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On Students' Computational Thinking Skills for Solving SRAC and its Theoretical Framework on Multi-Step Time Series Forecasting on River Erosion using GNN under RBL-STEM Learning Stages

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ABSTRACT: Computational thinking involves the use of computer science principles to solve complex problems, extending beyond simple programming to various life applications. In today's educational landscape, the promotion of these skills in the classroom is critical, yet students' computational thinking skills remain underdeveloped due to inadequate learning models. Key indicators of computational thinking include problem decomposition, algorithmic thinking, pattern recognition, abstraction, and generalization. This study presents RBL-STEM learning activities aimed at enhancing students' computational thinking through solving the Strong Rainbow Antimagic Coloring or SRAC problem and applying it to multi-step time series forecasting on river erosion using Graph Neural Networks or GNN. The research adopts a qualitative narrative method, beginning with the development of a prototype for multi-step time series forecasting on river erosion using SRAC and GNN, and progressing to the formulation of RBL-STEM learning steps. The results include a comprehensive RBL-STEM learning framework ready for implementation in future research. Learning framework offers student and educator a structured approach to integrating STEM on real life issues. By employing RBL-STEM, students are encouraging to solve river erosion problem systematically based on RBL stages. These finding suggest that the implementation of RBL-STEM with innovative mathematical problems such as SRAC can enhance students' combinatorial skills, leading to practical solutions for everyday issues through education.

KEYWORDS: Computational Thinking Skills, SRAC, Multi-step Time Series Forecasting, River Erosion, GNN, RBL-STEM

INTRODUCTION

Computational thinking skills are essential in this digital era. To keep up with the rapid advances in information and communication technology, people need to adopt a computational approach for problem solving and decision making. Computational thinking is the ability to create solutions using computer algorithms and other technologies. This skill is crucial across all subjects, including science, technology, engineering, mathematics, social studies, and reading, due to the increasing importance of digital skills and technology in these fields [1]. Computational thinking has recently gained attention within educational policy efforts [2]. Computational thinking involves a number of skills, such as problem decomposition (breaking down complex problems to simpler ones), developing algorithms (step-by-step solutions to problems), and abstraction [3]. The specific indicators and sub-indicators are detailed in **Table 1**.

SRAC is a method from graph theory where each vertex in graphs given different color based on specific rules. This method ensures that each edge in the graph has unique sum of colors[4]. It facilitates a deeper comprehension of graph properties and is instrumental in enhancing students' problem-solving capabilities and computational thinking skills. By mastering SRAC, students develop critical thinking and analytical abilities crucial for addressing intricate real-world problems. This study utilize time-series modeling that has been a crucial area of academic research, with applications in climate modeling, biological sciences, medicine, retail, and finance to solve river erosion problem [5].

One potential way lecturers could enhance students' computational thinking skills is by implementing the Research-Based Learning (RBL) model in their teaching which emphasizes hands-on experience, exploration, and experimentation to deepen understanding and improve problem-solving skills [6]. This method promotes active learner engagement in acquiring knowledge through investigation and discovery. In RBL, students act as researchers, seeking answers and solutions to assigned questions or tasks.

Essentially, RBL fosters deeper and more meaningful learning by involving students in exploring topics or issues that interest and are relevant to them [7]. This model involves a structured research process where students develop skills such as critical thinking and problem-solving abilities, promoting hands-on learning and generating new knowledge through systematic investigation and evidence-based conclusions [8]. Research-based learning (RBL) comprises seven stages: (1) problem posing, where open problems are identified within the research group; (2) encouraging learners to develop strategies for solving these problems; (3) data collection, which includes orientation, tabulation, and hypothesis formation; (4) data analysis, prediction, and validation processes; (5) formulating conjectures, corollaries, hypotheses/lemmas, theorems, and generalizations; (6) engaging in group discussions within the research group; and (7) reporting on the RBL findings.

