$  : Pre-test given to class groups to determine the initial condition of students' climate change literacy of the two classes

X : Implementation of RBL-STEM makerspace materials on recycling plastic waste into ecobricks

$O_2, O_4$  : Post-test given to class groups to determine the final condition of students' climate change literacy of the two classes after RBL-STEM makerspace materials implementation in the experiment class and a conventional instruction in the control class.



**Figure 2.** Flowchart of Experimental Design

### Research Subject

The subjects were 82 students in the even semester of the academic year 2023/2024, from the Faculty of Teacher Training and Education (FKIP), Jember University, Indonesia. This subject includes 42 students in the experimental class and 40 in the control class. Each semester, the study program offers a Combinatorics Course divided into two classes. The average age of students was 22 years. The Mathematics Modeling course used Indonesian as the language of instruction, with two lectures. Meanwhile, students shared similar cultural backgrounds and prior knowledge of the course. Selecting three interviewed students representing high, medium, and low literacy. The literacy level is based on post-test results: scores below 65 are categorized as low, 65-80 as medium, and above 80 as high. The selection of the sample was permitted by the Research Ethics Committee - FKIP, Jember University, Indonesia. Furthermore, some students were asked to join the makerspace to recycle plastic waste into ecobricks at UPTD Satdik SDN Tegal Besar 04, Jember, Indonesia.

### Research Instruments

The instruments employed in this study comprised three main components: a learning outcome test, a student response questionnaire, and a semi-structured interview protocol. The learning outcome test consisted of 30 items designed to measure students' climate change literacy, with scores ranging from 0 to 100. These items were systematically mapped onto six literacy indicators: (a) basic understanding of climate change (5 items), (b) awareness of climate change impacts (5 items), (c) ability to conduct climate-related research (5 items), (d) understanding of climate change causes (5 items), (e) understanding of mitigation and adaptation solutions (5 items), and (f) communication skills related to climate change (5 items). The test was administered as both a pre-test and a post-test to the control and experimental classes to assess learning gains.

The second instrument was a student response questionnaire designed to evaluate students' perceptions of the learning activities. The questionnaire initially included dichotomous (yes/no) items; however, for more robust statistical analysis using Structural Equation Modeling–Partial Least Squares (SEM-PLS), the instrument was further developed into six dimensions aligned with the climate change literacy indicators, each measured using multiple statements on a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). Each dimension consisted of 4–6 items, resulting in a total of 30 questionnaire items. Prior to distribution via Google Forms, the instrument underwent content validation by experts and pilot testing to ensure construct validity and reliability. Indicator loadings, composite reliability, and average variance extracted (AVE) were assessed using SmartPLS.

The third instrument was a semi-structured interview designed to provide an in-depth understanding of students' climate change literacy. Interview participants were selected using purposive sampling, representing high, medium, and low achievement levels based on post-test scores, with a total of 6–9 students involved. The interview protocol was designed to align directly with the six literacy indicators, ensuring consistency between quantitative and qualitative data. Data from the interviews were analyzed thematically using NVivo to identify patterns and support the interpretation of quantitative findings.

### **Data Analysis**

To assess the impact of RBL-STEM learning materials on students' climate change literacy, a pre-test and post-test comprising 20 question items each are administered. Validation and reliability tests, using inferential statistics such as Pearson Correlation, are conducted on these tests. The validity criteria for each item are as follows: if the significance level (2-tailed) is less than 0.05, the item is considered valid; this criterion is applied to all items. Subsequently, the instruments' reliability is evaluated using Cronbach's alpha. For reliability, Cronbach's alpha scores exceeding 0.6 indicate reliability. The pre-test and post-test instruments are derived from the main and sub-indicators of computational thinking ability.

Additionally, after establishing a valid and reliable test set, student assessment is conducted using pre- and post-tests following the implementation of RBL-STEM markerspace materials. The post-test data are analyzed using inferential statistics in SPSS and RStudio, specifically the independent-samples t-test. The primary objective of the t-test is to evaluate the potential impact of the materials on students' climate change literacy. A distinction in climate change literacy between the control and experimental classes is indicated when the independent-samples t-test yields a Sig (2-tailed) value less than 0.05. Conversely, when the Sig (2-tailed) value exceeds 0.05, no substantial difference is observed.

Before the paired-samples t-test, assessments of normality and homogeneity of the data are conducted, and the normality test is used to determine the degree of normality. The Kolmogorov-Smirnov test is used to assess normality, with a significance level of 0.05 or higher. Subsequently, the homogeneity test is used to determine whether the data from the two classes are homogeneous. The homogeneity test criteria state that when the significance value is greater than or less than 0.05, the data variances of the two groups are the same (homogeneous) or different (inhomogeneous), respectively. In-depth interviews were also conducted to explore the results from the data analysis (Gita et al., 2021). Students were selected for interviews based on post-test scores in climate change literacy. Selecting subjects with low, medium, and high levels of climate change literacy was the first step in the portrait phase. Questionnaires were used to interview the selected subjects, and the respondents' answers were recorded before being compared with the interview cards. By adding special coding to the cards, sub-indicators of climate change literacy were incorporated into their development. The interviewer connects the sub-indicators, represented by nodes and edges, after determining a logical answer, to show a phase portrait of the students' climate change literacy. Meanwhile, this research also investigated how students experienced exercise using

NVIVO software. SmartPLS was used to analyze the questionnaire to determine the relationship between RBL STEM variables and students' climate change literacy.

## RESULTS AND DISCUSSION

### Research and Development (R&D) Process

In this stage, a qualitative design, specifically R&D, was conducted. The ADDIE design framework was used to create learning materials, including five stages: analysis, design, development, implementation, and evaluation. The process of developing the learning materials comprised testing for validity, including content, construct, and language validity, as well as practicality and effectiveness. During the initial stage, performance and needs analyses were focused on enhancing students' climate change literacy. The results of the performance analysis were derived from the contextual problem in the STEM makerspace, which focused on recycling plastic waste into ecobricks. As part of implementing RBL-STEM makerspace materials, students were tasked with exploring the practical applications of ecobricks in daily life to mitigate plastic waste. In the context of exploring the use of ecobricks to reduce plastic waste, a variety of activities and projects were carried out in the makerspace framework.

