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The Integration of the RBL-STEM Learning Model and Graph Theory in Solving Transportation and Logistics Optimization Problems to Enhance Students' Computational Thinking Skills

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Abstract

This study aims to integrate the Research-Based Learning (RBL) model with the STEM approach and graph theory in solving transportation and logistics optimization problems to enhance students' computational thinking skills. The model is designed to train students in identifying transportation and logistics issues, exploring solutions based on graph theory, and analyzing and optimizing distribution routes using algorithms such as Dijkstra and Floyd-Warshall. This research employs a narrative qualitative method, analyzing research-based learning through six RBL-STEM phases: problem identification, initial solution exploration, data collection, data analysis, result interpretation, and model presentation. The results show that this approach significantly improves students' skills in problem decomposition, pattern recognition, algorithmic thinking, and abstraction in solving real-world problems. Concretely, students demonstrated an average score improvement of 23% in computational thinking indicators after participating in the learning process, particularly in designing optimal route graph models and constructing algorithmic logic for route selection. Moreover, the use of technologies such as Google Maps and graph modeling software enables students to perform real-time data-driven analysis. Therefore, this study proves that the integration of RBL-STEM and graph theory not only enhances conceptual understanding of transportation and logistics optimization but also equips students with applicable computational thinking skills for real-world contexts. This learning model can serve as a reference in developing more innovative and industry-relevant STEM-based teaching strategies.

Keywords: *RBL-STEM; Graph; Transportation; Logistics; Computational Thinking Skill.*

Abstrak

Penelitian ini bertujuan untuk mengintegrasikan model pembelajaran Research-Based Learning (RBL) dengan pendekatan STEM dan teori graf dalam menyelesaikan permasalahan optimasi transportasi dan logistik guna meningkatkan keterampilan berpikir komputasional mahasiswa. Model ini dirancang untuk melatih mahasiswa dalam mengidentifikasi masalah transportasi dan logistik, mengeksplorasi solusi berbasis teori graf, serta menganalisis dan mengoptimalkan jalur distribusi menggunakan algoritma seperti Dijkstra dan Floyd-Warshall. Metode penelitian yang digunakan adalah kualitatif naratif, dengan analisis pembelajaran berbasis riset melalui enam tahap RBL-STEM: identifikasi masalah, eksplorasi solusi awal, pengumpulan data, analisis data, interpretasi hasil, dan presentasi model. Hasil penelitian menunjukkan bahwa pendekatan ini secara signifikan meningkatkan keterampilan dekomposisi masalah, pengenalan pola, berpikir algoritmik, serta generalisasi dan abstraksi dalam pemecahan masalah dunia nyata. Secara konkret, mahasiswa menunjukkan peningkatan skor rata-rata pada indikator keterampilan komputasional sebesar 23% setelah mengikuti pembelajaran, khususnya dalam merancang model graf rute optimal dan menyusun logika algoritmik pemilihan jalur. Selain itu, pemanfaatan teknologi seperti Google Maps dan software pemodelan graf memungkinkan mahasiswa melakukan analisis berbasis data secara real-time. Dengan demikian, penelitian ini membuktikan bahwa integrasi RBL-STEM dan teori graf tidak hanya meningkatkan pemahaman konsep optimasi transportasi dan logistik, tetapi juga membekali mahasiswa dengan keterampilan berpikir komputasional yang aplikatif dalam dunia nyata. Model pembelajaran ini dapat dijadikan referensi dalam pengembangan strategi pengajaran berbasis STEM yang lebih inovatif dan relevan dengan kebutuhan industri berbasis teknologi.

Kata Kunci: *RBL-STEM; Graf; Transportasi; Logistik; Keterampilan Berpikir Komputasional.*

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1. INTRODUCTION

In the era of the Fourth Industrial Revolution and Society 5.0, mastering computational thinking skills has become a key competency that students must acquire, particularly in the fields of science, technology, engineering, and mathematics (STEM) [1]. Computational thinking encompasses the ability to break down complex problems into smaller components, recognize patterns, create abstractions, and develop algorithms to efficiently solve problems [2]. One of the applied fields that require these skills is transportation and logistics optimization, which is a real-world problem closely related to everyday life.

The optimization problems in transportation and logistics can be mathematically represented using graph theory concepts such as directed graphs, weighted graphs, shortest paths, and spanning trees. However, in educational practice, conventional approaches have yet to effectively integrate contextual aspects, problem-solving, and technology-based learning [3]. Therefore, a learning model is needed that not only emphasizes conceptual mastery but also fosters higher-order thinking skills and collaborative abilities [4].

Previous studies have examined the effectiveness of the Research-Based Learning (RBL) model and STEM education in enhancing students' problem-solving skills and creativity [5] [6]. Meanwhile, graph theory has been widely applied in modeling and solving transportation and logistics problems [7]. However, research that explicitly integrates the RBL-STEM learning model with graph theory applications to develop students' computational thinking skills remains highly limited [8].

Although each approach RBL, STEM, graph theory, and transportation/logistics contexts has been studied separately, no holistic approach has yet integrated all these elements into a comprehensive and unified learning model [9]. Furthermore, the aspect of students' computational thinking skills as a primary outcome has not been a central focus in previous studies [10]. Therefore, there is a significant research gap in developing a learning design that effectively connects mathematical concepts with real-world problems through a research-based and interdisciplinary approach.