Table 1. Computational Thinking Indicator and Sub-Indicator

No.	***Indicator***	***Sub Indicator***
1.	Problem Decomposition	a. Identify the problems b. Parse information to solve the problem
2.	Algorithmic Thinking	a. Determine the solution steps of the problem b. Apply the steps in solving the problem
3.	Pattern Recognition	a. Students can represent problem b. Students can determine the pattern of the problem. c. Students can determine the search strategy d. Students are able to determine the search strategy on problem representation
4.	Abstraction and Generalization	a. Students can analyze the final results of the data or information obtained with the initial hypothesis when solving the problems. b. Students can write about the relationship between problems and the search strategy. c. Students can describe the relationship between problems and strategy

Global K-12 education increasingly emphasizes STEM (science, technology, engineering, and mathematics) and the integration of computational thinking skills [9], [10]. Computational thinking, which utilizes mathematical algorithms to solve problems, is now recognized as essential for all students [11], [12]. Efforts are being made to integrate computational thinking into K-12 education and merge it with STEM through the RBL model to enhance combinatorial thinking skills [13], [14]. Countries such as the United States, China, Australia, and Finland have implemented policies aimed at promoting computational thinking within STEM education [15], [16]. Despite these integration efforts, further research is needed to assess their impact on computational thinking skills [9], [17], [18].

The combination of RBL and STEM approaches has received substantial attention in the swiftly changing field of education. This combination enhances critical thinking and problem-solving skills, establishing RBL-STEM as an emerging trend in contemporary educational practices [6], [19], [20]. This study explores the RBL-STEM model to improve computational thinking skills, focusing on Strong Rainbow Antimagic Coloring (SRAC) and applying it on river erosion, linked to Sustainable Development Goals (SDGs) [13]. It introduces an Activity Framework for RBL-STEM on multi-step time series forecasting on river erosion by using GNN, SRAC, and assesses computational thinking skills in this context.

