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A socio-cognitive conflict-integrated challenge-based learning model to improve scientific argumentation skills and scientific literacy

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ABSTRACT

This study aims to develop a prototype of the socio-cognitive conflict-integrated challenge-based learning model (SCC-ICBLM) to improve high school students' scientific argumentation skills and scientific literacy. The research design used an early-stage research and development approach (analysis, design, and development). Data were collected through curriculum document analysis, student and teacher questionnaires, and expert validation. The student questionnaire measured perceptions of learning, barriers and needs, conceptual understanding, scientific argumentation skills, scientific literacy, learning styles, and collaborative participation, while the teacher questionnaire covered learning contexts and learning tasks. The analysis showed that although students' perceptions of chemistry learning were high, their scientific argumentation skills and scientific literacy remained at a moderate level. In contrast, collaborative participation and readiness for learning contexts were high. Expert validation indicated that the SCC-ICBLM prototype was theoretically and pedagogically valid. This study contributes to pedagogical research by conceptualizing socio-cognitive conflict as a core, intentional mechanism in challenge-based learning, rather than as a peripheral discussion strategy. These findings provide an empirical basis for further research to test the model's effectiveness in real classroom contexts.

Keywords: challenge-based learning, chemistry education, scientific argumentation skills, scientific literacy, socio-cognitive conflict

INTRODUCTION

Although various studies have shown that challenge-based learning is effective in increasing motivation, learning engagement, and scientific literacy through contextual problem-solving (Rådberg et al., 2020; Suwono et al., 2019), this model generally focuses on the process of exploring challenges and developing final solutions, with relatively limited emphasis on the internal learning mechanisms that foster the systematic formation of scientific argumentation (Tian & Osman, 2025). In many implementations, student discussion and collaboration appear as supporting activities, but have not been explicitly designed to stimulate productive conflict of views as a means of developing scientific reasoning. As a result, the potential of challenge-based learning in developing scientific argumentation skills—particularly the ability to construct claims, use evidence, and conduct scientific justification—has not been optimally utilized.

On the other hand, the socio-cognitive conflict strategy has long been recognized as an effective approach to fostering cognitive development by constructively managing conflicting perspectives (Alt & Kapshuk, 2023; Butera et al., 2019; Roselli et al., 2022). Socio-cognitive conflict enables students to recognize the limitations of their understanding, compare different perspectives, and reconstruct knowledge through evidence-based argumentative dialogue (Long et al., 2018a, 2018b). However, in science education practice, this strategy is often implemented separately as a discussion technique or micro-intervention, without an integrated and sustainable learning framework. This results in incidental conflicts that do arise and are not always directed toward achieving the goals of strengthening scientific argumentation and scientific literacy.

Furthermore, most previous research on challenge-based learning and socio-cognitive conflict has focused on higher education or pre-service teacher education contexts (Galdames-Calderón et al., 2024; Georgiou et al., 2025; Huesca et al., 2024). These contexts have significantly different student characteristics compared to secondary school students, both in terms of cognitive readiness, self-regulation, and experience in scientific argumentation. At the high school level, students are at a developmental stage where abstract thinking skills are beginning to develop (Gero et al., 2021; Long et al., 2018b; Shekh-Abed et al., 2021). However, they still require explicit pedagogical scaffolding to manage disagreements, critically evaluate evidence, and connect scientific concepts to complex social issues (Ariely & Yarden, 2025; Zummo, 2022). Therefore, the implementation of learning models that do not account for these developmental characteristics may be less effective.

Based on these conditions, a learning model is needed that not only places contextual challenges as learning triggers but also consciously and systematically integrates socio-cognitive conflict as a core learning mechanism. The socio-cognitive conflict-integrated challenge-based learning model (SCC-ICBLM)was developed to fill this gap by combining challenge-based learning cycles and socio-cognitive conflict strategies within a coherent pedagogical framework. Conceptually, the SCC-ICBLM positions socio-cognitive conflict not as a side effect of social interactions, but as a pedagogical strategy intentionally designed to stimulate scientific argumentation and scientific literacy.

Pedagogically, the SCC-ICBLM is designed explicitly for chemistry learning in secondary schools, considering the demands of the independent curriculum and the development of 21st century competencies. Each learning stage—from orientation to real-world challenges, information exploration, negotiation and argumentation, to reflection and product dissemination—is designed to facilitate students' cognitive, social, and metacognitive engagement. Thus, the SCC-ICBLM offers a conceptually and pedagogically distinct learning approach from existing models, while providing a more appropriate framework for developing scientific argumentation skills and scientific literacy at the secondary school level.

Despite extensive research on challenge-based learning and socio-cognitive conflict, few studies have systematically integrated socio-cognitive conflict as a core pedagogical mechanism within a challenge-based learning framework, particularly at the secondary school level. Furthermore, few studies have grounded this integration in an explicit design and development process informed by empirical needs analysis and expert validation. Therefore, this study aims to develop a theoretically and pedagogically valid SCC-ICBLM prototype as a foundation for developing innovative learning models at the secondary school level. The development of this prototype focuses on designing learning syntax, social interaction principles, and pedagogical mechanisms that explicitly integrate contextual challenges with socio-cognitive conflicts as the main triggers of meaningful learning. By developing a validated prototype, this study is expected to provide a systematic conceptual and pedagogical framework to improve students' scientific argumentation skills and scientific literacy, particularly in chemistry learning. In addition, this SCC-ICBLM prototype is designed to meet the demands of the independent curriculum and the development of 21st century competencies, thereby serving as a basis for further research and for implementing sustainable learning in secondary schools.