In the second stage, specifically the design stage, the learning materials were developed. This included creating a lesson plan, student worksheets, assessment instruments, learning media, and a module guide for the makerspace. The module incorporates information and activities to facilitate hands-on, project-based learning in a makerspace environment, focusing on transforming plastic waste into ecobricks. The development stage comprises four essential steps, namely content, constructs, makerspace, and language validity. Content validity is used to evaluate STEM makerspace problems associated with the subject course studied in the class. Construct validity is used to evaluate RBL-STEM learning materials in terms of students' learning styles. Meanwhile, makerspace validity is applied to assess the materials concerning the process of recycling plastic waste into ecobricks. Language validity is used to evaluate the materials for compliance with the language comprehensible to the intended audience. Content, construct, makerspace, and language validity are assessed using assessment rubrics on a Likert scale of 1 to 5. The average results of the semester lesson plan, student worksheet, assessment instruments, learning media, and Makerspace guide module are shown in Table 3.

**Table 3.** The Validity Recapitulation Result on RBL-STEM Makerspace Materials

Aspect	Content	Construct	Makerspace	Language	Average
Makerspace guide module	88.5%	93.75%	89.4%	93.75%	95.6%
Lesson Plan	88.5%	93.7%	93.8%	93.65%	92.3%
Students' Worksheet	89.5%	92.6%	98.7%	94.75%	93.7%
Assessment Instruments	86.5%	89.5%	99.2%	94.75%	95.2%
Learning Media	86.5%	93.75%	93.7%	93.75%	93.8%

The fourth stage of the ADDIE model, specifically the implementation stage, is currently limited. This stage includes practicality and effectiveness testing. To conduct the test, RBL-STEM makerspace materials have been introduced in the classroom. A total of four observers have been engaged to evaluate the lecturer and students' learning activities, with a focus on enhancing climate change literacy through the recycling of plastic waste into ecobricks. In this research, practicality is defined as the quality or state of being sensible and realistic. The variable involves dealing with matters sensibly and focusing on practical considerations rather than abstract or theoretical ones. Emphasis is placed on achievability, functionality, and effectiveness in real-world situations. The materials are practical, considering the constraints and conditions of the situation. Practicality often involves considering feasibility, efficiency, and the ability to deliver tangible results. The average score on the practicality test is 3.73, and the achievement percentage is 94.6%, indicating that the learning materials meet the criteria.

The focus shifts to the fifth stage of the ADDIE model, specifically the effectiveness test. Using Pearson's correlation coefficient in inferential statistics, the pre-test validity results indicate that the significance scores (2-tailed) for the question items, ranging from 1 to 20, are below 0.05. This leads to the conclusion that the question instruments for all queries are valid. Alpha Cronbach's score for the pre-test reliability test is 0.863, exceeding the 0.60 threshold. Proceeding to the next phase of the effectiveness test, RBL-STEM makerspace materials were implemented, and a post-test was conducted after the learning cycle. The post-test question items mirror those of the pre-test, obviating the need for additional validity and reliability tests. However, before considering the paired-samples t-test, a normality test is important. The results showed that the significance value (p) in the Kolmogorov-Smirnov test is 0.201 ( $p > 0.05$ ). Based on the Kolmogorov-Smirnov normality test, the data are deemed normally distributed. Additionally, the significance value (p) in the Shapiro-Wilk test is 0.314 ( $p > 0.05$ ), which shows that the data is considered normally distributed.

The statistical analysis is presented using a paired-samples t-test to examine whether there is a significant difference between pre-test and post-test scores in the implementation of RBL-STEM makerspace materials on a limited set of tests in a single class. The results show that the Sig. (2-tailed) value is 0.002 at a 5% confidence level, less than 0.05. Additionally, the correlation between pre-test and post-test scores is 0.813, indicating a difference in scores after implementing the materials. The comparison of means between pre-test and post-test shows average scores of 60.132 and 85.325, respectively. This observation suggests that the post-test scores exceed the pre-test scores. Consequently, implementing the materials effectively enhances students' climate change literacy in the context of recycling plastic waste into ecobricks. The materials are suitable for integration into the RBL-STEM learning activities. The fifth stage concludes with the evaluation phase, and the quasi-experiment is extended to the control and experiment classes.

## The implementation of RBL-STEM Makerspace Materials

### Pre-test Data Analysis

This research included two classes, comprising 42 and 40 students in the experimental and control classes. Pretest questions were administered to assess students' initial understanding of climate change. After analyzing the results in the control class, 11% and 89% of students can be categorized as having medium and low levels of climate change literacy, respectively. Similarly, in the experimental class, the data analysis indicates that 9% and 92% possess moderate and low levels of climate change literacy, respectively. An online two-sample t-test was conducted in R-Shiny, with normality and homogeneity tests. The initial statistical assessment was a normality test to assess the degree of normality, as shown in Table 4.

**Table 4.** Normality Test Result

Statistic	p.value	Method	data.name
0.96	0.083	Shapiro-Wilk normality test	datasetInput()[, input\$var.y]
0.96	0.083	Shapiro-Wilk normality test	datasetInput()[, input\$var.y]

Based on Table 4, both classes are normally distributed because the p-value (0.083) is  $> 0.05$ . Furthermore, the statistical test used is the homogeneity test to determine whether the data distributions across the classes are homogeneous.

**Table 5.** Results of Homogeneity Test on Pre-Test

Test type	Data	F	df	Denom df	P-value	95% Confidence interval	Ratio of variances	of
F test	Score by Class	1.148	40	41	0.853	2.410	0.759	

From Table 5, both classes have the same variance, as the p-value (0.853) is  $> 0.05$ . Therefore, the classes are homogeneous, and after the tests, a two-sample independent t-test is conducted to determine the difference in the mean scores.

**Table 6.** Two-Sample T-Test Results on Pre-Test

Test type	Data	t	df	P-value	95% Confidence interval	Mean score in group A	Mean score in group B
T-test	datasetInput()[, input\$var.yt2b] by datasetInput()[, input\$var.g1]	-0.475	82	0.724	4.293	45.147	47.253

The significance p-value is  $0.724 > 0.05$  based on Table 6. Therefore, there is no difference in the mean test score on climate change literacy between students in the experimental and control classes.

### Post-test Data Analysis

Based on post-test data from the control class, 30.4%, 48.78%, and 20.82% of students are classified as having low, moderate, and high levels of climate change literacy, respectively. In the experimental class, 69.51% of students were classified as having moderate levels of climate change literacy, and 30.49% as having high levels. Furthermore, the independent-samples t-test was conducted online using the R-Shiny software. Before conducting the t-test for two independent samples, preliminary normality and homogeneity tests should be performed. The first statistical test is the normality test, which assesses whether the data from both classes are normally distributed.

