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How the CARE Model Enhances Scientific Literacy: Integrating Problem-Based Learning and Computational Thinking in Health Higher Education

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Abstract

Scientific literacy in health higher education continues to face challenges, particularly students' difficulties in interpreting scientific data, constructing evidence-based arguments, and understanding the scientific mechanisms underlying health-related cases. This condition indicates that problem-based learning is insufficient when limited to presenting authentic cases alone, but also requires the explicit structuring of scientific reasoning processes. Based on this need, this study answers how the CARE Model strengthens scientific literacy by utilizing the characteristics of Problem-Based Learning (PBL) and the principles of Computational Thinking (CT) to develop a more explicit, systematic, and traceable scientific reasoning pathway. The study employed a sequential explanatory intervention design involving 299 students from three health higher education institutions to identify pedagogical challenges, implement and examine the effectiveness of the model, and explain the mechanisms underlying scientific literacy enhancement. Data were analyzed descriptively and inferentially through the mapping of pedagogical challenges, measurement of improvement and effectiveness, and interpretation of the mechanisms strengthening scientific literacy. The findings indicate that the CARE Model produced stronger improvements in scientific literacy than PBL and conventional learning, as reflected in post-test achievement, moderate-to-high N-gain improvement, significant multivariate differences, and Tukey test results confirming the superiority of the CARE Model. The findings further show that scientific literacy enhancement occurs through three pedagogical mechanisms—structured problem framing and scientific reasoning, evidence-based inquiry and interpretation, and algorithmic elaboration and reflective evaluation—which continuously reorganize the scientific reasoning pathway from problem identification to evidence interpretation and science-based solution evaluation more systematically. These findings confirm that the CARE Model offers a more explicit pedagogical framework for enhancing scientific literacy among students in health higher education.

Introduction

The complexity of 21st-century healthcare services requires health professionals not only to master conceptual knowledge, but also to be able to understand, evaluate, and critically apply scientific information in professional practice. The development of evidence-based healthcare has transformed clinical decision-making processes into ones that increasingly depend on the ability to interpret scientific data, evaluate the quality of evidence, and connect empirical information with dynamic and complex health contexts [1], [2]. This shift positions the ability to understand scientific data, develop clinical reasoning, and make evidence-based decisions (evidence-based decision making) as essential capacities that need to be developed among students in health higher education [3]. Modern healthcare practice no longer relies solely on mastery of clinical procedures, but also on the ability to integrate scientific evidence into the process of systematically analyzing and solving health-related problems [4]. The significance of this need makes scientific literacy a core competency for health students because this ability supports the understanding of scientific mechanisms, the evaluation of evidence-based information, and more accurate professional decision-making.

Although scientific literacy is regarded as a fundamental competency in education, various international studies indicate that its development remains a serious challenge, particularly regarding students' ability to understand scientific phenomena, evaluate evidence, and apply scientific knowledge contextually [5], [6]. Findings from the Programme for International Student Assessment (PISA) consistently show that scientific literacy, including in Indonesia, still requires strengthening, particularly in understanding scientific phenomena, evaluating evidence, and using scientific knowledge to solve contextual problems. Similar challenges are also found in health higher education, where students continue to experience difficulties in interpreting scientific data, constructing evidence-based arguments (scientific argumentation), and understanding the scientific mechanisms underlying health-related cases [7], [8]. The complexity of these issues becomes increasingly evident in biochemistry learning, which requires the ability to systematically connect abstract concepts with physiological and clinical contexts [9], [10]. This condition indicates that instructional practices implemented thus far have not yet fully supported the optimal development of scientific literacy in health higher education.

As a response to the need to strengthen problem-solving and scientific reasoning, Problem-Based Learning (PBL) has become a widely adopted approach in health education because it supports authentic case-based learning, collaboration, and clinical decision-making [11], [12]. Nevertheless, the literature indicates that learning processes in PBL often develop openly and therefore do not always provide explicit guidance for students to understand scientific mechanisms, evaluate evidence, and construct data-based arguments [13]. Consequently, the enhancement of scientific literacy tends to develop as an indirect outcome of problem-solving activities [14]. At the same time, Computational Thinking (CT) has increasingly been regarded as relevant in health education because it provides a systematic thinking framework through decomposition, pattern recognition, abstraction, and algorithmic thinking to help students analyze problems, interpret evidence, and formulate data-based decisions more logically [15], [16]. However, the pedagogical connection between PBL characteristics and CT principles to strengthen scientific literacy remains insufficiently explained, particularly regarding how learning processes can explicitly guide students from problem identification toward evidence interpretation and science-based decision-making.

Based on these challenges, this study was proposed to answer how the CARE Model (Clarify the Problem, Analyze the Problem, Research and Investigation, Elaborate Algorithm, and Evaluate) strengthens scientific literacy by utilizing PBL characteristics and CT principles to develop a more explicit, systematic, and traceable scientific reasoning pathway. This study not only examines the impact of CARE implementation on improving scientific literacy, but also explains the pedagogical mechanisms underlying how the model operates within the context of health higher education. To address these instructional practice issues, this study addresses the following questions:

1. What pedagogical challenges hinder the development of scientific literacy among health students?
2. How does the implementation of the CARE Model influence students' scientific literacy in health higher education?
3. How does the CARE Model enhance scientific literacy through its pedagogical mechanisms?

Accordingly, the study focuses on three main areas, beginning with the identification of pedagogical challenges in the development of health students' scientific literacy, followed by the implementation and impact of the CARE Model on scientific literacy, and concluding with an explanation of the pedagogical mechanisms underlying how the CARE Model strengthens students' scientific reasoning in health higher education.

Literature Review

The CARE Model was constructed through the integration of Problem-Based Learning (PBL) and Computational Thinking (CT) as complementary approaches to support problem-solving and scientific reasoning. PBL positions authentic problems as the starting point of learning through investigation, discussion, and problem-solving activities to facilitate the contextual construction of knowledge [17], [18]. In health education, PBL has been widely recognized for strengthening problem-solving skills, academic collaboration, and students' active engagement in addressing professional cases [19], [20]. Nevertheless, reasoning processes in PBL often develop in an open-ended manner, meaning that scientific reasoning structures are not always formed explicitly [13], [14]. To address this limitation, CT offers a systematic thinking framework through decomposition, pattern recognition, abstraction, and algorithmic thinking, enabling complex problems to be broken down into more logical and structured solution pathways [21]. Empirical evidence further suggests that CT contributes to strengthening analytical abilities and systematic reasoning in solving complex problems [15], [16]. Taken together, the complementary characteristics of PBL and CT provide the conceptual foundation for the development of the CARE Model to support more explicit scientific reasoning in health higher education.