METHOD

Research Design

This study uses a research and development (R&D) approach with the analysis, design, development, implementation, and evaluation (ADDIE) model. However, this study focuses on three initial stages: analysis, design, and development, which aim to produce a prototype of the SCC-ICBLM that is theoretically and pedagogically valid. Prototype validity in this study is not interpreted as the effectiveness of implementation in the classroom, but rather as the conceptual and pedagogical feasibility of the model developed based on empirical data and expert validation.

Participants

This study involved high school chemistry students and teachers in Bali Province. A total of 594 students participated in a questionnaire to obtain data on learning needs, student characteristics, and initial profiles of scientific argumentation skills and scientific literacy. Additionally, 33 chemistry teachers were involved to provide information on the learning context, classroom conditions, availability of facilities and infrastructure, and challenges in implementing innovative learning models. Participants were selected using a multistage random sampling technique to ensure representativeness of the school context.

Research Procedures

Analysis stage

The analysis stage of this research was conducted to obtain a strong theoretical and empirical foundation for developing the SCC-ICBLM. The first analysis focused on the curriculum, specifically chemistry learning outcomes in phases E-F of the independent curriculum, to identify core competencies, essential materials, and process skills relevant to the development of scientific argumentation skills and scientific literacy. Next, a learning needs analysis was conducted using a questionnaire to explore students' levels of mastery in scientific argumentation skills and scientific literacy, the obstacles they faced, and their expectations for the learning model. The following analysis focused on student characteristics, including learning styles, participation in discussions, and their tendencies to deal with cognitive conflict. Furthermore, a learning context analysis was conducted with chemistry teachers to review classroom conditions, infrastructure readiness, and school policy support for the implementation of innovative learning. Finally, an analysis of chemistry competencies and tasks was conducted to formulate contextual, challenging, and stimulating socio-cognitive conflict learning activities. The results of all these analysis stages served as the primary basis for designing a model prototype that meets the actual needs of students and teachers in the field.

Design stage

The results of the analysis stage were used to design the SCC-ICBLM prototype. The prototype model was designed by combining the principles of the challenge-based learning model with the socio-cognitive conflict strategy, emphasizing the exploration of contextual issues, argumentative discussions, and evidence-based reflection.

Table 1. Needs analysis questionnaire blueprint for teachers

No	Aspects	Dimensions	Number of items
1	Learning context analysis	The physical environment and infrastructure facilities	5
		Policy and organizational support	5
		School culture and social environment	6
		Teacher readiness	6
2	Chemistry competency analysis and assignments	Students' chemical competencies	8
		Chemistry assignments	8
		Competency and task relevance analysis for SCC-ICBLM	4
Total number of statement items			42

Table 2. Needs analysis questionnaire blueprint for teachers

No	Aspects	Dimensions	Number of items
1	Learning needs analysis	Perceptions of chemistry learning	4
		Learning barriers and needs	5
		Expectations for chemistry learning	10
2	Analysis of student characteristics	Understanding of chemical concepts	6
		Learning style	4
		Scientific argumentation skills	5
		Scientific literacy	7
		Active participation in groups	5
Total number of statement items			46

Development stage

The expert validation stage was conducted to ensure the feasibility and quality of the SCC-ICBLM prototype before further implementation. The prototype was validated by three experts from educational psychology, pedagogy, and educational technology. The experts were asked to assess the prototype using a Likert-scale validation instrument and provide qualitative feedback, which the researchers used to make revisions. This validation process is a crucial step in ensuring that the developed model is not only theoretically valid but also suitable for practical use in high school chemistry learning.

Research Instruments

The research instruments in this study consisted of document analysis guidelines, student and teacher questionnaires, and an expert validation rubric. The document analysis guidelines were used as a systematic reference to record the findings from the review of phase E and phase F high school chemistry curriculum documents, specifically learning outcomes, essential materials, and process skills relevant to the development of scientific argumentation skills and scientific literacy. The main quantitative instrument in this study was a questionnaire, developed to collect empirical data as a basis for designing and validating the SCC-ICBLM prototype. The questionnaire was constructed using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree) and was administered to students and teachers. The teacher questionnaire focused on the analysis of the learning context and the analysis of chemistry competencies and tasks, which included the constructs of the physical environment and infrastructure facilities, policy and organizational support, school culture and social environment, teacher readiness, and the analysis of chemistry competencies and tasks, which included students' chemical competencies, chemistry assignments, and competency and task relevance analysis for SCC-ICBLM (**Table 1**).