This study presents a novel contribution through the innovative integration of the RBL-STEM learning model with the direct application of graph theory in the context of transportation and logistics optimization [11]. The primary focus is on developing students' computational thinking skills, rather than merely enhancing conceptual understanding [12]. This research employs a real-world project-based approach that fosters collaboration, data exploration, and the utilization of computational technology.

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Based on the research background and gap analysis presented above, the research problems in this study are formulated as follows: (1) What are the STEM elements involved in transportation and logistics optimization problems? (2) How can the RBL-STEM learning framework be structured to address transportation and logistics optimization problems to enhance students' computational thinking skills? and (3) How should the RBL-STEM learning activities and assessment instruments be designed in the context of transportation and logistics optimization problems to improve students' computational thinking skills? Accordingly, this study aims to achieve three main objectives: (1) To explain the STEM elements in transportation and logistics optimization problems; (2) To develop the RBL-STEM learning framework for transportation and logistics optimization problems to enhance students' computational thinking skills; and (3) To design RBL-STEM learning activities and assessment instruments within transportation and logistics optimization problems to foster students' computational thinking skills.

2. METHODS

The research method employed in this study is a qualitative narrative approach, specifically focused on the design and analysis of learning activities that integrate the Research-Based Learning (RBL) model with the Science, Technology, Engineering, and Mathematics (STEM) approach, synergistically combined with the application of graph theory to solve transportation and logistics optimization problems. This study aims to design structured, contextual, and applicable learning activities for students, ensuring a systematic learning flow. The learning activities are developed narratively, beginning with the identification of real-world problems in transportation and logistics, followed by the exploration of relevant graph theory concepts, the design of algorithmic-based solutions, and reflections on the practical implementation of these solutions. The entire learning process is structured to foster and enhance students' computational thinking skills in a meaningful way. The data collected in this study include observations during the planning and implementation of learning activities, reflective notes from both researchers and participants, and structured lesson plan documents. These data are then analyzed thematically to evaluate the quality and relevance of the developed learning model, as well as to assess its effectiveness in supporting the enhancement of students' computational thinking skills.

3.RESULTS

In the context of transportation and logistics optimization problems, the four STEM elements Science, Technology, Engineering, and Mathematics are harmoniously integrated to achieve applicative and solution-oriented research objectives. This integration not only enhances students'

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conceptual understanding but also encourages them to develop interdisciplinary thinking skills in solving real-world problems. The following section presents an example of the integration flow of these four elements, illustrating how each discipline contributes specifically to the problem identification process, solution design, testing, and result evaluation. The synergy of these elements highlights the great potential of the STEM approach in generating innovative solutions that are not only theoretical but also practical and relevant to real-life applications, particularly in addressing the challenges of transportation and logistics systems.

3.1 STEM Elements in Transportation and Logistics Optimization Problems

3.1.1 Science Element

The science elements in transportation and logistics optimization problems play a crucial role in providing a fundamental understanding of the natural and social phenomena that underpin transportation systems and goods distribution. In the context of education, science serves as an entry point for students to analyze environmental, geographical, and social factors that influence the efficiency of transportation systems, such as weather conditions, regional density, and societal mobility patterns. Understanding these aspects enables students to identify key variables affecting logistics systems while also recognizing the real-world complexities present in the field.

Furthermore, through a scientific approach, students are encouraged to develop curiosity and critical thinking skills by posing observation-based questions regarding transportation and logistics phenomena in their surroundings. For instance, they may investigate the causes of congestion at specific points, delays in goods distribution, or inefficiencies in delivery routes. This investigative process follows the steps of the scientific method, starting with observation, problem formulation, hypothesis development, field data collection, and initial data analysis.

On the other hand, the scientific dimension also encourages students to consider sustainability aspects within transportation and logistics systems. They can evaluate the environmental impact of distribution patterns, carbon emissions from logistics vehicles in **Figure.1**, or energy consumption in specific transportation systems. Thus, the integration of science in learning not only equips students with factual understanding but also fosters ecological awareness and social responsibility in designing solutions that prioritize efficiency and sustainability.

Through the integration of scientific elements in RBL-STEM and graph theory, students are trained to analyze problems from a scientific perspective before progressing to the technical and computational stages. This approach serves as a fundamental framework for developing computational thinking skills that go beyond mere technical problem-solving, emphasizing a comprehensive consideration of empirical contexts and the complexities of real-world scenarios.