**Table 7.** Normality Test of Post-test Results

Statistic	p.value	Method	data.name
0.96	0.08	Shapiro-Wilk normality test	datasetInput()[, input\$var.y]
0.96	0.08	Shapiro-Wilk normality test	datasetInput()[, input\$var.y]

Based on Table 7, both groups follow a normal distribution, as the p-value of 0.08 is greater than 0.05. Additionally, the homogeneity test was performed to examine whether the data variants of the two groups were homogeneous.

**Table 8.** The Results of the Homogeneity Test on the Post-test

Test type	Data	F	df	Denom df	P-value	95% Confidence interval	Ratio of variances
F test	Score by Class	0.699	82	85	0.465	1.502	0.699

Based on Table 8, both classes have equal variance, as the p-value (0.465) is  $> 0.05$ . Subsequently, normality and homogeneity tests were conducted, and two independent-samples t-tests were performed to determine the level of disparity in the mean scores on climate change literacy tests.

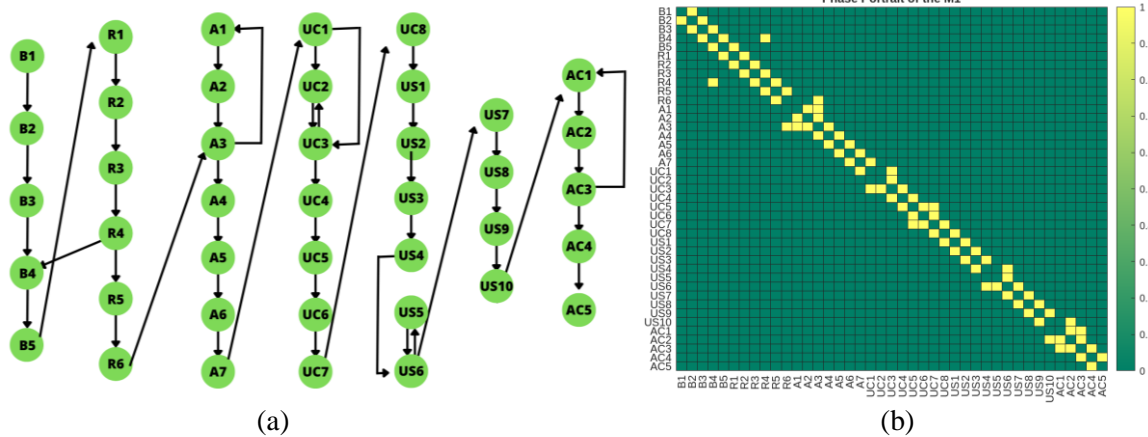
**Table 9.** Two-Sample T-Test Results on Post-Test

Test type	Data	t	df	P-value	95% Confidence interval	Mean score in group A	Mean score in group B
T-test	datasetInput()[, input\$var.yt2b] by datasetInput()[, input\$var.g1]	-3.75	80	0.005	-1.737	66.274	71.686

Based on Table 9, the p-value is 0.005, which is less than 0.05. This indicates a disparity in the mean score on the climate change literacy assessment test between students in the control and experiment classes after implementing RBL-STEM markerspace materials in the experiment class.

**The Phase Portrait of Students' Climate Change Literacy**

A phase portrait depicts the flow of individuals' thinking in diagram form. Students were interviewed, and the transcript was recorded during the implementation of the materials. The three subjects selected were high, medium, and low student climate change literacy, denoted by M1, M2, and M3, respectively. The phase portrait was represented in a graph, including two elements: a vertex and an edge. Figure 3(a) shows the thinking process of climate change literacy in a graph, and Figure 3(b) represents the matrix adjacency of the phase portrait.



**Figure 3.** (a) Graph Representation of M1, (b) Adjacency Matrix of Distance One of M1

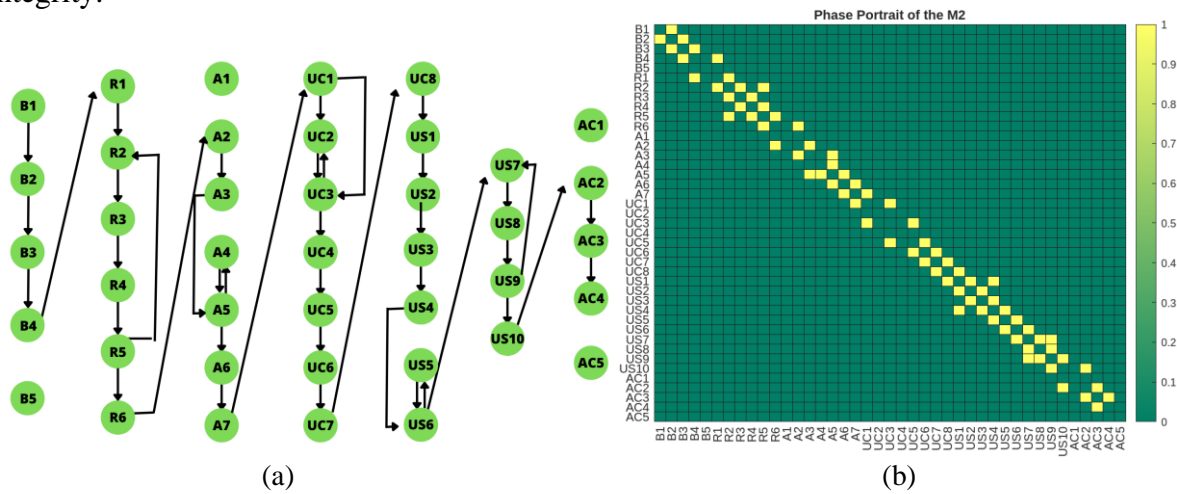
Based on the above graph, Total Depth (TD), Mean Depth (MD), Relative Asymmetry (RA), and Real Relative Asymmetry (RRA) of subject M1 regarding climate change literacy were analyzed to assess climate change literacy and obtain the integrity value for each vertex. TD represents the total number of path lengths of the observed sub-indicators. Table 10 presents the distribution results of the integrity analysis. Table 10 shows that the sub-indicator UC3 has the lowest RRA value of 1.315. A small RRA value indicates that UC3 has the highest integrity among the other vertices.