A student questionnaire was designed to measure student learning needs and characteristics relevant to the development of the SCC-ICBLM. This instrument encompasses two main aspects: a learning needs analysis, which includes the constructs of perceptions of chemistry learning, learning barriers and needs, and expectations for chemistry learning, and an analysis of student characteristics, which includes the constructs of understanding of chemical concepts, learning style, scientific argumentation skills, scientific literacy, and active participation in groups (**Table 2**).

The questionnaire development was conducted through several stages, including a literature review to identify indicators for each construct, the development of an instrument grid, the formulation of statement items, and adjustments to the context of chemistry learning in secondary schools. The instrument's content validity was ensured through theoretical validation by experts in educational evaluation, research methodology, chemistry education, and language. Each questionnaire, for both teachers and students, was reviewed by three experts to assess the suitability of the indicators to the construct being measured, the clarity of the wording, and the instrument's readability. The expert review results indicated that all statement items met the criteria for theoretical validity and adequately represented the construct being measured.

The instrument's reliability in this study was assessed using a theoretical approach that emphasized conceptual consistency among items within each construct. Reliability considerations were made by examining the uniformity of meaning, response direction, and internal coherence between statements within a construct, and were reinforced through expert input. This approach was used to ensure that each construct was measured consistently and stably, as a basis for mapping students' needs and characteristics in the development of the SCC-ICBLM prototype. Therefore, instrument reliability is interpreted as theoretical consistency.

The questionnaire, specifically designed to assess cognitive constructs (understanding of chemical concepts, scientific argumentation skills, and scientific literacy), was administered during the analysis phase of the ADDIE model, prior to the design

Table 3. The rubric blueprint for assessing the model of SCC-ICBLM is reviewed from the perspective of educational pedagogy, psychology, and educational technology

No	Aspects	Dimensions	Number of items
1	Educational psychology	Theoretical integration	3
		Cognitive and critical thinking	3
		Affective and motivational	3
		Social and collaboration	3
		Creativity and innovation	3
		Metacognition and reflection	3
		Social and contextual contributions	3
2	Pedagogy	Conceptual clarity	3
		Learning syntax	3
		Implementation	3
		Pedagogical principles	3
		Evaluation and reflection	3
		Instructional impact	3
3	Educational technology	Instructional design appropriateness	3
		Utilization of technology	3
		Accessibility and inclusivity	3
		Interactivity and engagement	3
		Evaluation and feedback	3
		Sustainability and scalability	3
Total number of statement items			57

of the SCC-ICBLM prototype. The data obtained were used to map students' initial conditions, identify their cognitive strengths and weaknesses, and determine the pedagogical needs to be accommodated in the model design.

In addition to the questionnaire, an expert validation instrument was used to assess the feasibility of the SCC-ICBLM prototype from the perspectives of educational psychology, pedagogy, and educational technology. This validation rubric included 57 items distributed across three main aspects (**Table 3**). Each rubric was theoretically validated by three experts in psychology, pedagogy, and educational technology and was used to assess conceptual clarity, syntactic coherence, pedagogical principles, and learning technology support.

Data Analysis Techniques

The data analysis in this study used both qualitative and quantitative methods to provide a comprehensive picture of the prototype's needs and feasibility. Qualitatively, data from the curriculum analysis were analyzed descriptively to identify patterns, constraints, and relevant inputs for the creation of the SCC-ICBLM prototype. Meanwhile, the questionnaire data were analyzed using the mean (M) and standard deviation (SD). The results were converted into categories: 1.00-1.80: very bad/very low/very invalid, 1.81-2.60: bad/low/invalid, 2.61-3.40: good enough/high enough/valid enough, 3.40-4.20: good/high/valid, and 4.21-5.00: very good/very high/very valid.

RESULTS

Results of the Analysis Stage

Analysis of high school chemistry curriculum

The curriculum analysis was conducted by reviewing the learning outcomes documents for chemistry, phase E (grade 10) and phase F (grade 11-grade 12) in the independent curriculum. This analysis aimed to map core competencies, essential materials, and process skills relevant to the development of SCC-ICBLM, which is oriented towards improving students' scientific argumentation skills and scientific literacy.

Conformity with research objectives

Based on the chemistry learning outcomes, both phases (E and F) include elements of chemical understanding and process skills that directly support the strengthening of scientific argumentation skills and scientific literacy. These competencies include understanding chemical concepts in real-life contexts, skills in applying scientific methods, conducting data analysis, evaluating critically, and communicating scientifically using evidence-based arguments. All of these elements align with the principles of the challenge-based learning model, which prioritizes contextual problem-solving, and with the socio-cognitive conflict strategy, which emphasizes social interaction through constructive differences of opinion.

Results of competency, material, and skills mapping

An analysis of the chemistry curriculum yielded several important findings, as follows:

1. Phase E emphasizes the introduction and application of basic chemical concepts (basic chemical laws, atomic structure, chemical reactions, and global environmental phenomena) and the mastery of the initial steps of the scientific process, such as observing, questioning, planning investigations, and communicating results.