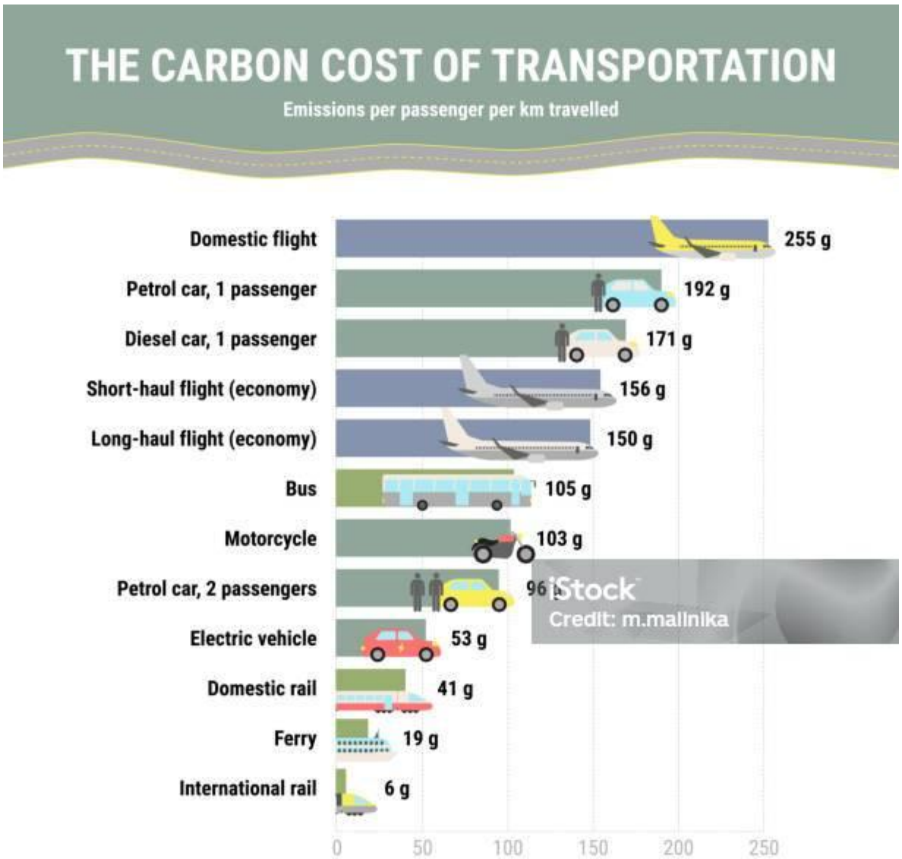

Figure 1 CO_2 emission diagram for various logistics transportation modes [13]

3.1.2 Technology Element

The technology element in transportation and logistics optimization plays a crucial role as a bridge between data and action. In the context of Research-Based Learning (RBL) integrated with STEM, students are guided to utilize various information technology tools and systems to collect, visualize, and analyze transportation data more efficiently. Technology facilitates their understanding of real-world conditions through access to digital maps, GPS sensors, traffic big data, and graph analysis software. Consequently, students not only acquire information from primary sources but also learn to integrate technology into the decision-making process, particularly in route optimization strategies (**Figure.2**).

The integration of technology in the learning process encourages students to conduct simulations and explore data-driven logistics solutions. For instance, they can utilize network modeling software (such as Python) to design optimal delivery routes based on specific parameters, including distance, time, and vehicle capacity. Additionally, traffic monitoring applications like Google Maps or logistics tracking systems are incorporated into the learning

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process, allowing students to understand real-time transportation dynamics and respond adaptively to changing conditions. These activities strengthen computational thinking skills, as students are required to develop logic- and data-driven solutions using digital tools.

Furthermore, technological elements facilitate cross-system integration, supporting the concept of smart logistics. Students are introduced to how technologies such as the Internet of Things (IoT) and Geographic Information Systems (GIS) are utilized in the industry to detect delivery delays, automatically optimize routes, and efficiently manage warehouses. This understanding fosters a forward-thinking and problem-solving mindset, highlighting the importance of technological adaptation in addressing modern logistics challenges. Through this approach, technology is not merely a tool but also serves as a training ground for systematic and innovative thinking among students.

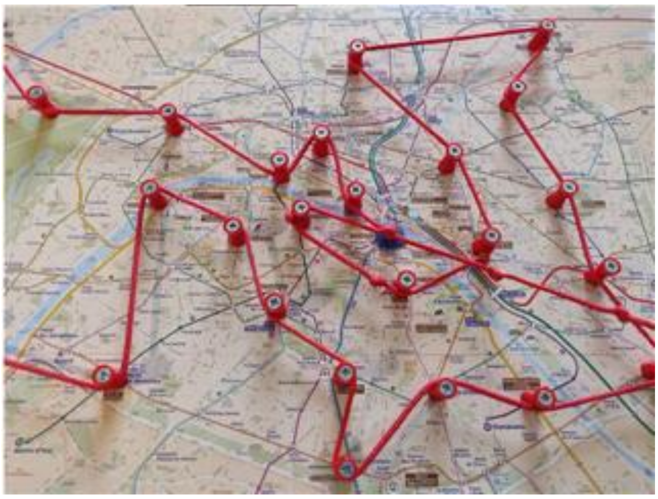

Figure 2 Route Optimization in Logistics [14]

3.1.3 Engineering Element

The Engineering element in the context of transportation and logistics optimization focuses on designing functional, efficient, and applicable solutions to real-world problems faced by society. In RBL-STEM-based learning, students are not only challenged to understand problems from a theoretical perspective, but also to design logistics systems or mechanisms that can effectively solve these issues in a practical and concrete manner. Engineering serves as the implementation phase, where ideas, data, and models that have been analyzed are transformed into system designs or prototype solutions. Students are encouraged to engineer distribution systems or transportation routes by considering various real-world constraints, such as vehicle capacity, travel time efficiency, operational costs, and demand dynamics in specific locations. They design optimal distribution network schemes in **Figure.3**, for example, by applying graph theory

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principles to develop the shortest route or minimum-weight route models for improved logistical efficiency.