Pedagogically, the CARE Model is grounded in a synthesis of constructivist and social-constructivist learning theories, operationalized into each learning syntax and enriched by the characteristics of Problem-Based Learning (PBL) and Computational Thinking (CT). The Clarify the Problem stage is informed by the constructivist perspective, which explains that initial understanding develops through assimilation and accommodation as individuals connect new information with pre-existing cognitive structures [22]. This stage is further reinforced by the principle of learning by doing, which positions contextual experience as the starting point of learning [23], as well as meaningful learning theory, emphasizing the integration of new knowledge with prior understanding [24]. At this stage, the PBL characteristic of authentic problems is incorporated to help students understand health-related issues within real-world contexts. Moving forward, the Analyze the Problem stage focuses on cognitive construction processes aimed at understanding logical relationships among problem components [22], supported by discovery learning that emphasizes gradual exploration of patterns and knowledge organization [25]. This stage also incorporates the CT principle of problem decomposition, enabling students to break down complex problems into simpler components so that scientific causal relationships can be understood more systematically.

Within the Research & Guide Investigation stage, social interaction, collaboration, and scaffolding function as essential mechanisms for knowledge construction through collective inquiry [26], while

meaningful learning theory further strengthens the integration of newly acquired information into existing cognitive structures [24]. This syntax is also enriched by PBL characteristics, particularly inquiry and collaborative learning, to support evidence-based investigation. A major innovation of the CARE Model lies in the Elaborate Algorithm stage, specifically designed to assist students in constructing systematic solution pathways through stepwise representations of reasoning. This stage is reinforced by discovery learning, which emphasizes gradual knowledge organization [25], experiential and reflective learning [23], and the CT principle of algorithmic thinking to establish more logical and systematic reasoning pathways. Finally, the Evaluate stage positions reflection as a central component of learning through assessing the effectiveness of solutions and their relevance to real-world contexts, while also integrating the reflective characteristics of PBL in evaluating problem-solving processes [23]. Through the integration of learning theories, PBL characteristics, and CT principles, the CARE Model is therefore structured to support more explicit and systematic scientific reasoning in strengthening health students' scientific literacy.

Conceptually, integrating the CARE syntax is intended to foster scientific literacy, encompassing the ability to understand scientific phenomena, solve problems, interpret data, communicate scientific information, and evaluate the application of knowledge in real-life contexts [27]. The Clarify the Problem and Analyze the Problem stages contribute to scientific understanding by facilitating problem identification and systematic exploration of causal relationships. Subsequently, the Research & Guide Investigation stage supports the search, evaluation, and communication of scientific evidence through data-based inquiry, whereas Elaborate Algorithm strengthens problem-solving by enabling students to organize solution procedures in a logical and structured manner. Reflection and evaluation are further emphasized in the Evaluate stage, where students assess the effectiveness of solutions and their applicability to authentic situations. Collectively, the interconnection among these stages demonstrates that the CARE Model provides a more explicit structure for scientific reasoning, making it relevant for strengthening scientific literacy in health higher education contexts that require students to understand health phenomena, interpret scientific evidence, and make systematic science-based decisions.

Research Methodology

This study employed a sequential explanatory intervention design to investigate how the CARE Model enhances students' scientific literacy in health higher education through the identification of pedagogical challenges, testing the effectiveness of the intervention, and interpreting the learning mechanisms that explain how CARE enhances scientific literacy. This approach is commonly used in educational research to generate an understanding that focuses not only on intervention effectiveness, but also on learning needs and the pedagogical processes underlying changes in learning outcomes [28]. The study was conducted through three interconnected stages, namely the identification of initial challenges in scientific literacy and biochemistry learning, the implementation of the CARE Model using a quasi-experimental pretest–posttest control group design, and the interpretation of learning mechanisms explaining the improvement of students' scientific literacy. This research structure was used to generate

a more comprehensive understanding of pedagogical needs, the effectiveness of the CARE Model, and the learning processes underlying scientific literacy improvement among health students.

The study involved 299 students in health higher education from three institutions offering health biochemistry courses, particularly on metabolism topics requiring the ability to understand scientific phenomena, connect biochemical mechanisms with clinical contexts, and interpret scientific evidence in solving health-related cases. Students participated in three learning groups consisting of the CARE group, the Problem-Based Learning (PBL) group, and the conventional learning group as a comparison group within the quasi-experimental design. The CARE Model was implemented through five learning syntax phases, namely Clarify the Problem, Analyze the Problem, Research and Investigation, Elaborate Algorithm, and Evaluate, which were designed through the integration of Problem-Based Learning characteristics and Computational Thinking principles, including decomposition, pattern recognition, abstraction, and algorithmic thinking. This integration was directed toward strengthening learning processes that focus not only on exploring authentic problems, but also on developing scientific reasoning more explicitly through the identification of cause-and-effect relationships, the evaluation of scientific evidence, and the organization of more systematic and reflective solution steps for health-related problems.

Data collection covered three main domains aligned with the focus of the research findings, namely students' scientific literacy pedagogical challenges, the effectiveness of the CARE Model, and the pedagogical mechanisms of CARE learning. Data to explain the initial challenges of scientific literacy were obtained through observations of biochemistry learning, evaluation of the limitations of Problem-Based Learning (PBL) implementation, and a literature review of reputable scientific articles regarding the relationship between PBL, Computational Thinking, and scientific literacy in health education to understand pedagogical gaps in the development of students' scientific literacy. Data from model implementation outcomes were collected through learning outcome measurement instruments developed according to the dimensions of scientific literacy proposed by OECD (2023). Meanwhile, data to explain how CARE enhances scientific literacy were obtained through observations of learning syntax implementation (implementation fidelity) using a model implementation observation sheet to identify the consistency of each CARE phase, as well as a literature review to interpret how the integration of PBL characteristics and Computational Thinking principles supports the understanding of scientific phenomena, evidence interpretation, and science-based problem-solving through more explicit, systematic, and reflective reasoning processes.

Data analysis was conducted in stages according to the focus of the research findings. Descriptive analysis was used to identify the initial challenges of students' scientific literacy based on observations of learning processes, evaluation of limitations in PBL implementation, and a literature review regarding pedagogical gaps in developing scientific literacy in health education. The effectiveness of the CARE Model in improving scientific literacy was analyzed through normalized gain (N-gain) calculations to measure the magnitude of learning improvement, followed by assumption testing, multivariate analysis of variance (MANOVA), and Tukey post hoc tests to identify differences in improvement across learning

groups. Meanwhile, analysis regarding how CARE enhances scientific literacy was conducted through descriptive analysis of learning syntax implementation (implementation fidelity), integrated with a literature review to explain how the integration of PBL characteristics and Computational Thinking principles supports the understanding of scientific phenomena, evidence interpretation, and science-based problem-solving in a more explicit, systematic, and reflective manner.