Table 4. Results of the analysis of perceptions of chemistry learning

Statements	Responses	
	M	SD
The chemistry material I am learning is relevant to everyday life.	3.94	1.03
My teachers often relate chemistry topics to real-life problems around me.	4.26	0.93
I find chemistry lessons in class quite challenging and motivating.	4.05	0.84
My chemistry lessons help me understand how to solve problems.	3.89	0.94
Average total	4.04	0.94

Table 5. Results of the analysis of learning barriers and needs

Statements	Responses	
	M	SD
I often struggle to understand abstract chemistry concepts.	3.69	1.06
The school's laboratory facilities are adequate for chemistry experiments.	3.58	0.94
I have sufficient access to digital chemistry learning resources.	3.45	0.89
I need more hands-on activities to understand the concepts.	3.79	1.01
I need project-based/challenge-based/design-thinking guidance or modules.	3.63	0.97
Average total	3.63	0.97

2. Phase F focuses on deepening concepts and their application in advanced materials (reaction rates, equilibrium, acids and bases, thermochemistry, electrochemistry, and organic chemistry), as well as on more complex process skills such as formulating testable hypotheses, selecting appropriate research methods, analyzing data using various approaches, and evaluating and refining methods.
3. This mapping reveals that both phases have high potential to integrate contextual challenge activities in the challenge-based learning model and the socio-cognitive conflict strategy that facilitates scientific debate, meaning negotiation, and critical reflection.

Potential for integration into SCC-ICBLM

Based on the analysis of the high school chemistry curriculum, several integration opportunities have been identified as follows.

1. **Contextual challenges:** Real-world issues such as global warming, waste management, alternative energy, and materials innovation can be presented as authentic problems to be solved through student collaborative work.
2. **Socio-cognitive conflict:** Differences in data interpretation, method choice, or the determination of the best solution can spark argumentative discussions that strengthen scientific argumentation skills—for example, a debate over nanomaterial technology versus conventional technology in environmental mitigation.
3. **Strengthening scientific argumentation skills and scientific literacy:** Designed learning activities enable students to construct claims, support them with evidence, test the consistency of arguments, and connect chemical concepts to social, economic, and environmental implications.

Relationship with graduate profile dimensions

Competencies in chemistry learning outcomes support critical reasoning, creativity, collaboration, independence, and communication. The implementation of SCC-ICBLM strengthens these dimensions through learning activities that require students to think critically in solving real-world problems, be creative in designing solutions, collaborate in group discussions, be open to differing perspectives, and be responsible for the results of their scientific work.

In summary, analysis of the high school chemistry curriculum in phase E and phase F indicates that learning outcomes support the development of scientific argumentation skills and scientific literacy. Phase E focuses on mastery of basic concepts and early process skills, while phase F emphasizes the analysis, evaluation, and application of chemical concepts in social and environmental contexts. This trend indicates a shift toward higher-order reasoning and provides space for evidence-based discussion and collaboration. Overall, the structure of the high school chemistry curriculum aligns with the development of socio-cognitive challenge- and conflict-based learning, which serves as the basis for the SCC-ICBLM.

Analysis of learning needs

A learning needs analysis is the next important analysis to be carried out to identify learning needs to support the creation of the SCC-ICBLM prototype. The results of this learning needs analysis are shown in tables.

The results of the analysis of students' perceptions of chemistry learning (**Table 4**) showed a positive trend, with an overall average score of 4.04 (SD = 0.94), indicating a high level of learning. The statement with the highest score was the connection between chemistry learning and real-life problems (M = 4.26; SD = 0.93), followed by the perception that chemistry learning is challenging and motivating (M = 4.05; SD = 0.84). These findings indicate a dominant trend that students are aware of the relevance of chemistry and have a positive attitude towards learning, although the problem-solving aspect still shows a relatively lower score (M = 3.89; SD = 0.94).

The analysis of students' learning barriers and needs (**Table 5**) showed an overall average score of 3.63 (SD = 0.97), indicating a reasonably high level. The main obstacles experienced by students were difficulty understanding abstract chemical concepts (M

Table 6. Results of the analysis of expectations for chemistry learning

Statements	Responses	
	M	SD
I hope chemistry learning can be connected to real life.	3.80	1.00
I want chemistry learning to involve hands-on practical activities or experiments.	3.97	1.02
I hope to work collaboratively in groups while learning chemistry.	3.40	0.82
I want chemistry learning to use engaging media or technology.	3.97	0.99
I hope my teachers give me space to ask questions and express my opinions.	3.81	0.92
I want to learn chemistry to improve my critical thinking skills.	3.92	0.93
I hope to complete challenges or projects that encourage creative thinking.	3.90	0.95
I want chemistry learning to focus not only on memorization but also on conceptual understanding.	3.99	1.00
I hope to apply my chemistry knowledge to solve real-world problems.	3.86	0.97
I want to learn chemistry to become more confident in expressing my ideas and thoughts.	3.90	0.99
Total average	3.85	0.96

Table 7. Results of the analysis of the understanding of chemical concepts

Statements	Responses	
	M	SD
I can explain basic concepts in chemistry in my own words.	3.29	0.87
I can apply the chemical concepts I have learned to solve problems.	3.35	0.85
I understand how one chemical concept relates to another.	3.33	0.87
I understand the meanings of chemical symbols and the notation used in equations and reactions.	3.29	0.85
I can relate observable events (macroscopic) to their constituent particles (microscopic) and chemical symbols.	3.12	0.84
I can provide logical scientific reasoning when explaining a chemical phenomenon.	3.27	0.89
Total average	3.28	0.86