Furthermore, the engineering element allows students to consider aspects of safety, reliability, and sustainability in transportation systems. They can design technology-based logistics systems, such as automated delivery routing, smart warehouse integration, or even develop prototypes for future logistics concepts, including the use of drones and electric vehicles for goods delivery. These activities encourage students not only to solve current logistical challenges but also to innovate and anticipate future logistics issues using structured and creative engineering approaches. By integrating the engineering element into the learning process, students experience a comprehensive thought process, beginning with problem identification, data analysis, system design, and solution testing. This significantly contributes to the enhancement of computational thinking skills, as students engage directly in modeling, algorithmic thinking, and the application of data-driven and logic-based technical solutions.

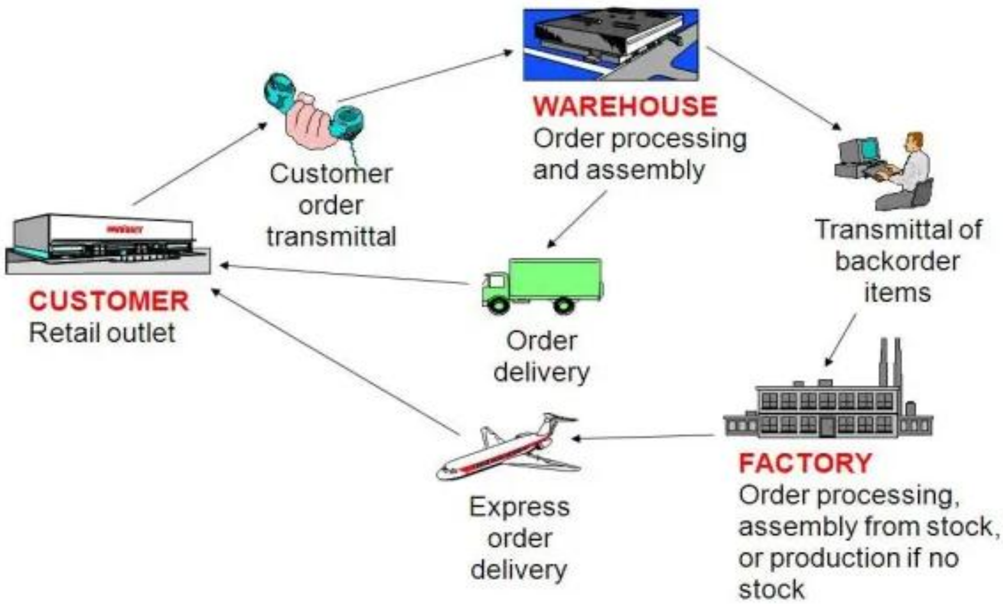

Figure 3 Graph Theory-Based Design Scheme for Logistics or Transportation Networks

3.1.4 Mathematics Element

The Mathematics element serves as a fundamental basis in solving transportation and logistics optimization problems, as mathematics provides a logical, systematic, and quantitative framework for problem-solving. In RBL-STEM-based learning, students are encouraged to apply mathematical concepts such as graph theory, matrices, functions, and statistics to understand the structure of transportation systems, formulate mathematical models, and analyze the efficiency of distribution routes. By utilizing a mathematical approach, students can transform real-world problems into formal representations that can be analyzed rationally and systematically.

One of the most relevant applications is the use of graph theory, where vertices (nodes) represent locations such as warehouses, terminals, or delivery points, and edges represent transportation routes connecting these locations. As illustrated in **Figure.4**, students utilize weighted graphs to determine the fastest, shortest, or most cost-efficient routes using algorithms such as Dijkstra’s algorithm or the Floyd-Warshall algorithm. This application not only enhances their understanding of graph structures but also strengthens their mathematical modeling skills, enabling them to efficiently solve complex logistical problems.

Furthermore, students are introduced to optimization concepts, both manually and with the assistance of software tools, to minimize total time, distance, or distribution costs. They learn to formulate mathematical models in the form of equation systems, objective functions, and constraints, followed by an analysis of optimal solutions. This process enhances students' computational thinking skills, particularly in algorithmic thinking and abstraction, as they must structure problem-solving steps logically and consistently.

Thus, the integration of the mathematics element not only helps students understand theories in an abstract manner but also encourages them to apply logical reasoning and mathematical structures to make informed decisions within complex transportation and logistics systems. This aligns with the primary goal of learning, which is to enhance computational thinking skills through modeling, quantitative calculations, and analytical reasoning.