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RESEARCH FINDING

A. RBL-STEM Activity Framework

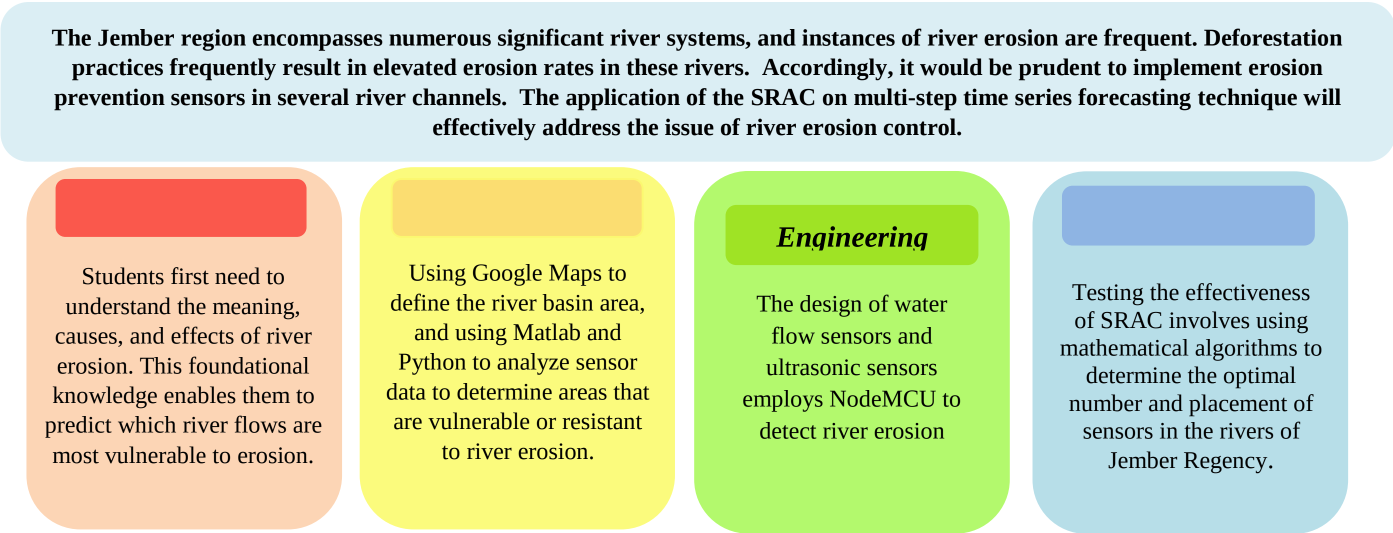

Figure 1. STEM elements in river erosion cases

It integrates the RBL model with STEM, starting with open-ended problems identified by the research group. The issues that have been identified and the implications of the STEM framework are illustrated in **Figure 1**. This study focuses on determining the required number of sensors through various stages of the RBL-STEM approach. These stages involve: (1) gathering data related to factors influencing river erosion such as flow discharge and watershed width; (2) using Google Maps to visualize watershed graphs of Jember District; (3) applying the SRAC concept to map river flow and identify optimal locations for erosion monitoring posts; (4) installing water flow and ultrasonic sensors for detecting erosion; (5) assessing sensor placement effectiveness by monitoring data via ThinkSpeak and using Python for forecasting; and (6) presenting research outcomes and evaluating student reports based on computational thinking indicators. The detailed RBL-STEM integrated framework summary is available in **Figure 2**.

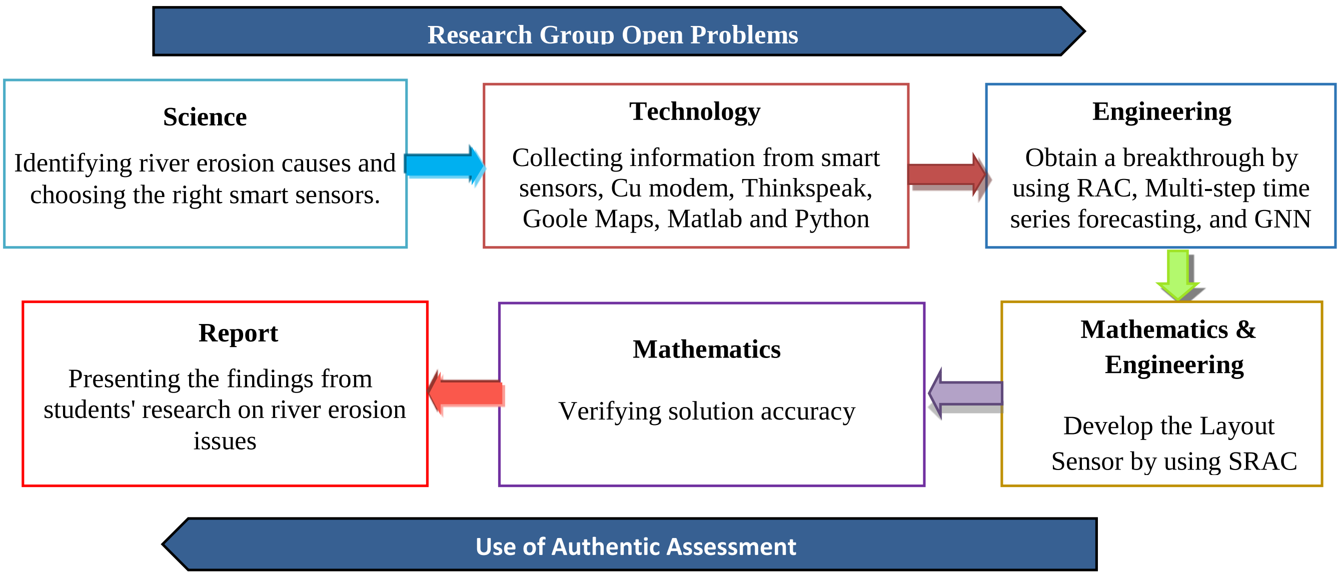

Figure 2. RBL-STEM activity framework

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In teaching mathematics, its practical relevance in everyday life is crucial. Previous research emphasizes the importance of engaging directly with real-world problems to stimulate high-level thinking processes, including innovative problem-solving, which are key aspects of computational thinking [21]. The SRAC study also addresses real-life issues such as river erosion. This paper aims to solve the smart sensor placement problem using SRAC method and river erosion prediction using the GNN method

***Science Elements*:** The study begins by examining a prevalent problem of river erosion in Jember Regency. The given problem is to develop an analysis of river erosion factors and design a river erosion sensor, which it involves identifying factors influencing river erosion, such as river discharge and watershed width. Students are tasked with designing sensors capable of gathering data on these factors in Jember Regency. They are expected to devise water flow sensors and ultrasonic sensors for this purpose. The depict of the watershed of Jember illustrated in **Figure 3**.