**Table 10.** The Distribution Score of Real Relative Asymmetry (RRA) of Subject M1

No	Subindicator	RRA	No	Subindicator	RRA	No	Subindicator	RRA
1.	B1	3.024	15.	A4	1.839	29.	US3	2.033
2.	B2	2.803	16.	A5	1.785	30.	US4	2.131
3.	B3	2.595	17.	A6	1.741	31.	US5	2.462
4.	B4	2.396	18.	A7	1.708	32.	US6	2.242
5.	B5	2.589	19.	UC1	1.686	33.	US7	2.375
6.	R1	5.652	20.	UC2	1.95	34.	US8	2.518
7.	R2	2.705	21.	UC3	1.315	35.	US9	2.672
8.	R3	2.429	22.	UC4	1.686	36.	US10	2.837
9.	R4	2.237	23.	UC5	1.708	37.	AC1	3.421
10.	R5	2.115	24.	UC6	1.834	38.	AC2	3.013

No	Subindicator	RRA	No	Subindicator	RRA	No	Subindicator	RRA
11.	R6	2.005	25.	UC7	1.746	39.	AC3	3.201
12.	A1	2.121	26.	UC8	1.81	40.	AC4	3.409
13.	A2	2.121	27.	US1	1.867	41.	AC5	3.630
14.	A3	1.906	28.	US2	1.945			

Figure 4 (a) shows the thinking process of M2 climate change literacy, and Figure 4 (b) shows the matrix adjacency of the portrait phase. Table 11 shows the distribution results of the integrity analysis. The sub-indicators A7 and UC1 have the RRA value of 1.325. The RRA value for this sub-indicator is considered the best, as lower RRA values indicate higher integrity.



**Figure 4.** (a) Graph Representation of M2, (b) Adjacency Matrix of Distance One of M2

**Table 11.** The Distribution Score of Real Relative Asymmetry (RRA) of Subject M2

No	Subindicator	RRA	No	Subindicator	RRA	No	Subindicator	RRA
1.	B1	2.694	15.	A4	-0.246	29.	US3	1.753
2.	B2	2.477	16.	A5	1.369	30.	US4	1.912
3.	B3	2.743	17.	A6	1.339	31.	US5	2.086
4.	B4	2.086	18.	A7	1.325	32.	US6	2.274
5.	B5	-	19.	UC1	1.325	33.	US7	2.484
6.	R1	1.912	20.	UC2	1.339	34.	US8	2.484
7.	R2	1.753	21.	UC3	1.369	35.	US9	-0.203
8.	R3	3.955	22.	UC4	-	36.	US10	-0.217
9.	R4	2.006	23.	UC5	1.412	37.	AC1	-
10.	R5	1.629	24.	UC6	1.470	38.	AC2	-0.217
11.	R6	1.543	25.	UC7	1.543	39.	AC3	-0.217
12.	A1	-	26.	UC8	1.629	40.	AC4	-0.203

No	Subindicator	RRA	No	Subindicator	RRA	No	Subindicator	RRA
13.	A2	1.470	27.	US1	1.999	41.	AC5	-
14.	A3	1.412	28.	US2	3.961			

Figure 5(a) depicts the thinking process for M3 climate change literacy, and Figure 5(b) shows the matrix adjacency for the portrait phase. Table 12 shows that the sub-indicator UC3 has the RRA value of 1.487. The RRA value for this sub-indicator is considered the best, as lower values indicate higher integrity.

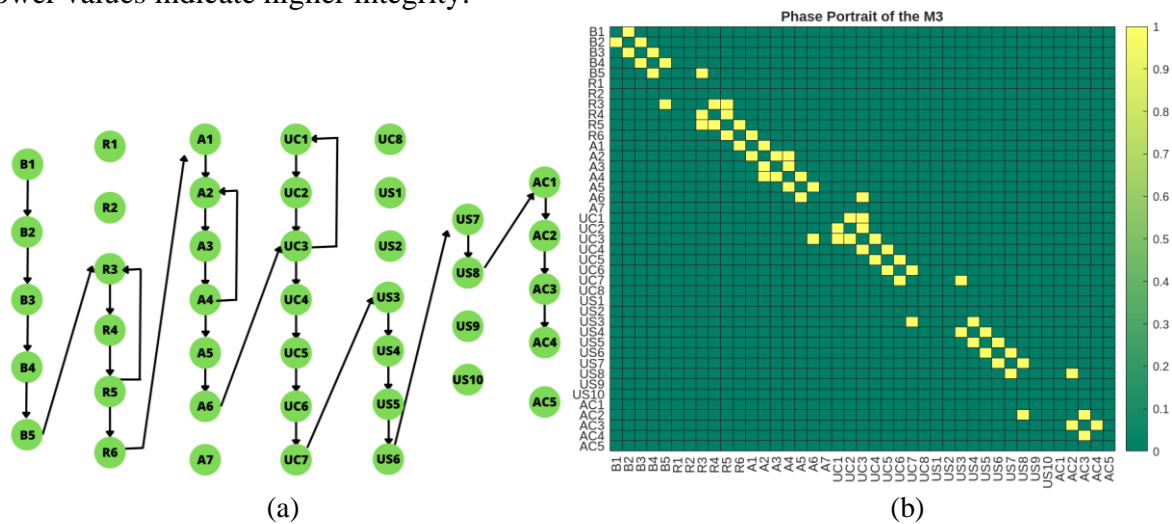


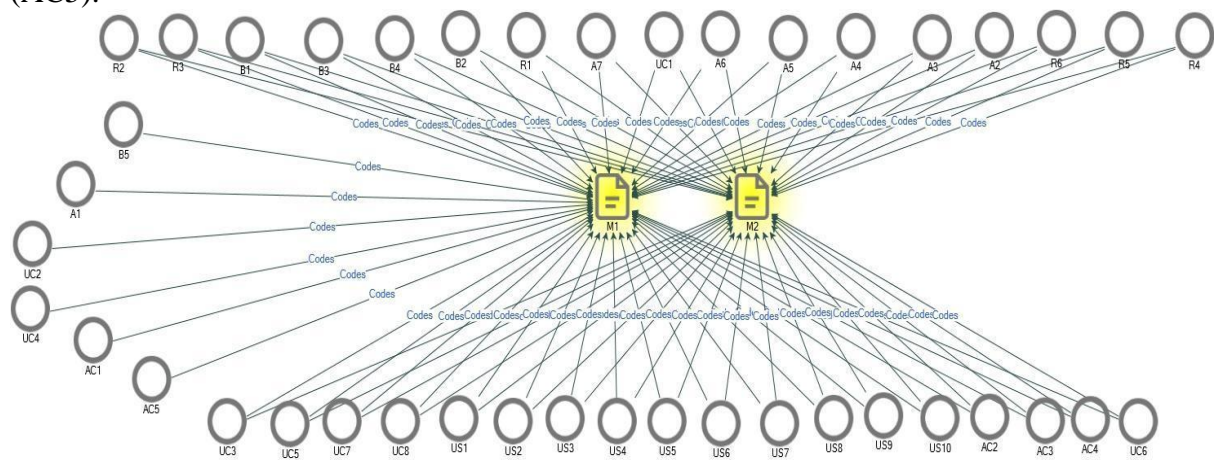
Figure 5. (a) Graph Representation of M2, (b) Adjacency Matrix of Distance One of M3