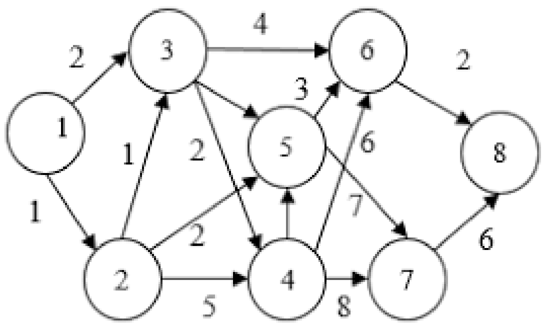

Figure 4 Illustration of Graph Theory Application in Transportation and Logistics

3.2 RBL-STEM Framework

The following framework integrates the Research-Based Learning (RBL) model with the STEM approach and graph theory to address transportation and logistics optimization problems, aiming to enhance students' computational thinking skills. In the initial phase of the RBL syntax, students are required to identify key challenges in transportation and logistics systems, such as route efficiency, distribution timeliness, and the environmental impact of transportation systems. Within the context of science and mathematics-based learning, students are encouraged to understand various factors influencing logistics system efficiency, including road network

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structures, traffic density, and distribution patterns. Additionally, they explore how these factors can be mathematically modeled using graph theory and computational approaches to develop more effective solutions.

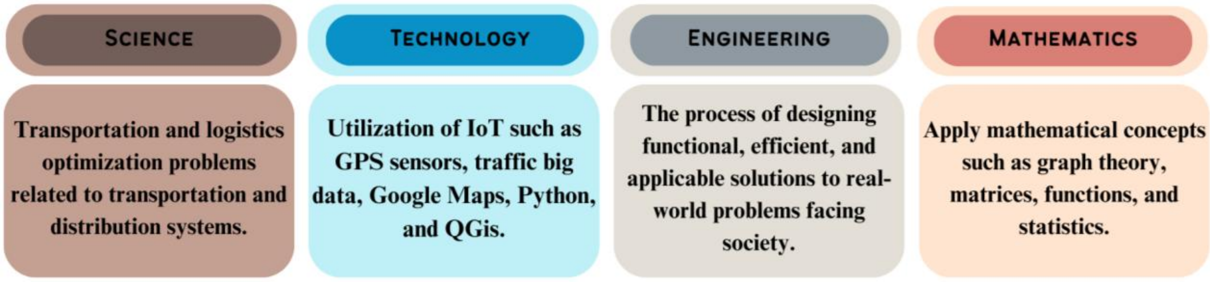

Figure 5 STEM Elements in Transportation and Logistics Optimization Problems

Figure.5 illustrates the integration of STEM elements in transportation and logistics optimization, while **Figure.6** presents the RBL-STEM framework. Science plays a crucial role in understanding the factors influencing transportation systems, such as traffic patterns and infrastructure conditions. Technology utilizes IoT-based tools, including GPS sensors, traffic big data, Google Maps, Python, and QGIS, to analyze and optimize transportation networks. Engineering ensures that the designed solutions are not only theoretical but also functional and efficient in real-world transportation systems. Meanwhile, Mathematics supports system modeling by applying graph theory, matrices, functions, and statistics to determine optimal routes and predict traffic patterns. The RBL-STEM learning process begins with the identification of transportation-influencing factors, followed by data collection and analysis, as well as the application of graph theory and route optimization algorithms to enhance distribution system efficiency. Data normalization is conducted to eliminate bias before the model is evaluated using optimization metrics and integrated with an IoT-based traffic monitoring system for real-time data acquisition. This framework also involves statistical data processing and analysis, interpretation, and generalization of results, culminating in scientific reporting and communication through authentic assessment, which evaluates students' understanding based on real-world experiences. By integrating the STEM approach with graph theory, this framework aims to develop students' computational thinking skills in solving transportation and logistics challenges efficiently and systematically.