Results and Discussion

Pedagogical Challenges in Developing Scientific Literacy among Health Students

Pedagogical challenges in developing scientific literacy among health students were identified through the synthesis of conceptual and empirical findings within the context of health higher education. Conceptual findings were obtained through a literature review regarding the implementation of Problem-Based Learning (PBL), the development of scientific literacy, and pedagogical challenges in biochemistry learning in health education. Empirical findings were obtained through observations of biochemistry learning, questionnaires and interviews with course instructors, as well as mapping the initial profile of scientific literacy abilities among 299 students in three Nursing Study Programs in health higher education institutions. The synthesis of these two sources of findings was utilized to identify pedagogical challenges in the development of students' scientific literacy while formulating the need for a learning model appropriate to the context of health education. The integration of findings was further used as a foundation for mapping the relationships among pedagogical challenges, which may explain why the implementation of the CARE Model is necessary.

Based on Fig. 1, the development of the CARE Model originated from the synthesis of conceptual and empirical findings to identify pedagogical challenges in the development of students' scientific literacy in health higher education. The literature indicates that Problem-Based Learning (PBL) has developed as a dominant approach in health education because it supports case-based learning, clinical decision-making, and the integration of interdisciplinary knowledge relevant to the professional needs of health students [11], [13]. PBL characteristics enable students to develop conceptual understanding through the exploration of authentic problems in a more contextual and participatory manner [29]. PBL is also considered effective in developing problem-solving abilities and knowledge integration in health education [20], [30]. However, most PBL implementations still focus on general learning outcomes, whereas stages of scientific thinking, such as phenomenon clarification, cause-and-effect analysis, evidence interpretation, and science-based solution evaluation, have not yet been explicitly structured in learning processes [3], [31]. This situation indicates that the development of health students' scientific literacy still requires a clearer pedagogical structure to guide scientific reasoning processes in a gradual and reflective manner.

The need for a pedagogical structure becomes increasingly important when linked to the development of scientific literacy in health education. Studies focusing on the relationship between PBL, scientific

literacy, and biochemistry learning remain relatively limited, although scientific literacy is now understood as a multidimensional competency encompassing critical thinking, evidence-based decision-making, and scientific participation in real-life contexts [32], [33]. Strengthening these competencies requires a learning environment that encourages scientific inquiry, data analysis, evaluation of evidence-based information, and the connection between scientific concepts and authentic contexts [27], [34]. Inquiry-based learning and scientific reflection are considered more effective in helping students construct and evaluate knowledge contextually [35]. Participatory and problem-based approaches are also considered important in strengthening scientific literacy among higher education students [36]. The gap between problem-based learning, scientific literacy, and the context of health biochemistry highlights the need for a more structured learning model to support students' scientific reasoning in health higher education explicitly and continuously.

This conceptual overview was subsequently examined through empirical findings obtained from observations of biochemistry learning, questionnaires and interviews with lecturers, as well as mapping the initial profile of scientific literacy abilities among 299 Nursing Study Program students in three health higher education institutions. Observations showed that biochemistry learning was still dominated by concept delivery and question-and-answer patterns, meaning that students' engagement in scientific inquiry and evidence-based problem exploration had not yet developed optimally. In fact, biochemistry learning in health education requires not only mastery of metabolism concepts, but also the ability to understand biological cause-and-effect relationships, analyze health phenomena, and evaluate scientific information contextually [37], [38]. Learning processes that insufficiently structure scientific inquiry and reasoning may limit the development of deeper and more applicable conceptual understanding [39], [40]. Pedagogical challenges, therefore, are not only related to the complexity of the material, but also to how learning experiences are designed so that students become more actively engaged in scientific thinking processes.

A similar pattern was evident in questionnaire and lecturer interview findings, which showed that the implementation of Problem-Based Learning (PBL) had not yet been fully carried out, particularly in the stages of solution development (37.04%) and problem-solving evaluation (25.93%), followed by learning organization (18.52%) and problem orientation (14.81%). Students' initial scientific literacy profile also showed that the ability to relate scientific concepts to health contexts was at 49%, explaining scientific phenomena at 44%, using scientific evidence at 41%, data interpretation at 36%, and scientific evaluation at 34%. The development of scientific literacy in health education requires learning approaches that strengthen evidence interpretation, scientific information evaluation, and data-based decision-making more explicitly [27]. Problem-based learning will be more effective when accompanied by a pedagogical structure that guides students through problem clarification, scientific inquiry, solution elaboration, and systematic learning reflection [3], [36]. Students' initial profiles and learning implementation patterns indicate that the development of scientific literacy requires a more structured learning model to support scientific reasoning continuously.

CARE Model Implementation and Its Impact on Scientific Literacy

Previous findings indicate that health biochemistry learning still faces challenges in helping students develop systematic scientific reasoning, critically evaluate evidence, and formulate science-based solutions to complex health problems. These limitations indicate that strengthening scientific literacy is insufficient when relying solely on the presentation of contextual problems, but also requires a learning structure capable of guiding students to understand problems, interpret evidence, and reflect on decisions more explicitly. Based on this need, the CARE Model was implemented as an integration of Problem-Based Learning (PBL) and Computational Thinking (CT) principles to strengthen students' scientific reasoning processes through learning stages that are more systematic, evidence-based, and reflective. From this point onward, an explanation is presented regarding the conceptual design of the CARE Model, the implementation of learning syntax at each phase, and its impact on the development of students' scientific literacy based on changes in learning outcomes, the magnitude of improvement, and differences in achievement across learning groups.

Figure 2 presents the conceptual design and syntax of the CARE Model as an integration of Problem-Based Learning (PBL) and Computational Thinking (CT) to strengthen students' scientific literacy in health biochemistry learning. CARE syntax adapts PBL stages into five learning phases reinforced by CT dimensions. Clarify the Problem phase helps students understand phenomena and formulate problem focus through the exploration of authentic problems as the basis for conceptual understanding development [39], reinforced by the CT principle of problem decomposition to break down complex problems into more structured and understandable components [21]. Meanwhile, Analyze the Problem phase helps students connect data, symptoms, and biochemical mechanisms to develop causal reasoning through problem organization [30], reinforced by pattern recognition in CT to identify relational patterns among problem components [41]. Research and Investigation phase emphasizes evidence-based inquiry through searching, interpreting, and using relevant scientific sources to understand problems [20]. Continuing to Elaborate Algorithm, this phase emphasizes solution development through logical and evidence-based reasoning to establish problem-solving pathways [42], reinforced by algorithmic thinking in CT to organize solution steps explicitly and systematically [21]. Finally, Evaluate phase functions to assess the quality of solutions and their relevance to health contexts through reflection on problem-solving outcomes [13], reinforced by CT in encouraging more systematic evaluation of students' thinking strategies and metacognition [41]. The operationalization of CARE syntax is subsequently demonstrated through learning activities at each model phase and the expected developmental outcomes.