Figure 3. Jember district watershed map based on Google Map

***Technology Elements*:** During this phase, technology played a crucial role with the use of Google Maps, ThinkSpeak, Matlab, and Python applications. The given problem is to create a graphical representation of the Jember District Watershed. As a result of addressing science element problem, a sensor was identified for placement in each river's flow. This process generates data integrated into the ThingSpeak application, which is then used for forecasting in Matlab and Python applications. Then students are required to utilize Google Maps technology to create a graphical representation. Using these representations, students can analyze river erosion occurrences by deploying sensors as outlined in Problem 1. After placing the sensors, data processing occurs through ThinkSpeak technology, resulting in Excel data outputs. These outputs are then forecasted using the Python program, generating a graph visualization that determines the placement of the river erosion monitoring station, as depicted in **Figure 4**.

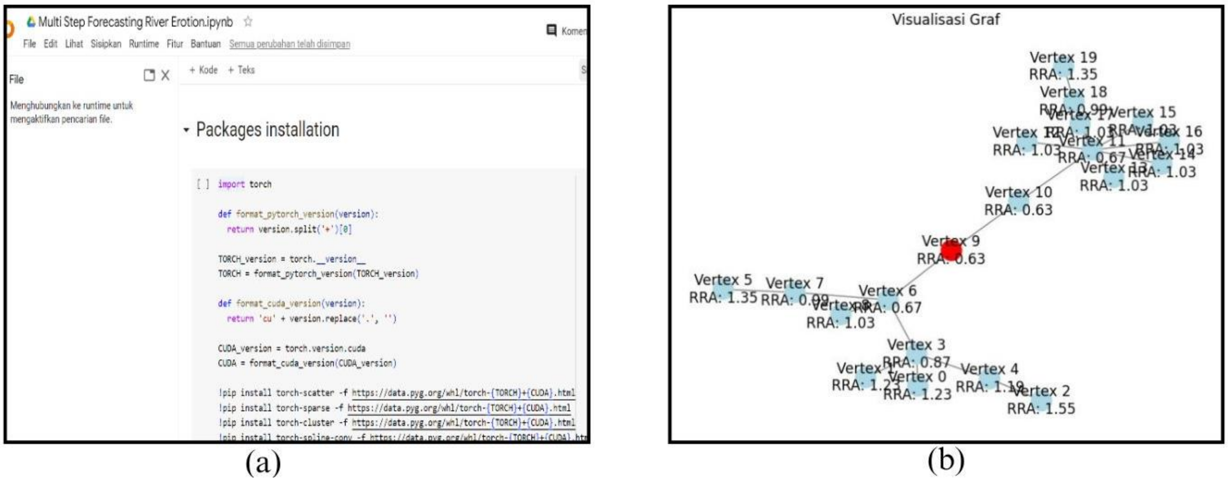

Figure 4. (a) Multi-step time series forecasting using phyton; (b) RRA result on Jember district watershed graph

***Engineering Elements*:** Engineering elements involves the process of assembling a sensor to produce data capable of predicting river erosion conditions. To solve the problem, students learned to apply the SRAC method into a graphical representation to determine the number of smart sensors across different river basin. The concepts covered were: (1) performing antimagic labeling on all vertex in the graph, starting from one to multiple vertex; (2) calculating edge weights by summing vertex labels connected by

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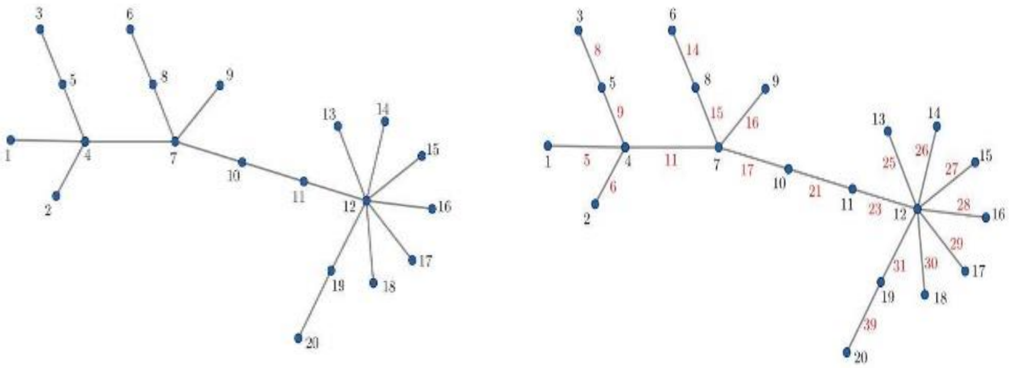
the edge; (3) analyzing rainbow paths in graphs, ensuring each pair of vertices has at least one distinct rainbow path; and (4) repeating labeling until all pairs of vertices have paths with different colors if any rainbow path has the same color (edge weight).