Table 8. Results of learning style analysis

Statements	Responses	
	M	SD
I learn effectively through pictures, diagrams, graphs, and colors.	3.66	1.02
I learn effectively through listening and discussion.	3.75	1.00
I learn effectively through reading and writing.	3.72	1.01
I learn effectively through direct experience, practice, and physical movement.	3.97	1.06
Total average	3.78	1.02

= 3.69; SD = 1.06) and limited laboratory facilities (M = 3.58; SD = 0.94). At the same time, the need for more hands-on, challenge-based learning activities also received a high score (M = 3.79; SD = 1.01). This pattern indicates a dominant trend of a gap between positive perceptions of chemistry learning and limited learning experiences that support in-depth conceptual understanding.

Furthermore, the analysis of students' expectations for chemistry learning (**Table 6**) showed an overall M score of 3.85 (SD = 0.96), indicating high expectations for more meaningful learning. Students' highest expectations were that chemistry learning would not only focus on memorization, but also on conceptual understanding (M = 3.99; SD = 1.00), as well as the use of engaging learning media and technology (M = 3.97; SD = 0.99). Furthermore, students also expressed a strong expectation of being able to apply chemistry knowledge to solve real-world problems (M = 3.86; SD = 0.97). This trend demonstrates a consistent need for chemistry learning that is contextual, collaborative, and oriented toward the development of higher-order thinking skills.

Analysis of student characteristics

Student characteristics data collected via questionnaires included understanding of chemistry concepts, scientific argumentation skills, scientific literacy, learning styles, and participation in learning. The results of this data collection are shown in tables.

The results of the analysis of students' understanding of chemical concepts (**Table 7**) show an overall average score of 3.28 (SD = 0.86), which falls within the sufficient category. The highest score was found in the ability to apply chemical concepts to solve problems (M = 3.35; SD = 0.85), while the lowest score was found in the ability to relate macroscopic, microscopic, and symbolic phenomena (M = 3.12; SD = 0.84). These findings indicate a dominant trend that students have sufficient basic conceptual understanding but still face difficulties in more abstract aspects of chemical representation.

Analysis of student learning styles (**Table 8**) shows an average score of 3.78 (SD = 1.02), with the highest tendency towards kinesthetic learning styles or learning through direct experience (M = 3.97; SD = 1.06). Visual (M = 3.66; SD = 1.02) and auditory (M = 3.75; SD = 1.00) learning styles also showed relatively high scores. This pattern indicates a dominant trend that students learn more effectively through direct activities and interactions that are relevant to challenge-based, collaborative learning.

The results of the analysis of students' scientific argumentation skills (**Table 9**) show an overall average score of 3.54 (SD = 0.92), which is considered relatively high. The highest-scoring aspects were the ability to include data or facts to support arguments (M = 3.63; SD = 0.90) and the ability to constructively evaluate peers' opinions (M = 3.63; SD = 0.95). In contrast, the appropriate use of chemical terms and concepts in scientific communication showed a relatively lower score (M = 3.40; SD = 0.95).

Table 9. Results of scientific argumentation skills analysis

Statements	Responses	
	M	SD
I can express my opinions or conclusions based on observations or analysis.	3.54	0.92
I always include data, facts, or experimental results to support my arguments.	3.63	0.90
I can explain why the evidence I provide supports the claims I make.	3.52	0.89
I can critique and evaluate my peers' opinions while respecting differences of opinion.	3.63	0.95
I strive to use chemical terms and concepts appropriately when communicating.	3.40	0.95
Total average	3.54	0.92

Table 10. Results of scientific literacy analysis

Statements	Responses	
	M	SD
I can connect the science I learn in school to real-life events and problems in society.	3.33	0.88
I can explain phenomena in nature or in everyday life using scientific concepts.	3.25	0.89
I can design simple experiments and evaluate their accuracy to answer scientific questions.	3.24	0.86
I can understand and conclude from graphs, tables, and data from scientific experiments.	3.28	0.86
I understand basic concepts in science such as energy, matter, the Earth system, and life.	3.48	0.85
I know the systematic steps in conducting experiments or scientific investigations.	3.32	0.86
I recognize that scientific knowledge can change in light of new evidence and discoveries.	3.65	0.96
Total average	3.36	0.88

Table 11. Results of the analysis of active participation in groups

Statements	Responses	
	M	SD
I actively express my opinions and ideas in group work.	3.60	0.96
I listen to and respond well to my group members' opinions.	3.86	0.95
I fulfill my responsibilities within the group to complete shared tasks.	3.93	0.92
I am willing to work together and reach agreements to help the group achieve its goals.	3.94	0.94
I respect my group members' opinions and differing ways of thinking.	3.98	0.97
Average total	3.86	0.95

Table 12. Results of the analysis of the physical environment and infrastructure facilities

Statements	Responses	
	M	SD
The school's chemistry laboratory has adequate basic equipment for practical work in accordance with the curriculum.	3.85	0.91
Chemicals for experiments are available according to learning needs.	3.64	1.03
The school has technological facilities (computers, LCDs, & Internet connection) that can support challenge-based learning.	4.48	0.76
The school environment supports outdoor learning.	3.88	1.05
The school library provides adequate resources for chemistry learning.	3.82	0.95
Average total	3.93	0.94

This trend indicates that students have a foundation for evidence-based argumentation but still need to strengthen their understanding of scientific concepts.