Table 12. The Distribution Score of Real Relative Asymmetry (RRA) of Subject M3

No	Sub Indicator	RRA	No	Sub Indicator	RRA	No	Sub Indicator	RRA
1.	B1	3.271	15	A4	1.568	29	US3	1.891
2.	B2	3.011	16	A5	1.523	30	US4	2.025
3.	B3	2.769	17	A6	1.496	31	US5	2.178
4.	B4	2.545	18	A7	-	32	US6	2.348
5.	B5	2.339	19	UC1	1.738	33	US7	2.536
6.	R1	-	20	UC2	1.738	34	US8	2.742
7.	R2	-	21	UC3	1.487	35	US9	-
8.	R3	2.151	22	UC4	1.532	36	US10	-
9.	R4	2.195	23	UC5	1.595	37	AC1	-
10.	R5	1.989	24	UC6	1.676	38	AC2	2.966
11.	R6	1.855	25	UC7	1.774	39	AC3	3.208
12.	A1	1.738	26	UC8	-	40	AC4	3.468
13.	A2	1.639	27	US1	-	41	AC5	-
14.	A3	1.729	28	US2	-			

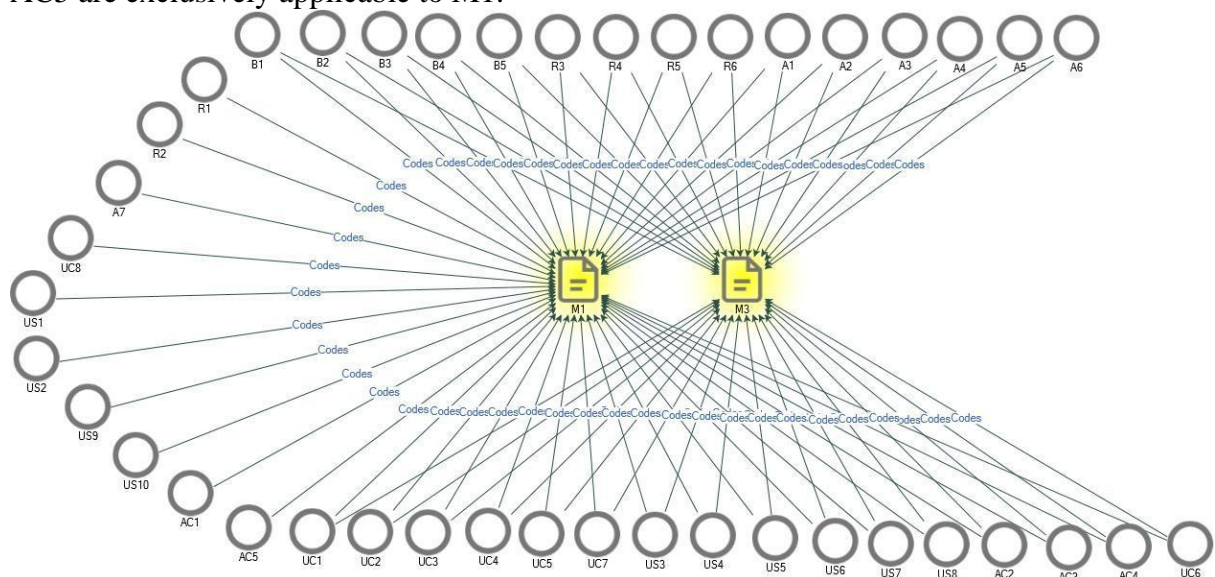


climate change, is divided into several sub-indicators, namely Data Collection and Analysis (A1), Scientific Literacy (A2), Research Proposal Development (A3), Field Research Skills (A4), Laboratory Research (A5), Modeling and Simulation (A6), and Geographic Information Systems (GIS) (A7). Furthermore, the fourth indicator, Understanding the causes of climate change, is divided into several sub-indicators, namely carbon dioxide (CO<sub>2</sub>) concentrations (UC1), temperature trends (UC2), ice cap and glacier retreat (UC3), sea level rise using satellite data (UC4), extreme weather events (UC5), ecosystem changes (UC6), forest loss (UC7), and fossil fuel emissions (UC8). The fifth indicator, Understanding solutions to address climate change, is divided into several sub-indicators, namely, renewable energy deployment (US1), energy efficiency (US2), carbon capture and storage (US3), afforestation and reforestation (US4), waste reduction and recycling (US5), urban planning (US6), corporate sustainability (US7), emission reduction targets (US8), technological innovation (US9), and climate resilience planning (US10). The last indicator, the ability to communicate on climate change, is divided into 5 sub-indicators: Clarity of Messaging (AC1), Engagement and Interactivity (AC2), Feedback Mechanisms (AC3), Tailored Messaging (AC4), and Visual Communication (AC5).



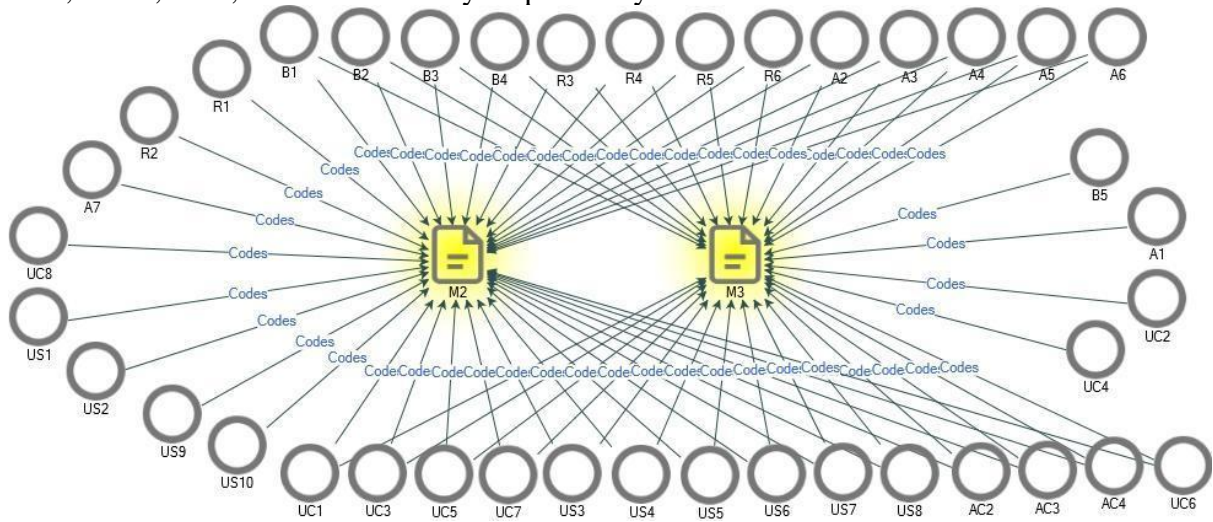
**Figure 8.** The Interview Results Comparison between M1 and M2