Table 1
Operationalization of CARE Syntax and Expected Learning outcomes

CARE Syntax	Core Learning Activities	Instructional Support	Scientific Literacy Focus	Expected Learning Outcomes
Clarify the Problem	Identifying scientific phenomena and defining health-related problems	Contextual cases, modules, and student worksheets	Understanding scientific phenomena	Students identify scientific problems and understand health phenomena contextually
Analyze the Problem	Analyzing biochemical mechanisms and causal relationships	Guided discussion and conceptual materials	Scientific problem solving	Students establish causal relationships and explain health-related problems systematically
Research and Investigation	Exploring scientific sources and interpreting health data	Scientific articles, digital tools, and evidence-based resources	Data interpretation	Students interpret scientific evidence and use relevant information for problem analysis
Elaborate Algorithm	Constructing systematic and data-driven solutions	Worksheets, health data, and collaborative discussion	Data interpretation and scientific communication	Students develop logical and systematic evidence-based solutions
Evaluate	Evaluating solutions and reflecting on learning outcomes	Assessment rubrics and reflective feedback	Scientific evaluation and real-life application	Students evaluate scientific arguments and reflect on health-related applications

Table 1 presents the operationalization of the CARE Model through the interconnection among learning syntax, students' core activities, instructional support, scientific literacy focus, and achievement indicators at each learning phase. Clarify the Problem phase is directed toward helping students understand health phenomena and identify scientific problems contextually as the foundation for developing scientific reasoning. Analyze the Problem phase targets the ability to establish cause-and-effect relationships, connect biochemical concepts with health cases, and explain scientific problems more systematically. Data interpretation and evidence use begin to develop in the Research and Investigation phase when students explore scientific sources and interpret relevant information to support problem analysis, and are further strengthened in Elaborate Algorithm through the integration of evidence into the development of logical and structured solutions. Evaluate phase focuses on the ability to evaluate scientific arguments, reflect on solution quality, and understand the relevance of applying scientific concepts in real-world health contexts. Thus, each CARE syntax not only organizes learning activities but also targets the gradual and integrated development of scientific literacy indicators. The expected outcomes at each syntax phase are subsequently demonstrated through improvements in students' scientific literacy abilities following the implementation of the CARE Model.

Table 2
Pre-test and Post-test scientific literacy scores scross learning groups

Learning Group	N	Mean Pre-test	Mean Post-test	SD Pre-test	SD Post-test
Conventional	99	64.91	78.12	11.86	8.14
PBL	99	65.08	84.01	11.45	6.95
CARE	101	65.22	88.04	11.74	5.26

Table 2 presents changes in scientific literacy abilities among 299 students from three health higher education institutions, in which students were divided into three learning groups, namely CARE (N = 101), PBL (N = 99), and conventional learning (N = 99). In general, the mean pre-test scores across groups were relatively comparable, namely the conventional group (M = 64.91), PBL (M = 65.08), and CARE (M = 65.22), indicating that students' initial scientific literacy abilities tended to be comparable before the intervention was implemented. Following the learning implementation, all groups experienced improvements in post-test scores, with the CARE group showing the highest mean (M = 88.04), followed by PBL (M = 84.01), and conventional learning (M = 78.12), indicating that the integration of Problem-Based Learning and Computational Thinking within the CARE Model has the potential to provide greater reinforcement of students' scientific literacy abilities across various higher education contexts. The decrease in standard deviation at the post-test stage, particularly in the CARE group (SD = 5.26), also indicates more homogeneous learning outcomes after the learning process. The magnitude of improvement in scientific literacy abilities was subsequently analyzed using N-gain across learning groups in each institution.

Table 3
Magnitude of scientific literacy improvement based on N-Gain

Campus	N	N-Gain	Category
Campus A	98	0.651	Moderate
Campus B	111	0.643	Moderate
Campus C	90	0.778	High

Table 3 presents the magnitude of improvement in students' scientific literacy abilities based on N-gain analysis across three health higher education institutions following learning implementation. The results indicate that all campuses experienced improvements in scientific literacy abilities within the moderate to high categories, although with varying levels of improvement. Campus C obtained the highest N-gain score (0.778), which falls into the high category, indicating that the learning implementation exerted a stronger influence on improving students' scientific literacy within this context. Meanwhile, Campus A (0.651) and Campus B (0.643) were categorized as moderate, indicating reasonably strong improvements in scientific literacy abilities, although not as high as Campus C. The number of students at each campus also varied, namely 98 students at Campus A, 111 students at Campus B, and 90

students at Campus C. However, the relatively consistent improvement pattern across all campuses indicates that the CARE Model still demonstrates a tendency to be effective in strengthening students' scientific literacy across different institutional contexts. These findings are further reinforced through MANOVA analysis to identify differences in improvement across learning groups more specifically.

Table 4
Multivariate differences in scientific literacy based on MANOVA

Campus	Approx. F	Pillai's Trace	Num df	Den df	p-value
Campus A	11.613	0.393	4	190	< .001
Campus B	13.310	0.395	4	216	< .001
Campus C	11.520	0.419	4	174	< .001

Table 4 presents the results of MANOVA analysis on students' scientific literacy abilities across three campuses following learning implementation. The results indicate significant multivariate differences at each campus ($p < .001$), suggesting that the implementation of learning models produced different scientific literacy outcomes within each institutional context. Pillai's Trace values indicate a relatively strong effect tendency across all campuses, with Campus C (0.419) showing the highest value compared to Campus B (0.395) and Campus A (0.393), indicating that variations in scientific literacy outcomes resulting from differences in learning models developed more prominently in this implementation context. These findings are consistent with the N-gain results showing the highest improvement in Campus C, while further strengthening the indication that learning effectiveness developed differently across campuses. Differences in outcomes among learning models at each campus were subsequently analyzed more specifically through Tukey post hoc tests.

Table 5
Pairwise differences in scientific literacy based on Tukey Test

Campus	Comp.	Mean Difference	p-value	Interpretation
Campus A	CL	9.311	< .001	CARE significantly higher
	CARE	5.280	.005	CARE significantly higher
	PBL	4.031	.051	Not significant
Campus B	CARE	4.703	.015	CARE significantly higher
	CL	8.757	< .001	CARE significantly higher
	PBL	4.054	.042	Significant difference
Campus C	CARE	14.270	< .001	CARE significantly higher
	CL	16.867	< .001	CARE significantly higher
	PBL	2.600	.573	Not significant

Table 5 presents the results of Tukey post hoc tests on students' scientific literacy abilities to identify differences in achievement across learning groups at each campus. The analysis results show a relatively consistent pattern, in which the CARE group achieved significantly higher outcomes than conventional learning across all campuses ($p < .001$), as well as higher outcomes than the PBL group at Campus A ($p = .005$), Campus B ($p = .015$), and Campus C ($p < .001$). The largest differences were found at Campus C, indicated by the mean differences between CARE and conventional learning of 16.867 and between CARE and PBL of 14.270, suggesting that the effectiveness of the CARE Model developed more strongly within this implementation context. Meanwhile, differences between PBL and conventional learning showed inconsistent results, where the differences were not significant at Campus A ($p = .051$) and Campus C ($p = .573$), but were significant at Campus B ($p = .042$). These findings reinforce the pre-test–post-test, N-gain, and MANOVA results, which generally indicate that the CARE Model provides greater contributions to improving students' scientific literacy abilities than other learning models.