Analysis of students' scientific literacy (**Table 10**) shows an overall M score of 3.36 (SD = 0.88), which falls within the sufficient category. The highest score was for understanding that scientific knowledge can change with new evidence (M = 3.65; SD = 0.96), while the ability to design simple experiments and explain scientific phenomena showed relatively lower scores (M = 3.24; SD = 0.86 and M = 3.25; SD = 0.89). These findings indicate a dominant trend that students have fairly good epistemological awareness but still need support in application and investigative skills.

The results of the analysis of students' collaborative participation (**Table 11**) show an overall average score of 3.86 (SD = 0.95), indicating a high level in collaborative participation. The highest scores were for respecting group members' opinions (M = 3.98; SD = 0.97) and willingness to work together to achieve group goals (M = 3.94; SD = 0.94). This dominant trend indicates that students have strong social readiness to engage in collaborative learning based on discussion and negotiation.

Analysis of learning context

Context analysis was conducted to obtain information about the physical environment and infrastructure, policy support, school culture and environment, and teacher readiness to support the design of SCC-ICBLM. The results of this learning context analysis are shown in tables.

The analysis of the physical environment and learning infrastructure (**Table 12**) shows an overall average score of 3.93 (SD = 0.94), indicating at a high level. The highest score was found in the availability of school technology facilities to support challenge-based learning (M = 4.48; SD = 0.76), while the availability of chemicals for practicums showed a relatively lower score (M = 3.64; SD = 1.03). These findings indicate a dominant trend that technological support is relatively strong, while practicum facilities still need strengthening.

Table 13. Results of the analysis of policy and organizational support

Statements	Responses	
	M	SD
The principal supports innovative chemistry instruction that emphasizes 21st-century skills.	4.45	0.62
The school has policies that facilitate challenge-based learning.	4.30	0.59
A flexible lesson schedule is available for chemistry projects or experiments.	3.94	0.86
Fellow teachers support collaborative learning across subjects.	4.15	0.83
The school has a reward system for students who excel in science-based projects.	3.91	0.72
Average total	4.15	0.72

Table 14. Results of the analysis of policy and organizational support

Statements	Responses	
	M	SD
Students are accustomed to working in groups to complete assignments.	4.30	0.68
Students show a strong interest in chemical experiments.	4.06	0.79
Students are curious about real-world problems in their environment.	4.12	0.70
The school environment supports activities that develop 21st-century skills.	4.12	0.41
The school environment supports activities that develop science/chemistry skills.	4.24	0.75
Extracurricular activities support science learning (e.g., science clubs or research).	4.33	0.69
Average total	4.20	0.67

Table 15. Results of teacher readiness analysis

Statements	Responses	
	M	SD
Chemistry teachers possess the skills to design challenging and relevant learning projects.	3.76	0.75
Teachers are accustomed to using problem-based, project-based, or challenge-based learning approaches.	3.70	0.73
Teachers can integrate critical, creative, collaborative thinking, and communication skills into chemistry instruction.	3.79	0.60
Teachers can integrate scientific literacy /chemical literacy into chemistry instruction.	4.00	0.61
Teachers have access to professional training related to innovative learning.	4.00	0.61
Teachers can use digital technology to support chemistry instruction.	4.06	0.83
Average total	3.89	0.69

Table 16. Results of the analysis of students' chemical competencies

Statements	Responses	
	M	SD
Students can explain chemical concepts, principles, and laws related to natural phenomena and technology.	3.86	0.82
Students can design and conduct experiments to test hypotheses.	3.81	0.78
Students can process, analyze, and interpret experimental data.	3.72	1.01
Students can relate chemical concepts to environmental, social, and technological issues.	3.70	0.93
Students can effectively communicate the results of studies/experiments orally and in writing.	4.02	0.80
Students can work collaboratively in groups to solve chemical problems/projects/challenges.	3.94	0.73
Students can use information technology to support chemistry learning and research.	3.88	0.95
Students can evaluate chemical solutions applied to real-life problems.	3.73	1.05
Average total	3.88	0.84

The analysis of school policy and organizational support (**Table 13**) shows an average score of 4.15 (SD = 0.72), indicating a high level of support. Principal support for innovative learning received the highest score (M = 4.45; SD = 0.62), followed by school policies that facilitate challenge-based learning (M = 4.30; SD = 0.59). These findings suggest a strong institutional commitment to fostering 21st century learning.

Analysis of school culture and the social environment (**Table 14**) showed an overall M score of 4.20 (SD = 0.67), indicating a high level. The highest scores were for support for extracurricular science activities (M = 4.33; SD = 0.69) and students' habits of working in groups (M = 4.30; SD = 0.68). These findings indicate that a collaborative culture and orientation toward developing science skills have been well established in the school environment.