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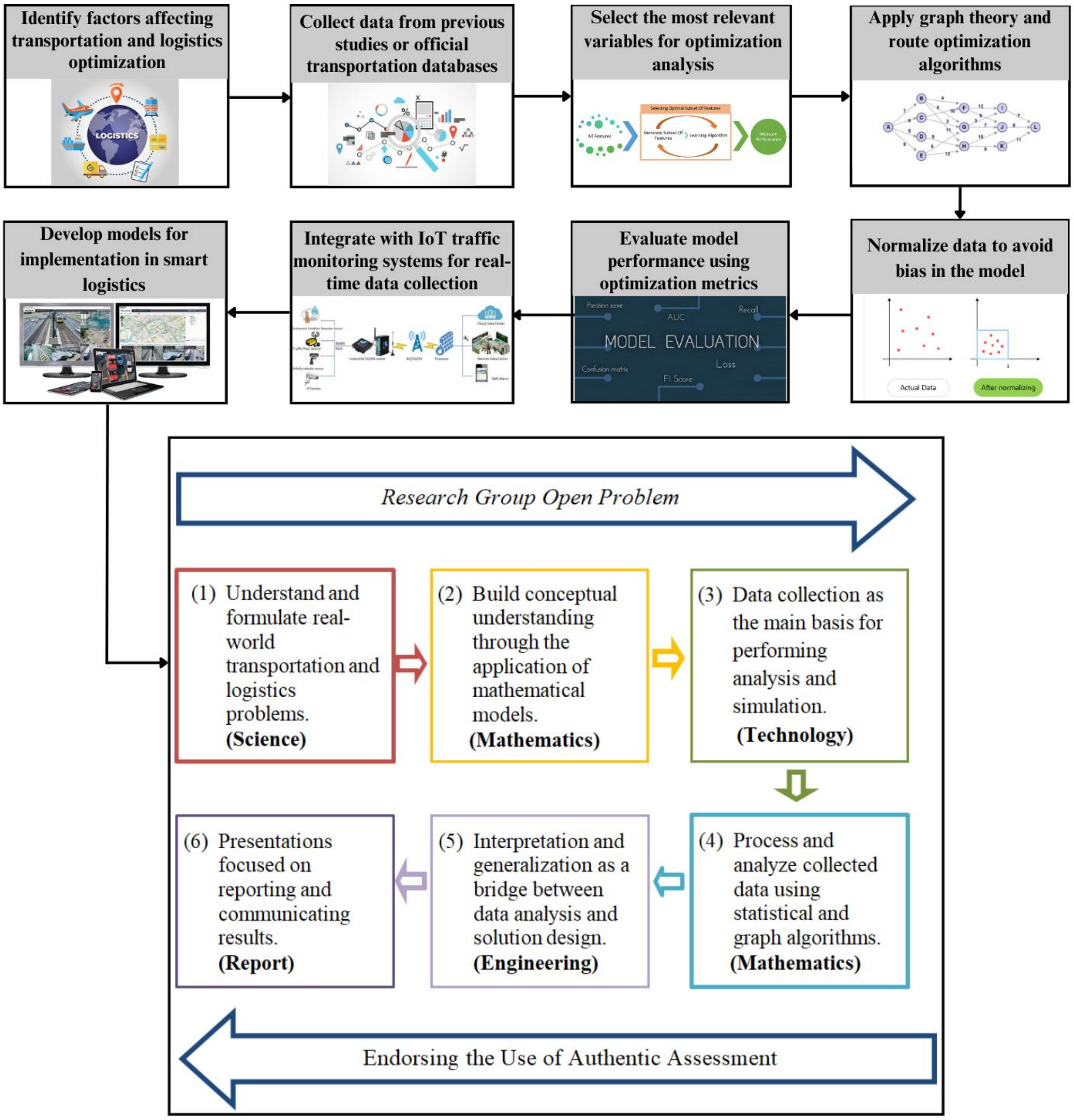

Figure 6 The syntactic framework of Research-Based Learning (RBL) with a STEM approach

3.3 RBL-STEM Activities and Assessment Instruments for Students' Computational Thinking Skills in Transportation and Logistics Optimization Problems

This section provides a detailed discussion of the six stages in the Research-Based Learning (RBL) model, which is integrated with the STEM approach. These six stages are systematically designed to illustrate the research-based learning process undertaken by students in the context of optimization problems in transportation and logistics. Each stage demonstrates how students actively engage in observing phenomena, formulating problems, collecting and analyzing data, and designing relevant solutions by applying the principles of science, technology, engineering, and mathematics in an integrated manner. Through this approach, students not only gain a

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conceptual understanding but also develop essential problem-solving skills. The primary objective of this learning process is to enhance students' comprehension of optimization concepts in the field of transportation and logistics while fostering their computational thinking skills. This is achieved through the application of graph theory as a mathematical tool that enables students to represent problems visually and quantitatively, analyze relationships between elements, and identify optimal solutions in a logical and structured manner. This approach also encourages students to make data-driven decisions by utilizing real-time digital tools and simulation software, thereby bridging theoretical knowledge with practical application in solving complex logistical challenges.

3.3.1 Stage 1: Problem Identification (Science)

To initiate the learning process based on Research-Based Learning (RBL) integrated with the STEM approach, students are guided through the initial phase, namely Problem Identification. In this stage, scientific elements are emphasized as the foundation for scientific reasoning, enabling students to comprehend and formulate real-world problems in the field of transportation and logistics. Students are encouraged to observe relevant phenomena in their surroundings, either through direct observation or by conducting literature reviews and analyzing secondary data. This process helps them identify critical issues such as delays in goods distribution, traffic congestion, or inefficient delivery routes. The goal of this phase is to foster students' contextual awareness of the complexities within logistics and transportation systems while cultivating their curiosity and motivation to explore solutions grounded in scientific methodologies. The series of learning activities for this phase is presented in Table 1.

Table 1. RBL-STEM Learning Activities in Stage One.

Stage 1	Learning Activities
Identifying fundamental transportation and logistics optimization problems	a. The lecturer explains the key issues being addressed, such as delays in distribution, inefficiencies in routing, or traffic congestion. b. Students identify factors influencing these problems, such as geographical conditions, travel time, vehicle capacity, and demand patterns. c. Students formulate research questions that are relevant and can be solved using the STEM approach and graph theory.

3.3.2 Stage 2: Initial Solution Exploration (Mathematics)

After students successfully identify real-world problems in transportation and logistics systems, the next step involves exploring initial solutions through a mathematical approach. At this stage, students begin developing a conceptual understanding by applying mathematical models to represent the formulated problems. Graph theory serves as a primary tool in this process, as it effectively illustrates distribution networks and inter-location relationships within transportation systems in a structured and visual manner. Students are encouraged to construct weighted graphs, directed graphs, or other relevant models that align with the problem context, allowing them to analyze potential routes, critical nodes, and efficiency factors such as travel time or cost. The learning activities at this stage are designed to strengthen students' abstract thinking and mathematical modeling skills, laying the foundation for subsequent stages of analysis and solution design. The details of this stage's activities are presented in Table 2 below.