Figure 8 shows the differences in the sub-indicators that can be passed by M1 and M2. There is a distinction between M1 and M2 since sub-indicators B5, A1, UC2, UC4, AC1, and AC5 are exclusively applicable to M1.



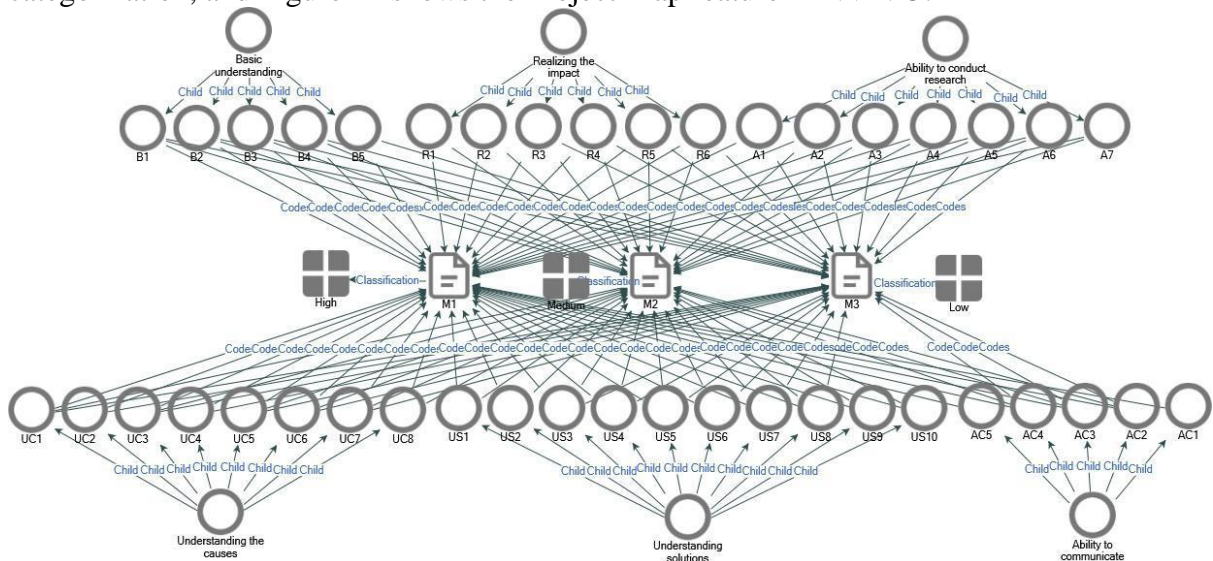
**Figure 9.** The Interview Results Comparison between M1 and M3

Figure 9 shows the differences in the sub-indicators that can be passed by M1 and M3. There are differences between M1 and M3 since sub-indicators R1, R2, A7, UC8, US1, US2, US9, US10, AC1, and AC5 can only be passed by M1.



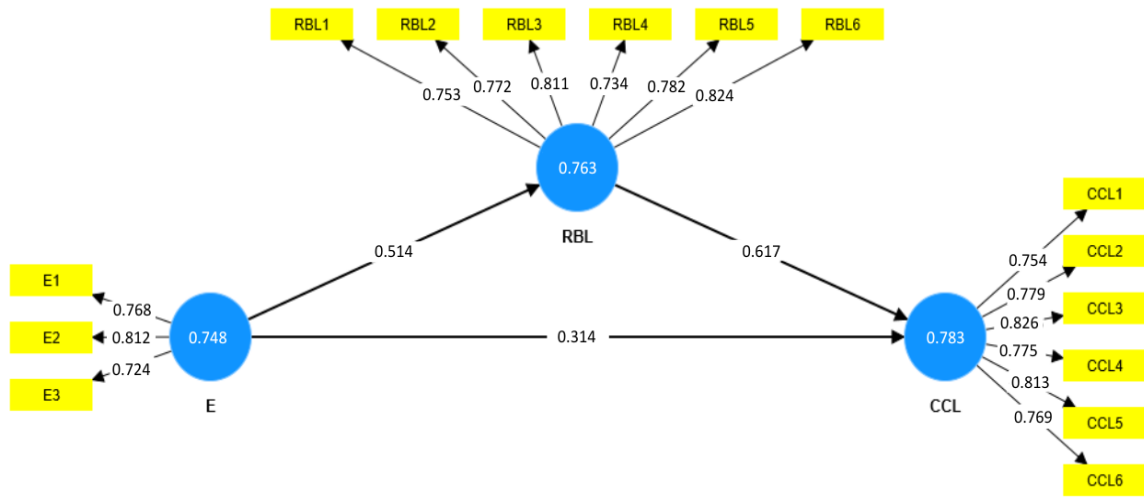
**Figure 10.** Comparison between M2 and M3

Figure 10 shows the differences in the sub-indicators that can be passed by M2 and M3. There is a difference between M2 and M3 since sub-indicators R11, R2, A7, UC8, US1, US2, US9, and US10 are passed only by M2. Meanwhile, sub-indicators B5, A1, UC2, and UC4 are only skipped by M3. The next step compares the students' total data with the pre-established categorization, and Figure 11 shows the Project Map feature in NVIVO.