Additionally, a GNN was applied for smart sensor placement. Figure 4a illustrates a tree-shaped graph representation, where each watershed has a designated monitoring station. These stations verify river erosion occurrences, ensuring multiple parties oversee the process. Once the sensor circuit was prepared, it was integrated into NodeMCU to collect data visible on ThinkSpeak. The ThinkSpeak data, forecasted using Python, triggers alerts for prompt river erosion response.

Mathematics Elements**:** Mathematics element will examine the efficacy of SRAC coloration concepts on river graphs. The first activity to study the effectiveness of the concept of SRAC on river graphs is elucidate the fundamental principles of SRAC. The mathematics activity is creating a point labelling (**Figure 5**a) and that results in different edge weight colorings (Figure 5b). As the watershed graph is fixed and does not require expansion, the subsequent step is to ascertain whether the edge weights that have been obtained thus far fulfill the criteria of strong rainbow antimagic coloring.



(a) (b)

Figure 5. (a) Graph representation of Jember district watershed, (b) Graph result using SRAC

The third activity then performs forecasting with the STGNN technique. The fourth activity in the mathematics component involves calculating the Real Relative Asymmetry (RRA) value, which determines the central location for the river erosion monitoring post. The RRA results are then validated against the Python program's results, as shown in Figure 4b

B. Learning Activity with RBL-STEM Approach

This research follows six stages of RBL-STEM approach. These stages detail how students use the SRAC technique within the RBL-STEM framework to enhance their computational thinking skills in addressing river erosion problems.

First stage (science)**:** Involves identifying the various factors contributing to river erosion, particularly river flow discharge and watershed area. It's crucial to determine the necessary data as efficiently as possible. A detailed explanation of stage 1 is provided in **Table 2**.

Table 2. Learning Activities with RBL-STEM Approach on Problem Analysis

Stage 1	***Learning Activity***
Investigate the problems associated with river erosion and the factors that can impact it (Science).	• The lecturer discusses the risks associated with river erosion. • Pose thought-provoking questions about the factors contributing to river erosion and methods to reduce its rate. • Explain the relationship between river erosion and factors such as water discharge, watershed width, and river depth. • Students engage in developing foundational structures by identifying the necessary data for calculations. • Students initiate group discussions.

Second stage (Technology): Involves utilizing smart sensor technology and the ThinkSpeak application to gather data on river flow discharge and watershed area. A detailed explanation of this stage is provided in **Table 3**.

Table 3. Learning Activities with RBL-STEM Approach for data collection

Stage 2	***Learning Activity***
Data analysis derived from numerical processing by intelligent sensors linked to the ThinkSpeak application (Technology).	• The lecturer introduces smart sensor technology, specifically water flow and ultrasonic sensors. • Students collaborate in groups to develop a smart sensor circuit that connects to the ThinkSpeak application. • Each group tests their assembled smart sensor. • The validation of these smart sensors within the ThinkSpeak application is conducted

***Third Stage* (*Mathematics*)**: In this stage of the project, students engage in developing innovative solutions to address river erosion issues through the application of the SRAC concept. The process begins with an introduction to SRAC, where students gain a comprehensive understanding of its principles and applications. Subsequently, they conceptualize the watershed as a graph, applying the SRAC technique to identify and analyze its Spanning Tree. More specific information regarding this stage can be found in **Table 4**, which outlines the detailed steps and objectives of their exploration and application of SRAC in mitigating river erosion challenges.