Overall, the findings indicate that the CARE Model provides a stronger contribution to the development of students' scientific literacy abilities than both Problem-Based Learning and conventional learning, as reflected in post-test achievement, N-gain, and significant differences identified through MANOVA and Tukey post hoc analyses. These findings indicate that the strengthening of scientific literacy develops when learning processes are not only oriented toward problem-solving, but also structure scientific reasoning more explicitly and systematically. Clarify the Problem and Analyze the Problem phases support the understanding of scientific phenomena and cause-and-effect relationships, while Research and Investigation and Elaborate Algorithm strengthen the ability to select, interpret, and organize scientific evidence into logical and structured solutions. Evaluate phase subsequently strengthens scientific communication and evaluation abilities through reflection on argument quality and the relevance of solutions within health contexts. These findings indicate that the CARE Model not only strengthens the mastery of health biochemistry concepts, but also supports the development of scientific literacy through more systematic, reflective, and contextual scientific thinking processes.

How CARE Model Enhances Scientific Literacy

Previous findings indicate that the CARE Model consistently produced higher improvements in scientific literacy abilities than Problem-Based Learning (PBL) and conventional learning across three health higher education institutions, as reflected in the pre-test–post-test, N-gain, MANOVA, and Tukey post hoc results. However, these outcomes do not fully explain how learning processes within the CARE Model operate to produce stronger improvements in scientific literacy. Understanding the effectiveness of a learning model requires not only evidence of improved learning outcomes, but also explanations regarding how implementation quality, learning experiences, and student engagement shape the gradual process of ability development. Therefore, the effectiveness of the CARE Model was examined through the consistency of learning syntax implementation (implementation fidelity), model practicality from lecturers' perspectives, and student acceptance throughout the learning process. The synthesis of these findings provides an empirical foundation for explaining how the integration of Problem-Based Learning

characteristics and Computational Thinking principles within the CARE Model supports the development of scientific literacy through more explicit, systematic, and reflective reasoning processes.

Table 6
Synthesis of CARE Model implementation and Acceptance Across

Implementation Dimension	Indicators	Empirical Findings	Pedagogical Interpretation
CARE Syntax Implementation Fidelity	Consistency of CARE syntax implementation across four learning sessions	CARE syntax implementation increased consistently across institutions: Campus A (91%–95%), Campus B (91%–96%), and Campus C (86%–95%), indicating increasingly stable implementation	CARE syntax became progressively internalized across learning sessions, suggesting strong procedural consistency and adaptability across institutional contexts
Lecturer Practicality Response	Ease of use, classroom adjustment, time allocation, instructional device suitability	Lecturers reported very high practicality (92.31%), with strong ratings for ease of use (91.67%), classroom adjustment (91.67%), instructional device suitability (95.83%), and adequate time management (83.33%)	CARE was perceived as systematic, feasible, and realistic for classroom implementation, supporting structured learning processes
Instructional Flexibility	Topic adaptation and adjustment to student needs	Adaptation to topic/material received the highest score (100%), while adjustment to student needs reached 91.67%, indicating strong contextual flexibility	CARE supported adaptive and contextualized learning by allowing instructional activities to align with disciplinary content and student characteristics
Student Learning Response	Ease of use, activity attractiveness, learning relevance, activity flexibility, skill development	Student responses were highly positive (94.14%), with strong scores for ease of use (93.54%), activity attractiveness (92.95%), learning relevance (94.46%), flexibility (93.26%), and skill development (96.49%)	CARE learning activities were perceived as engaging, meaningful, and supportive of active participation and scientific skill development
Learning Goal Attainment	Scientific literacy and creative thinking improvement	Lecturers perceived strong achievement in scientific literacy (95.83%) and creative thinking (91.67%), supported by students' high perception of skill development (96.49%)	CARE supported higher-order scientific reasoning through structured problem framing, inquiry, and reflective evaluation

Table 6 shows that the implementation of the CARE Model across three health higher education institutions was conducted consistently, practically, and positively accepted by both lecturers and

students. The increasing implementation of syntax across four learning sessions indicates that each CARE phase became progressively internalized throughout the learning process. From lecturers' perspectives, CARE was perceived as having a clear and flexible syntax structure while supporting the achievement of learning competencies, particularly scientific literacy and creative thinking. Meanwhile, students demonstrated very positive levels of acceptance, particularly regarding learning relevance, activity flexibility, and skill development, reflecting meaningful and contextual learning experiences. Overall, these findings indicate that the effectiveness of the CARE Model is not only associated with final learning outcomes, but is also supported by implementation quality, flexibility in learning processes, and student engagement throughout instruction. This empirical foundation provides a basis for explaining how learning processes within the CARE Model operate to strengthen scientific literacy among students in health higher education.

Figure 3 visualizes how the CARE Model enhances scientific literacy through the reorganization of problem-based learning processes into three interconnected pedagogical mechanisms. Rather than functioning as separate learning stages, the five CARE syntax phases form a sequence of reasoning processes that gradually shift students from understanding problems toward evidence-based investigation and the development of reflective and traceable solutions. The integration of Problem-Based Learning (PBL) characteristics and Computational Thinking (CT) principles enables each CARE phase to contribute to different dimensions of scientific literacy while remaining complementary to one another. Clarify the Problem and Analyze the Problem phases help students understand scientific phenomena and construct problem structures more systematically, Research and Guide Investigation strengthens the process of evaluating and interpreting scientific evidence, whereas Elaborate Algorithm and Evaluate guide students in developing and reflecting on solutions through more explicit reasoning processes. The interaction among these three mechanisms becomes the foundation for explaining how CARE not only produces improvements in scientific literacy, but also develops scientific reasoning processes in a more structured manner throughout learning.

These implementation conditions indicate that scientific literacy strengthening in CARE begins to develop through structured problem framing and scientific reasoning, which develops from the integration of the Clarify the Problem and Analyze the Problem phases. Syntax implementation across three health higher education institutions demonstrated a consistent pattern of improvement from the beginning to the end of learning, with implementation increasing from approximately 86–91% to 95–96%, indicating that problem clarification and analysis processes became increasingly internalized as implementation frequency increased. This condition indicates that students became progressively more accustomed to understanding health phenomena, clarifying problem contexts, and developing initial assumptions before entering more in-depth investigation stages. From lecturers' perspectives, high perceptions regarding the ease of syntax implementation (91.67%), classroom adjustment (91.67%), and instructional device suitability (95.83%) indicate that the early CARE phases were perceived as having clear, systematic, and easily operationalized structures within health learning contexts. These findings are reinforced by students' perceptions regarding ease of learning use (93.54%), activity attractiveness (92.95%), and learning relevance to life and health fields (94.46%), indicating that activities involving

phenomenon clarification and problem analysis were understood as contextual, engaging, and meaningful learning experiences.