The results of the teacher readiness analysis (**Table 15**) show an overall average score of 3.89 (SD = 0.69), indicating a high level of readiness. The highest-scoring aspects were teachers' ability to use digital technology in chemistry learning (M = 4.06; SD = 0.83) and access to professional training (M = 4.00; SD = 0.61). Meanwhile, teachers' experience in implementing challenge-based learning showed a relatively lower score (M = 3.70; SD = 0.73). This trend indicates that teachers are well prepared, although they still need to be strengthened in the practice of implementing innovative learning models.

Analysis of chemistry competencies and tasks

Chemistry competencies and tasks are required to design SCC-ICBLM. The results of the analysis of chemistry competencies, tasks, and their relevance to the design of SCC-ICBLM are shown in tables. The results of the analysis of students' chemical competencies (**Table 16**) show an overall average score of 3.88 (SD = 0.84), indicating a high level of competence. The highest-scoring aspect is the ability to communicate experimental results orally and in writing (M = 4.02; SD = 0.80), followed by the ability

Table 17. Results of the analysis of chemistry assignments

Task type	Frequency		Difficulty level		Potential to increase scientific argumentation skills		Potential to increase scientific literacy	
	M	SD	M	SD	M	SD	M	SD
Experimental worksheets based on standard procedures	4.75	0.76	3.87	0.69	3.62	0.78	4.24	0.69
Experimental data analysis assignments	3.67	0.69	3.74	0.73	3.98	0.64	4.31	0.77
Mini research projects based on real-life problems	3.52	0.83	3.69	0.77	3.62	0.96	3.95	0.84
Group presentations of chemistry literature reviews	4.01	1.02	3.87	0.93	3.72	1.05	3.98	0.72
Case studies of chemistry-based environmental/industrial issues	3.79	0.94	2.63	0.69	3.72	0.92	3.97	0.67
Class discussions related to actual chemical phenomena	3.85	0.71	3.87	0.85	3.63	0.73	4.05	1.02
Making simple chemical products (e.g., soap, natural indicators)	3.73	0.87	3.77	0.84	3.61	0.79	3.82	0.72
Average total	3.88	0.84	3.65	0.79	3.69	0.83	4.02	0.77

Table 18. Results of competency and task relevance analysis for SCC-ICBLM

Statements	Responses	
	M	SD
The assignments meet the requirements of CP phases E-F.	3.99	0.73
The assignments encourage students to identify problems and seek solutions.	3.71	0.89
The assignments involve effective student collaboration.	4.24	0.77
The assignments are relevant and can be used as challenges in SCC-ICBLM.	3.62	0.92
The average total	3.89	0.83

to work collaboratively in groups (M = 3.94; SD = 0.73). In contrast, the ability to evaluate chemical solutions applied to real-life problems shows a relatively lower score (M = 3.73; SD = 1.05). These findings indicate a dominant trend that students already have good basic competencies in scientific communication and collaboration, while evaluative skills still need strengthening.

The results of the analysis of the types and characteristics of chemistry learning tasks (**Table 17**) show an average score of 3.88 (SD = 0.84) for task frequency and 3.65 (SD = 0.79) for difficulty level. The most frequently used task was a standard procedure-based practicum worksheet (M = 4.75; SD = 0.76), while real-world problem-based mini-research was used less frequently (M = 3.52; SD = 0.83). In terms of the potential for developing scientific argumentation skills, experimental data analysis had the highest score (M = 3.98; SD = 0.64), while in terms of the potential for increasing scientific literacy, experimental data analysis and discussion of actual chemical phenomena showed high scores (M = 4.31; SD = 0.77 and M = 4.05; SD = 1.02). These findings suggest that analytical and data-based tasks have greater potential in supporting the development of higher-level scientific skills.

Furthermore, the results of the analysis of the relevance of competencies and learning tasks to the development of the SCC-ICBLM (**Table 18**) show an overall average score of 3.89 (SD = 0.83), which is in the high category. The aspect with the highest score is student collaborative engagement in learning tasks (M = 4.24; SD = 0.77), while the relevance of tasks as challenges in the SCC-ICBLM shows a relatively lower score (M = 3.62; SD = 0.92). These findings indicate a dominant trend that, although chemistry learning tasks are aligned with learning outcomes and encourage collaboration, there is still room to optimize task design to be more challenging and systematically integrated into the SCC-ICBLM framework.

Results of the SCC-ICBLM Design Stage

Data or information obtained from the results of the needs analysis in the ADDIE model is used to design the SCC-ICBLM prototype. The prototype design can be shown in **Figure 1**.

Based on the prototype, SCC-ICBLM has the following characteristics.

1. The SCC-ICBLM syntax consists of
   (a) challenge orientation,
   (b) problem identification,
   (c) information exploration,
   (d) negotiation and argument,
   (e) synthesis and solution,
   (f) reflection and evaluation, and
   (g) product dissemination.
2. Challenge-oriented instruction aims to spark students' interest, motivation, and curiosity about real-world issues.
3. The negotiation and argumentation stages enable students to develop scientific argumentation skills and scientific literacy through the socio-cognitive conflict strategy.