Table 2. RBL-STEM Learning Activities in Stage Two.

Stage 2	Learning Activities
Initial solution exploration: mathematical modeling based on graph theory	a. The lecturer introduces fundamental concepts of graph theory relevant to representing transportation and logistics systems, such as weighted graphs, directed graphs, and network graphs. b. Students identify graph elements, such as vertices (nodes) representing distribution locations and edges (links) representing transportation routes. c. Students begin constructing graph models based on previously formulated problems by assigning weights to edges based on parameters such as distance, travel time, and cost.

3.3.3 Stage 3: Data Collection (Technology)

After students develop a mathematical model based on graph theory, the next stage in the learning process involves data collection as the primary foundation for conducting analyses and simulations of transportation and logistics systems with greater accuracy. At this stage, technology plays a central role, as students are guided to utilize various digital sources and tools to access and obtain the necessary data. Students can gather data from scientific literature, digital maps, traffic monitoring applications such as Google Maps and open-source datasets that provide information on travel routes, estimated travel times, vehicle capacity, and distribution demand patterns. This process not only enhances students’ skills in searching for and selecting relevant data but also familiarizes them with real-world technological practices commonly used in the planning and optimization of modern logistics systems. The details of the learning activities at this stage are presented in Table 3 below.

Table 3. RBL-STEM Learning Activities in Stage Three.

Stage 3	Learning Activities
Data collection: Utilizing technology to support graph modeling	a. The lecturer explains data sources that can be used, such as digital maps, traffic monitoring applications, and open-source datasets related to transportation and logistics. b. Students access and collect relevant data from various digital platforms, such as Google Maps, Waze, and online logistics databases. c. Students record important information, including distances between nodes, travel time, vehicle capacity, and demand distribution patterns, for further analysis in the next stage.

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3.3.4 Stage 4: Data Analysis (Mathematics)

After students gather relevant data from various digital sources, the next phase in the learning process involves data analysis using a mathematical approach. At this stage, students process and evaluate the collected data utilizing statistical methods and graph algorithms. This approach aims to identify key patterns related to transportation and logistics efficiency, such as delays, congestion, or load distribution across routes. Students are introduced to graph algorithms, such as Dijkstra’s algorithm for finding the shortest path or other minimum path algorithms relevant to network optimization. Through these activities, students are trained to apply mathematical logic and computational thinking in formulating systematic analytical steps and drawing conclusions based on the results of modeling and calculations. The details of the activities in this phase are presented in Table 4.

Table 4. RBL-STEM Learning Activities in Stage Four.

Stage 4	**Learning Activities**
Data analysis: Using statistical methods and graph algorithms to determine optimal solutions	a. The lecturer explains the concept of data analysis using graph theory and statistical methods, while introducing relevant algorithms such as Dijkstra's algorithm and minimum spanning tree algorithms. b. Students process the collected data to calculate distances, travel time, and minimum weights between nodes in the distribution network. c. Students apply graph algorithms to determine optimal solutions, such as the fastest route or the most efficient distribution path, and document their analysis results.

3.3.5 Stage 5: Interpretation of Results and Generalization (Engineering)

The next stage in the RBL-STEM learning process is the interpretation of results and generalization, which focuses on the engineering element as a bridge between data analysis and solution design. At this stage, students are required to re-evaluate the mathematical analyses conducted in the previous phase and then interpret the significance of their findings within the real-world context of transportation and logistics systems. This process includes assessing distribution routes, route efficiency, and the impact of logistical decisions on travel time, operational costs, and environmental effects. Students are encouraged to design efficient, applicable, and contextually relevant logistical solutions based on engineering principles that account for various system constraints and variables. The activities in this stage aim to develop students' systematic, solution-oriented, and innovative thinking skills in addressing complex problems. The details of the learning activities at this stage are presented in Table 5.

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Table 5. RBL-STEM Learning Activities in Stage Five.

Stage 5	Learning Activities
Interpretation of results and generalization: designing logistics solutions based on graph analysis results	a. The lecturer provides examples of how graph analysis results can be translated into technical solutions within a logistics system. b. Students interpret graph modeling and analysis results to assess the efficiency of distribution routes, travel time, and resource requirements. c. Students design efficient and applicable logistics solutions by considering cost, time, capacity, and environmental impact based on engineering principles.

3.3.6 Stage 6: Model Presentation and Evaluation (Report)

As the final stage in the RBL-STEM learning process, students enter the presentation and model evaluation phase, which focuses on reporting and communicating their results. In this stage, students are required to discuss the solutions they have developed within their groups, reassess their designs based on feedback from both instructors and peers, and make revisions to refine their models. The final outcomes are presented in visual formats, such as graphs, distribution pathway schematics, or logistic system simulations, accompanied by a narrative explanation detailing the thought process and decision-making rationale. This activity not only assesses students' conceptual and technical understanding but also emphasizes the importance of scientific communication skills, collaborative work, and reflection on the learning process. The details of the learning activities at this stage are presented in Table 6.