**Figure 11.** Project Map of Climate Change Literacy on M1, M2, and M3

In the final analysis, SmartPLS will be used, and the initial analysis will include adopting the SEM-PLS algorithm to assess the model's, indicators', and sub-indicators' viability. According to Figure 12, the standard algorithm is examined using key components: the loading factor, reliability, and average variance extracted (AVE). The loading factor value is used to ascertain the convergent validity of sub-indicators. A sub-indicator is deemed to have good convergent validity when the value exceeds 0.7. For instance, the loading factor values for Ecobricks indicator (E), Research-Based Learning (RBL), and Climate Change Literacy (CCL) indicators are 0.748, 0.763, and 0.783, respectively. Detailed information regarding the loading factor value, Cronbach's alpha reliability, composite reliability, and average variance extracted is presented in Table 13.



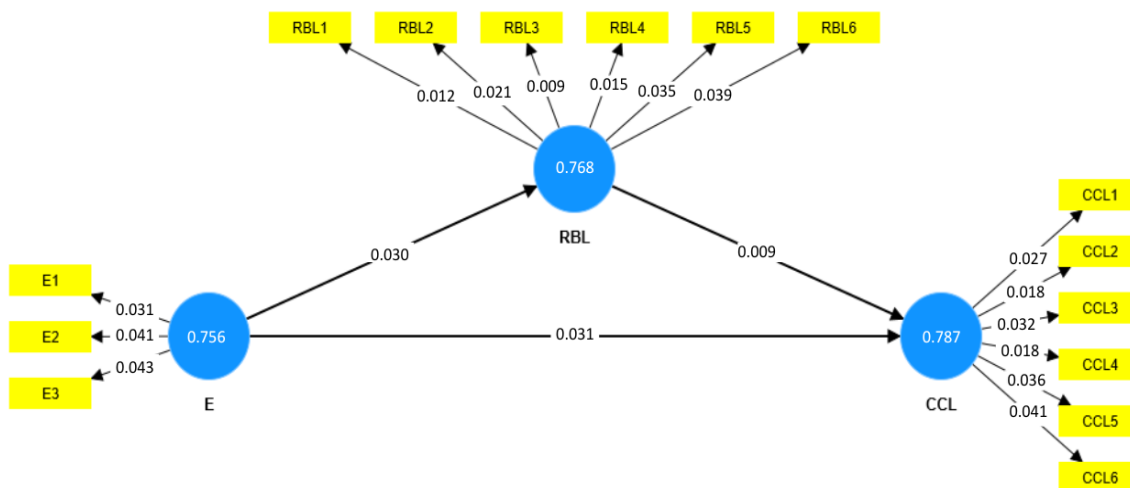
**Figure 12.** SEM-PLS Algorithm for Convergent Validity Values

**Table 13.** Loading Factor Value, Reliability Cronbach's Alpha, Composite Reliability, Average Variance Extracted

Indicator	Sub-indicator	Loading factor	Reliability Cronbach's Alpha	Composite Reliability	AVE
Ecobricks	E1	0.768	0.875	0.881	0.793
	E2	0.812			
	E3	0.724			
Research-Based Learning	RBL1	0.753	0.836	0.847	0.824
	RBL2	0.772			
	RBL3	0.811			
	RBL4	0.734			
	RBL5	0.782			
	RBL6	0.824			
Climate Change Literacy	CCL1	0.754	0.812	0.823	0.815
	CCL2	0.779			
	CCL3	0.826			
	CCL4	0.775			
	CCL5	0.813			
	CCL6	0.769			

Based on Table 13, the sub-indicators in the model have loading factors greater than 0.7, indicating good convergent validity. A sub-indicator with a good convergent validity value indicates an ability to assess good indicators. In addition to analyzing the value of convergent validity, other parameters in testing the model include Cronbach's alpha, composite reliability, and average variance extracted. The Cronbach's alpha and composite reliability values serve as

criteria for determining the indicator. An indicator is considered reliable when both Cronbach's alpha and composite reliability values exceed 0.7. According to Table 9, the indicators show reliability, meeting the criteria for an effective SEM model assessment. Another parameter in SEM model evaluation is the AVE, which indicates an indicator's convergent validity. AVE value exceeding 0.5 indicates good convergent validity, as shown in Table 8. Furthermore, the cross-loading factor is used to test discriminant validity. The discriminant validity test is used to ensure that each latent variable is distinct from the other indicators. The cross-loadings analysis shows that each latent variable has a distinct pattern of loadings.



**Figure 13.** SmartPLS Bootstrapping Result

The next analysis was a bootstrapping analysis, as shown in Figure 13. This research tested three hypotheses and found a significant effect, namely H1: Ecobricks (E) → Research Based Learning (RBL) ( $p = 0 < 0.05$ ,  $t = 31.143 > 1.96$ ). Therefore, Ecobricks has a close relationship with Research-Based Learning, H2: Research-based learning (RBL) → climate change literacy (CCL) ( $p = 0 < 0.05$ ,  $t = 33.263 > 1.96$ ). The research-based learning has a close relationship with climate change literacy, H3: Ecobricks (E) → Climate Change Literacy (CCL) ( $p = 0 < 0.05$ ,  $t = 23.154 > 1.96$ ). Subsequently, the path coefficients for the direct and indirect effects were analyzed. The p-value of the path Ecobricks (E) → Research Based Learning (RBL), Research-Based Learning (RBL) → Climate Change Literacy (CCL), Ecobricks (E) → Climate Change Literacy (CCL), and Ecobricks (E) → Research Based Learning (RBL) → Climate Change Literacy (CCL) was 0.030, 0.014, 0.031, and 0.009, respectively. Based on these results, the path coefficient for the indirect effect is significant. Therefore, the integration of RBL-STEM makerspace materials focused on recycling plastic waste into ecobricks had the greatest impact on students' climate change literacy.

### Overall findings

Understanding climate change is very important in the contemporary era, allowing individuals and communities to make well-informed decisions, implement effective mitigation and adaptation strategies, and contribute to global efforts of addressing challenges. By gaining insight into the scientific aspects, individuals are better equipped to participate in sustainable practices, conserve natural resources, and advocate for policies to improve environmental stewardship (Karsgaard & Davidson, 2023). Moreover, climate literacy is essential to mitigating the economic, health, and environmental impacts of a changing climate. By integrating education into the curriculum and promoting public awareness, a population capable of navigating the complexities of issues can be obtained.

Literacy plays an important role in tackling climate change. This variable empowers individuals to understand the scientific principles of climate change, promoting a deep understanding of its causes and consequences (Candiago et al., 2023). The knowledge is

instrumental in guiding informed decision-making at both individual and societal levels. Climate-literate individuals engage in sustainable practices, support environmentally friendly policies, and advocate for initiatives to reduce greenhouse gas emissions (Kolenatý et al, 2023). Literacy enables effective communication and collaboration, essential components for building a collective response to the challenges posed by climate change. In addition, it acts as a catalyst for meaningful action, equipping people with the tools to become sustainable and resilient.