Furthermore, consistency of implementation and high levels of acceptance toward the Clarify the Problem and Analyze the Problem phases indicate that students not only followed learning procedures, but also began to develop more systematic ways of thinking in understanding health-related problems. The perspective of Computational Thinking explains that scientific problem-solving requires problem decomposition and pattern recognition so that complex phenomena can be understood through more organized problem structures [43], [44]. In problem-based learning, the clarification phase plays an important role in helping students identify the core of problems and establish initial conceptual relationships before entering the investigation stage [29], [45]. However, in Problem-Based Learning practice, clarification processes often develop openly, meaning that the quality of reasoning is strongly influenced by students' initial abilities to select information and organize problems [46], [47], [48]. From this point, the CARE Model moves further through the integration of Clarify the Problem and Analyze the Problem, which not only helps students recognize problems, but also trace relational patterns, causes, and scientific mechanisms underlying health phenomena more explicitly. Therefore, understanding of phenomena does not stop at problem identification, but develops into the foundation of scientific reasoning that supports the dimensions of explaining scientific phenomena and problem-solving. This conceptual foundation subsequently becomes an important basis when students enter evidence-based investigation processes in the following stage.

At the following stage, scientific literacy strengthening develops through evidence-based inquiry and interpretation, which emerges through the implementation of the Research and Guide Investigation phase. The continuously increasing implementation of CARE syntax across three health higher education institutions indicates that investigation processes became increasingly internalized through repeated learning practices, meaning that students were not only directed to search for information, but also engaged in case-based inquiry through the exploration of scientific sources, evidence collection, and data interpretation relevant to health contexts. This process became a space for students to examine the initial assumptions developed during problem clarification and analysis before moving toward solution development in the subsequent stage. From lecturers' perspectives, high perceptions regarding implementation flexibility, particularly in topic or material adaptation (100%) and adjustment to students' needs (91.67%), indicate that the CARE investigation phase was able to accommodate diverse learning contexts while supporting more contextual inquiry processes. At the same time, aspects related to time allocation suitability and time efficiency (both 83.33%) indicate that investigation processes within CARE require sufficient discussion space so that students can explore cases more deeply. These findings are reinforced by students' perceptions regarding activity attractiveness (92.95%), learning flexibility (93.26%), and learning relevance to real-life situations (94.46%), indicating that investigation activities were perceived as engaging, adaptive, and closely connected to the health contexts encountered by students.

High student engagement during the investigation phase indicates that learning within CARE moves beyond merely understanding problems toward the development of evidence-based understanding through deeper inquiry processes. The perspective of scientific inquiry explains that scientific literacy develops when students are provided opportunities to evaluate information quality, interpret evidence, and connect data with scientific explanations before constructing conclusions or solutions [49], [50], [51]. In Problem-Based Learning, investigation indeed helps students connect empirical data with scientific concepts, but the direction of evidence-seeking often develops unevenly because students are required to independently determine the quality and relevance of the information used [20], [52]. At this point, the Research and Guide Investigation phase in CARE plays a more strategic role. Students are not only involved in collecting information, but are also guided to evaluate source validity, interpret data, and construct evidence-based arguments more systematically. This phase becomes an important bridge between problem framing processes in the initial phase and solution development in the final stage, because without adequate evidence interpretation, problems are easily understood through assumptions and resulting decisions lose their empirical foundation. This process strengthens the dimensions of data interpretation and scientific communication, while simultaneously preparing students to develop more logical and accountable solutions in the following stage.

At the final stage, scientific literacy strengthening develops through algorithmic elaboration and reflective evaluation, which emerges from the integration of the Elaborate Algorithm and Evaluate phases. The consistently increasing implementation of CARE syntax across three health higher education institutions indicates that students became progressively more capable of following solution elaboration and learning evaluation stages more systematically through repeated model implementation. This condition indicates that students not only generated solutions to health-related problems, but also began to organize problem-solving steps in more structured, logical, and explainable ways before evaluating the relevance and appropriateness of the resulting solutions. From lecturers' perspectives, high perceptions regarding learning goal attainment, particularly in improving scientific literacy (95.83%) and creative thinking (91.67%), indicate that elaboration and evaluation phases were perceived as effective in supporting the achievement of core learning competencies. These findings are reinforced by students' perceptions regarding skill development, which received the highest score (96.49%), indicating that students directly experienced the benefits of CARE in developing systematic, reflective, and evidence-based thinking abilities within health contexts.

The strengthening of abilities at this stage indicates that learning within the CARE Model does not stop at evidence-based investigation, but moves toward more explicit solution development and evaluation processes through traceable reasoning. The perspective of Computational Thinking explains that solving complex problems requires algorithmic thinking to organize solution steps in logical, systematic, and replicable ways [15], [16]. In problem-based learning, reflection on solutions helps students evaluate argument validity and the effectiveness of decisions made [11], [53]. Nevertheless, Problem-Based Learning generally does not provide explicit stages that help students organize solution pathways systematically before conducting evaluations. In this regard, the presence of the Elaborate Algorithm phase in the CARE Model provides a clear distinction because students are guided to organize solution

steps logically, examine relationships among decisions, and trace the scientific reasoning underlying selected solutions before entering the Evaluate phase. As a result, scientific reasoning does not merely emerge as an outcome of discussion, but develops as a process that becomes more traceable and consciously reflected upon. This experience strengthens the dimensions of scientific evaluation and scientific communication, while simultaneously complementing the development of the five dimensions of scientific literacy that progressively emerge through the interaction of the three mechanisms within the CARE Model.

Based on these findings, how the CARE Model enhances scientific literacy can be explained through the way this model reorganizes problem-based learning processes into more explicit, gradual, and traceable scientific reasoning throughout learning. Scientific literacy strengthening begins when students are guided to understand health phenomena and frame problems more systematically through structured problem framing and scientific reasoning, meaning that problems are not only recognized, but also broken down into cause-and-effect relationships and initial scientific explanations. This process subsequently moves toward evidence-based inquiry and interpretation, in which initial assumptions developed in the previous stage are examined through the exploration of scientific sources, evaluation of information validity, and interpretation of evidence relevant to health contexts. At the final stage, algorithmic elaboration and reflective evaluation help students organize solutions logically, trace the scientific reasoning underlying decisions made, and reflectively evaluate solution appropriateness based on evidence. Through this pattern, the CARE Model does not merely adopt the characteristics of Problem-Based Learning, but extends them through the integration of Computational Thinking principles, making scientific reasoning processes more structured and traceable. The interaction among these three mechanisms enables the development of various dimensions of scientific literacy—ranging from explaining scientific phenomena, problem-solving, data interpretation, scientific communication, to scientific evaluation—more progressively throughout the learning process.