Table 6. RBL-STEM Learning Activities in Stage Six.

Stage 6	Learning Activities
Model presentation and evaluation: discussion, revision, and final presentation of logistics solutions	a. Students discuss the logistics solution model they have developed with their group members to receive feedback and improvements. b. Students revise their model based on feedback from lecturers and peers, both in terms of technical and logical aspects. c. Students present the final results in visual forms (graphs, diagrams, optimal route simulations) and narrative explanations that describe the reasoning process and justification for the designed solution.

The following is the assessment framework used as the foundation for developing an instrument to evaluate students' computational thinking skills. The indicators included in this framework are designed to represent learning outcomes directly related to students' ability to apply logical, systematic, and algorithmic thinking processes in problem-solving. This framework not only encompasses cognitive aspects but also includes analytical skills, problem-solving abilities, and reflection on the thinking process. In this study, the computational thinking skills assessment framework, integrated with STEM elements, is systematically presented in Table 7. This

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instrument is designed to measure the extent to which students comprehend fundamental concepts, apply STEM principles, and integrate them into solving contextual and real-world problems, particularly in the fields of transportation and logistics. Consequently, this instrument serves as a crucial tool for assessing the effectiveness of the RBL-STEM learning model in enhancing students' computational thinking skills.

Table 7. Assessment Instrument for Students' Computational Thinking Skills.

Indicator	Sub-Indicator	Description
Problem Decomposition	1. Identifying the main components of the transportation and logistics system. 2. Breaking down complex problems into smaller, more manageable parts. 3. Determining the necessary data for each part of the problem.	1. Identify key aspects of the transportation system, such as distribution points, delivery routes, and travel time. 2. Explain the steps to break down an inefficient distribution system into sub-problems. 3. Provide a list of required data for each sub-problem.
Pattern Recognition	1. Analyzing data or graph representations to identify patterns in routes, travel time, or congestion. 2. Connecting identified patterns to logistics problems.	1. Create a graph or diagram illustrating delay patterns in deliveries across multiple routes. 2. Explain the correlation between traffic congestion and logistics inefficiencies.
Algorithmic Thinking	1. Designing logical step-by-step processes in the form of an algorithm to solve a problem. 2. Applying graph processing algorithms (e.g., Dijkstra's algorithm) to determine the optimal route.	1. Write a step-by-step algorithm to determine the shortest route from point A to point B. 2. Apply Dijkstra's algorithm to the distribution graph that has been constructed and interpret the results.
Generalization and Abstraction	1. Formulating a general model based on the derived solution. 2. Simplifying complex information into a model that can be used for similar cases.	1. Explain how the designed solution can be applied to other regions with similar logistics characteristics. 2. Create an abstract model of a transportation system based on a real-world case and explain its meaning.

4. DISCUSSION

The findings of this study indicate that the integration of Research-Based Learning (RBL), the STEM approach, and graph theory in the teaching of transportation and logistics optimization significantly enhances students' computational thinking skills. This model not only aids students in understanding theoretical concepts but also enables them to apply problem decomposition, pattern recognition, algorithmic thinking, as well as generalization and abstraction skills in real-world contexts. Unlike previous studies that primarily focused on conceptual understanding or technological implementation in the industry [15] [16], this research presents a holistic approach that integrates graph modeling and data analysis into research-based learning processes. By utilizing graph theory, such as Dijkstra's and Floyd-Warshall's algorithms, students can develop optimal solutions for transportation routes based on factors such as time, cost, and resource efficiency.

Furthermore, the use of technologies like Google Maps, Waze, and graph modeling software enables students to conduct real-time data-driven analyses, aligning with the findings of Dare et al. regarding the significance of artificial intelligence and digital technology in logistics optimization [17]. The interpretation and generalization stage demonstrates that students are not only capable of determining optimal solutions but also consider environmental sustainability and economic efficiency in transportation model design. This approach distinguishes this study from previous research [18] [19], which primarily focused on mathematical modeling and individual learning without assessing the effectiveness of teamwork and scientific communication. Through the presentation and model evaluation stages, students not only develop analytical skills but also enhance collaboration and critical thinking in solving data-driven problems.

5. CONCLUSION

This study demonstrates that integrating the Research-Based Learning (RBL) model with the STEM approach and graph theory significantly enhances students' computational thinking skills in solving transportation and logistics optimization problems. Through six systematic learning stages, students not only grasp the fundamental concepts of graph theory and distribution route optimization but also develop essential skills such as problem decomposition, pattern recognition, algorithmic thinking, and generalization and abstraction in real-world problem-solving. The utilization of technology, such as digital maps and graph modeling software, enables students to conduct real-time data-driven analyses and develop more efficient logistics solutions. Furthermore, this study highlights that an interdisciplinary approach connecting science, technology, engineering, and mathematics provides a more contextual and applicable learning experience. Consequently, the integration of RBL-STEM and graph theory not only enhances students' conceptual understanding but also equips them with systematic, logical, and data-driven thinking skills to address real-world logistics challenges. Therefore, this learning model can serve as an innovative strategy in STEM-based education to enhance students' computational thinking skills and their preparedness for technology-driven workplaces.

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