Integrating literacy into educational curricula from primary school through university is essential for building a well-prepared generation to address the challenges of climate change (Molthan-Hill et al. 2022). Incorporating age-appropriate content can instill foundational knowledge on climate science, environmental sustainability, and the interconnectedness of human activities with the planet. As students progress through education, more advanced topics related to climate change impacts, mitigation strategies, and adaptation measures can be introduced. This educational method enhances scientific literacy and cultivates a sense of environmental responsibility and critical thinking abilities. By extending climate literacy into university education, students can delve deeper into specialized areas such as climate policy, renewable energy technologies, and sustainable development to address and mitigate the impacts of climate change (Kranz et al, 2022). A comprehensive, continuous approach to climate literacy in education is crucial for promoting a well-informed, proactive citizenry. Therefore, this research has implemented RBL-STEM makerspace materials on recycling plastic waste into ecobricks.

Repurposing plastic waste into ecobricks constitutes a dual-sided contribution to the impact of climate change. Positively, ecobricks provide a tangible solution to mitigate plastic pollution by transforming discarded plastic into a functional building material, reducing the environmental impacts associated with improper disposal (Li, 2022). This practice raises awareness of plastic pollution and actively involves communities in sustainable waste management. The use of ecobricks in construction has the potential to reduce demand for conventional materials with higher carbon footprints, contributing to a more environmentally friendly environment (Xia et al., 2023). However, potential limitations, such as energy requirements for ecobrick production and concerns about the long-term durability and safety of structures, should be acknowledged. Even though ecobricks offer localized solutions, it is important to consider their scalability and the need for comprehensive methods to address plastic waste and climate change on a broader scale.

Promoting students in school to recycle plastic waste into ecobricks is a commendable initiative. This hands-on method empowers students with practical knowledge of waste management and instills a sense of environmental responsibility from an early age (Requena et al, 2022). By actively participating in the process of creating ecobricks, students witness the transformation of waste into a constructive resource and gain a deeper understanding of environmental challenges (De Sousa, 2022). This experiential learning can have a lasting impact, shaping students into environmentally conscious individuals who adopt sustainable practices. Furthermore, the collaborative nature of the projects promotes teamwork and community inclusion, creating a positive ripple effect beyond the classroom. The integration of recycling initiatives into the educational curriculum enhances both academic and practical learning, nurturing a generation that values environmental stewardship.

The implementation of RBL-STEM makerspace materials shows positive results in improving students' climate change literacy. The integration provides students with hands-on experiences and inquiry-based learning opportunities to actively explore and understand the complexities. This method enhances scientific knowledge and cultivates critical thinking by fostering a deeper understanding of the interconnected nature of environmental issues (Alcorin and Verdeprado, 2022). Additionally, implementing the materials may contribute to a more comprehensive and lasting understanding of the subject by actively engaging students in real-world problem-solving related to climate change. These positive outcomes underscore the

importance of innovative, experiential educational methods for effectively addressing the challenges posed by climate change and promoting climate literacy among students. Makerspace activities on recycling plastic waste into ecobricks at the school level are shown in Figure 14.



**Figure 14.** Makerspace Activities on Recycling Plastic Waste into Ecobricks at the School Level in UPTD Satdik SDN Tegal Besar 04 Jember, Indonesia

The implementation of RBL-STEM makerspace materials, focusing on Research-Based Learning in Science, Technology, Engineering, and Mathematics, has resulted in enhanced students' climate change literacy. By analyzing experiential learning, this method enables students to actively engage with real-world problems related to climate change, promoting a profound understanding of their complexities. The interdisciplinary nature of STEM education provides a comprehensive perspective, integrating scientific, technological, engineering, and mathematical principles to address the multifaceted aspects of climate change. The materials cultivate critical thinking ability through problem-solving activities, empowering students to analyze evidence and make informed decisions. Moreover, the long-term impact of research-based learning experiences promotes a sense of personal responsibility and commitment to sustainable practices. Collaborative learning environments, application of knowledge to practical situations, and increased students' engagement contribute to positive results. The materials prepare students for future careers in fields crucial for addressing the challenges of climate change.

## CONCLUSION

In conclusion, implementing RBL-STEM makerspace materials on recycling plastic waste enhanced students' climate change literacy. This research included two parts: the R&D process and the quasi-experiment. The results showed that the developed learning materials met the criteria of validity, practicality, and effectiveness. The average score on the practicality test was 3.73, with an achievement percentage of 94.6%, indicating that the learning materials met the validity, practicality, and effectiveness criteria. Since the p-value (2-tailed) was 0.005 ( $<0.05$ ), the implementation of the materials promoted students' climate change literacy through recycling plastic waste into ecobricks. This was also in line with the phase portrait, NVIVO analysis, and SmartPLS analysis. However, exploring the long-term impact of the materials on students' climate change literacy was quite challenging.

## RECOMMENDATION

The following future works were proposed: i) longitudinal research to assess the sustained impact of RBL-STEM makerspace materials on students' climate change literacy; ii)

the impact of the materials varies across different demographic groups, such as gender, socio-economic status, or academic performance. Understanding potential disparities can inform strategies for more equitable educational interventions, iii) the role of teacher training and ongoing support in the successful implementation of the materials, iv) exploring how the materials can be adapted and implemented in different cultural and contextual settings. The effectiveness of the programs may vary based on socio-economic factors, educational systems, and cultural norms; v) the integration of RBL-STEM makerspace activities into the formal curriculum on students' learning outcomes; and vi) examining how the materials can be inclusive and accessible to students with diverse learning needs and abilities.

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#### AUTHOR CONTRIBUTIONS STATEMENT

Name of Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
Tri Dyah Prastiti	✓	✓	✓	✓	✓	✓		✓	✓	✓			✓	
Idha Novianti		✓				✓		✓	✓	✓	✓	✓		
Endang Wahyuningrum	✓		✓	✓			✓			✓	✓		✓	✓
Dafik					✓		✓			✓		✓		✓
Zainur Rasyid Ridlo					✓		✓			✓		✓		✓
I. Lutfiatul Mursyidah		✓				✓		✓	✓	✓	✓	✓		
Okti Anis Safiati					✓		✓		✓	✓		✓		✓

#### CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

#### DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, TDP, upon reasonable request.

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