Table 4. Learning Activities with RBL-STEM Approach on Graph Representation

Stage 3	***Learning Activity***
Creating innovative solutions to address river erosion problems using the SRAC concept (Mathematics).	• Introducing the concept of SRAC. • Representing the watershed of Jember Regency as a graph. • Each student group works on proving and developing theorems related to SRAC, applying them to the graph of Jember Regency watersheds. • Determining the optimal placement for the river erosion monitoring post, which will provide alarm signals for prompt response to erosion events.

Fourth Stage (Engineering): Involves assembling smart sensors (water flow and ultrasonic sensors) and integrating them with ThinkSpeak to predict river erosion warnings. **Table 5** provides a more detailed explanation of this stage.

Table 5. Assembly of Smart Sensors Utilizing the SRAC technique.

Stage 4	***Learning Activity***
Assembly of smart sensors ready for placement in the watershed, guided by SRAC results (Engineering).	• Assembling smart sensors integrated with NodeMCU and ThinkSpeak. • Converting the watershed graph to a spanning tree. • Each group generates a spanning tree from the Jember Regency Watershed graph. • Simulating the placement of smart sensors on the spanning tree within each student group.

Fifth stage (Technology): Involves evaluating the effectiveness of smart sensors in detecting river erosion based on SRAC results. Detailed information about this stage is provided in **Table 6**.

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Table 6. **Testing the Results of Deploying River Erosion Sensors Based on the SRAC Concept.**

Stage 5	*Learning Activity*
Testing the placement results of smart sensors (water flow and ultrasonic) for river erosion detection (Technology).	• Analyzing data from the ThinkSpeak application over a specified time period. • Reporting the findings from the ThinkSpeak analysis. • Evaluating and clarifying the results of student research.

Sixth stage (Report)**:** Students compile and present a report on their research findings, specifically focusing on the use of the SRAC technique for river erosion problems. They participate in a Focus Group Discussion (FGD), allowing other groups to evaluate their conjecture abilities. Further details on this stage are provided in **Table 7**.

Table 7. RBL STEM Learning Activities in RTM

Stage 6	*Learning Activity*
Discussion within the research group forum, including RG members and other researchers, about practical issues related to the study of SRAC (RBL Report).	• Students compile a research report on the application of SRAC for addressing river erosion issues. • Students deliver presentations in class for group discussion (Focus Group Discussion, FGD). • Lecturers assess and elaborate on the findings of student research, concluding with a summary of the discussion outcomes. • Teachers broadcast and elucidate the findings of student research, summarizing the results of the discussion.

DISCUSSION

The findings from this study hold significant value as they delve into the RBL-STEM framework, particularly in the context of SRAC materials. This framework offers educators and students alike a structured approach to integrating STEM principles to address issues such as river erosion, which is a critical target under the Sustainable Development Goals (SDGs) [22]. By employing RBL-STEM, students are encouraged to explore problems, gather relevant data on mitigating river erosion, and systematically analyze these findings through the stages of research-based learning.

The application of STEM methodologies also fosters innovation in devising environmental solutions [23] .Thereby enhancing students' computational thinking abilities when tackling river erosion using the SRAC concept. This integrated approach ensures that scientific inquiry forms the foundation, ICT utilization serves as a cornerstone, engineering solutions drive strategies, and mathematical analysis guides problem-solving efforts. For instance, students can determine optimal locations for monitoring stations across diverse river basins, contributing to the preservation of Indonesia's rich cultural heritage, including its multitude of batik motifs.

Moreover, the integration of RBL-STEM enriches students' historical literacy by enabling them to explore various batik motifs deeply [24] This approach enhances their ability to recognize historical events, comprehend past narratives, develop research skills, and utilize ICT for exploring mathematical concepts. These advancements in historical literacy are evident throughout the stages of RBL-STEM implementation, as depicted in Figure 11, which illustrates varying degrees of student engagement across initial, main, and final stages of the learning process.

CONCLUSION

The study's findings outline the integration of RBL methodology with the STEM approach, focusing on applying the SRAC technique to address river erosion problems and enhance combinatorial skills. A key outcome is the framework for RBL activities within STEM, emphasizing the SRAC method. Additionally, the study contributes a framework for assessing combinatorial skills. These findings facilitate future research aimed at refining tools and analyzing the implementation of RBL-STEM methodologies

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