Conclusion

This study demonstrates that the CARE Model is more effective in improving scientific literacy among health higher education students than Problem-Based Learning (PBL) and conventional learning, as reflected in improvements in learning outcomes, N-gain, and differences in achievement across learning groups. This effectiveness develops because CARE does not merely facilitate problem-solving, but reorganizes problem-based learning processes through the integration of Computational Thinking principles, allowing scientific reasoning to develop in more explicit, systematic, and traceable ways. Scientific literacy strengthening develops through three complementary pedagogical mechanisms, namely structured problem framing and scientific reasoning, which help students understand health phenomena and establish cause-and-effect relationships more systematically; evidence-based inquiry and interpretation, which strengthen the ability to evaluate and interpret scientific evidence contextually; and algorithmic elaboration and reflective evaluation, which encourage students to develop and reflect upon solutions grounded in scientific logic. Unlike conventional PBL, which tends to allow reasoning processes to develop more openly, CARE provides a learning structure that explicitly guides students

from problem identification toward evidence interpretation and solution evaluation more systematically. These findings confirm that the integration of Problem-Based Learning and Computational Thinking within the CARE Model not only strengthens multiple dimensions of scientific literacy, but also offers a more adaptive pedagogical framework to support evidence-based learning and scientific decision-making in health higher education.

Declarations

Institutional Review Board Statement

This study was approved by the **Health Research Ethics Committee (HREC)/*Komisi Etik Penelitian Kesehatan (KEPK), Universitas Muhammadiyah PKU (UMPKU)* Surakarta, under Ethical Clearance No. 477B/LPPM/UMPKU/IX/2025**. All research procedures were conducted in accordance with the applicable ethical standards and institutional regulations governing research involving human participants.

Informed Consent Statement

Informed consent was obtained from all participants prior to data collection. Participation in the study was voluntary, and all participants were informed about the purpose, procedures, potential benefits, and their rights as research participants. Participant anonymity and confidentiality were maintained throughout the study.

Conflicts of Interest

The authors declare that there are no actual or potential conflicts of interest regarding the conduct of this research or the publication of this manuscript.

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Author Contribution

Septi Aprilia (SA) contributed to conceptualization, methodology, investigation, data curation, formal analysis, visualization, writing – original draft, and project administration. Sentot Budi Rahardjo (SBR) contributed to methodology, validation, formal analysis, and writing – review and editing. Sulistyo Saputro (SS) contributed to supervision, conceptualization, methodology, validation, resources, and

writing – review and editing. Weni Hastuti (WH) contributed to investigation, validation, data interpretation, and writing – review and editing.

Data Availability

The data supporting the findings of this study include data used to evaluate the implementation and effectiveness of the CARE learning model in enhancing students' scientific literacy. These data are available from the corresponding author, Septi Aprilia, upon reasonable request. Access to the data will be considered in accordance with the purpose of the request, applicable research ethics requirements, participant privacy protection, and relevant institutional policies.

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Figures

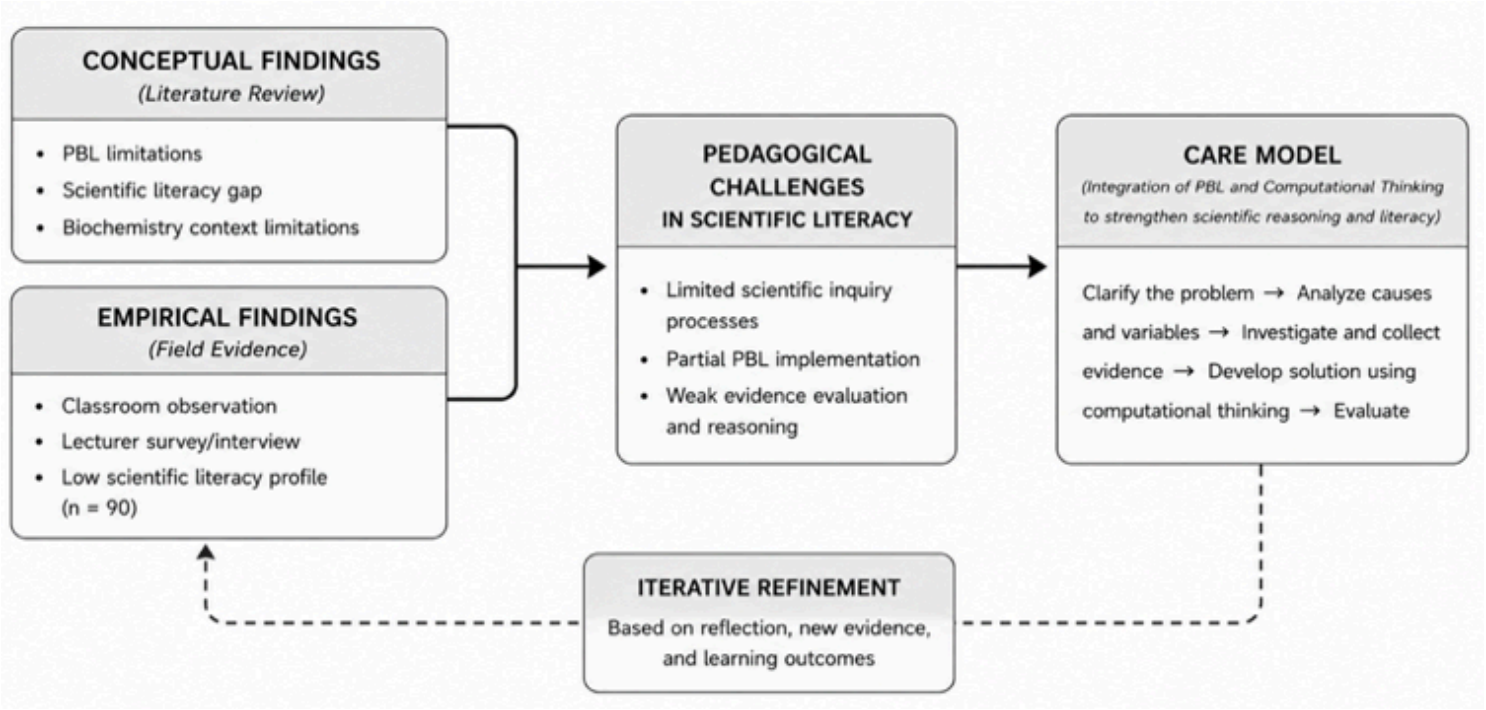


Figure 1

Pedagogical challenges underpinning the development of the CARE Model

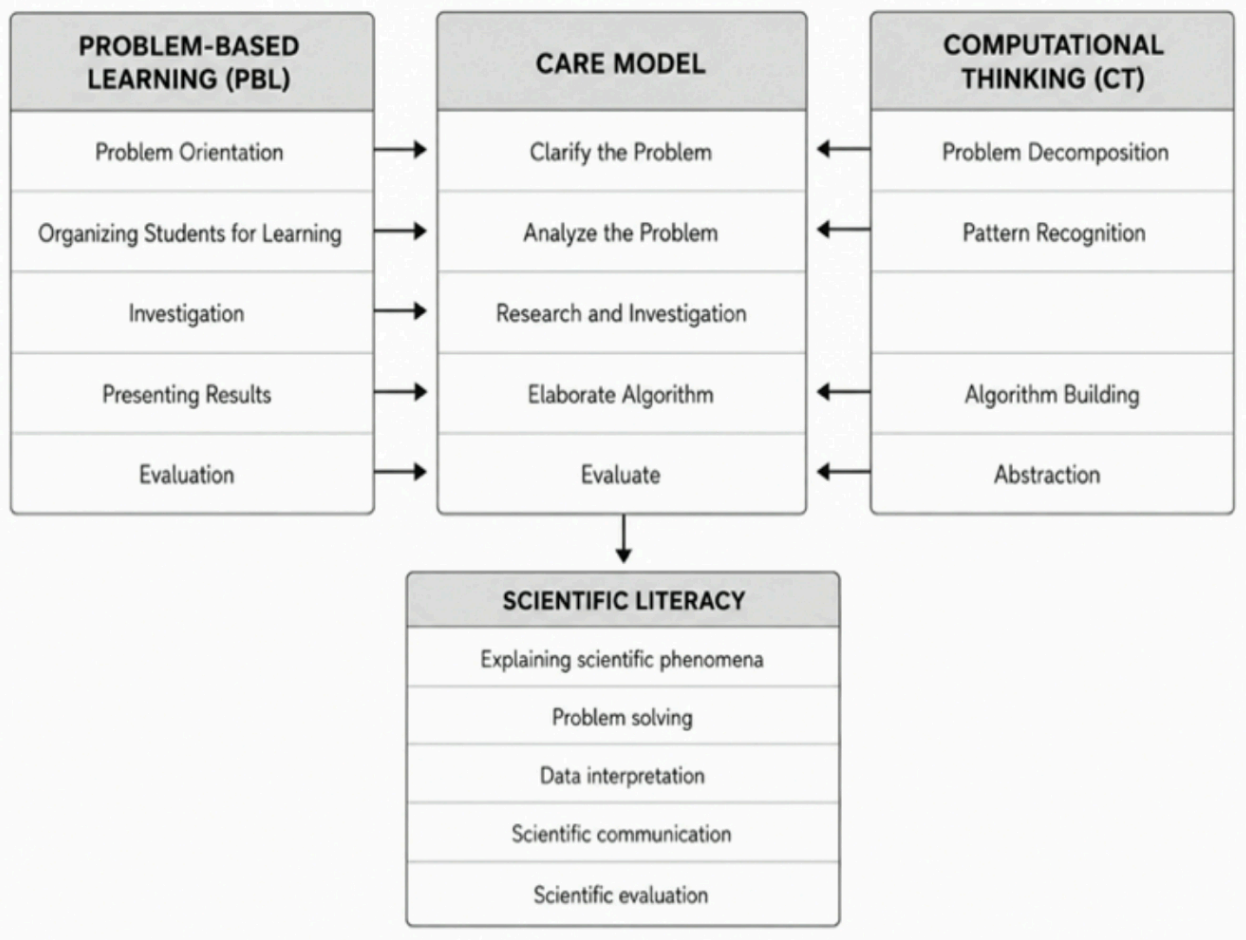


Figure 2

CARE Model framework for scientific literacy development

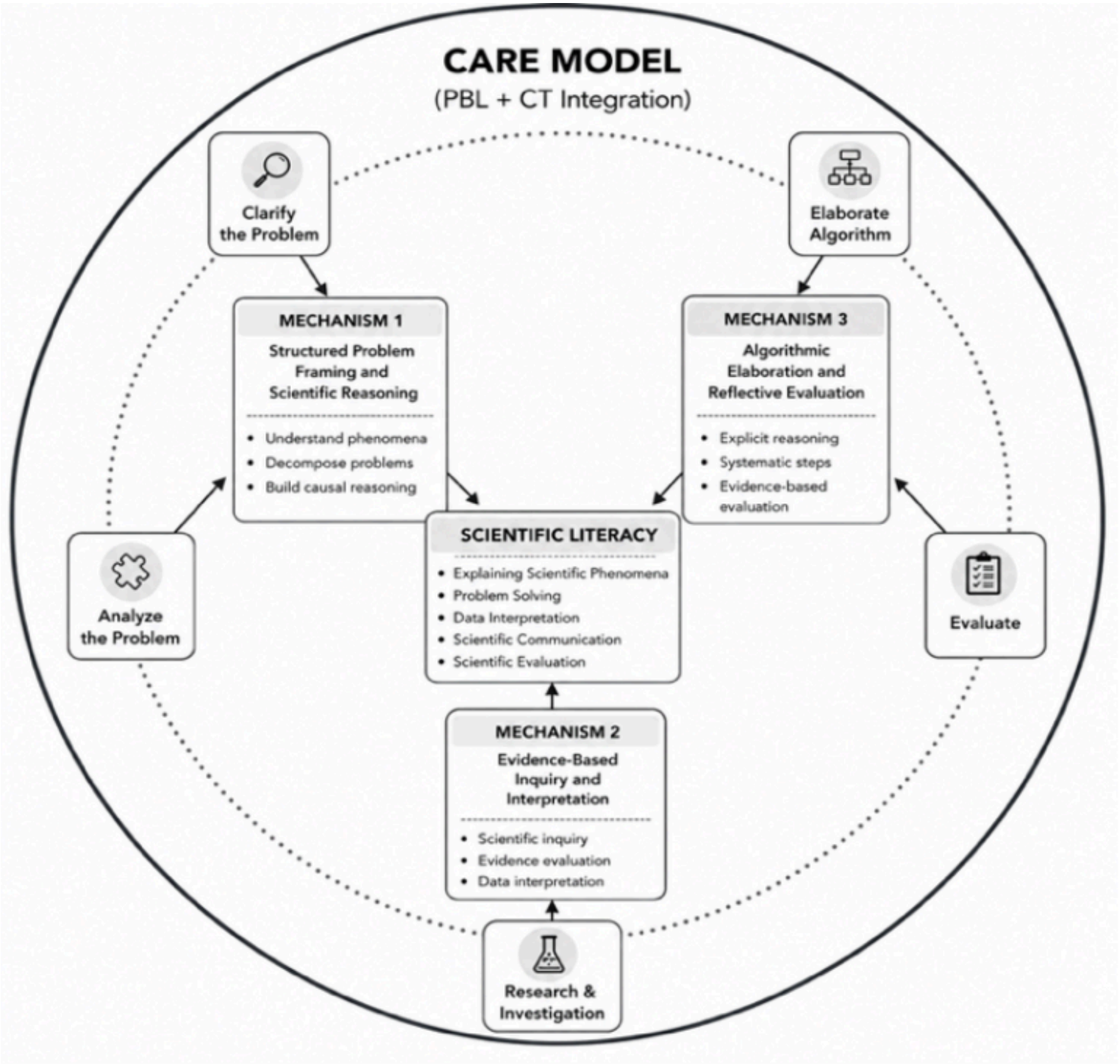


Figure 3

How the CARE Model enhances scientific literacy