Results of the SCC-ICBLM Development Stage

At this stage, SCC-ICBLM was validated in the fields of educational psychology, pedagogy, and technology. Three validators were employed in each field. The validation results for SCC-ICBLM are shown in tables.

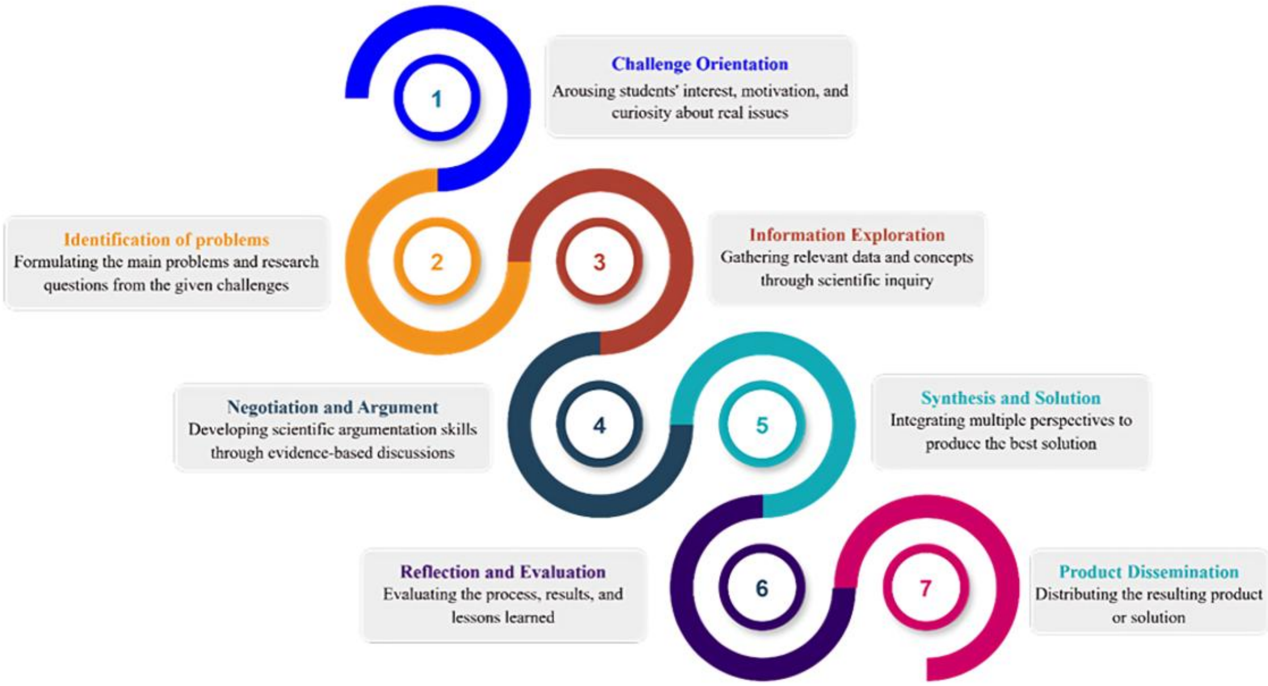

Figure 1. SCC-ICBLM design (Source: Authors' own elaboration)

Table 19. Results of validation by educational psychology experts on SCC-ICBLM

Dimensions	Indicators	Description	Responses	
			M	SD
Theoretical integration	Relevance of philosophical foundations	Alignment of progressivism, constructivism, humanism, etc. with learning objectives.	4.00	1.00
	Consistency of learning theory integration	Integration of cognitive, constructivist, experiential, collaborative, and self-determination theories into the model syntax.	3.67	0.58
	Justification for educational psychology	Strength of theoretical arguments in each phase of SCC-ICBLM.	3.67	0.58
Cognitive and critical thinking	Facilitation of critical thinking	Ability to encourage analysis, evaluation, and synthesis.	3.67	1.15
	Information processing principles	Alignment with the processes of encoding, storage, retrieval, and transfer of learning.	3.67	0.58
	Revised Bloom's taxonomy	Integration with cognitive levels C1-C6.	4.67	0.58
Affective and motivational aspects	Intrinsic motivation (self-determination theory)	Fulfillment of autonomy, competence, and relatedness.	3.33	0.58
	Empathy and social awareness	Development of empathy and social sensitivity in students.	4.00	1.00
	Resilience and growth mindset	Tolerance of failure and encouragement of continuous learning.	4.00	1.00
Social and collaboration	Social interaction	Quality of discussion, negotiation of meaning, and scaffolding.	3.67	1.15
	Collaborative skills	Positive interdependence, individual responsibility, and mutually supportive interactions.	3.67	0.58
	Interpersonal skills	Development of leadership, communication, and collaboration.	3.67	0.58
Creativity and innovation	Divergent thinking	Fluency, flexibility, originality, and elaboration in ideation.	4.00	1.00
	Real innovation	Transformation of ideas into prototypes and tested solutions.	4.00	1.00
	Creative environment	Support for collective creativity and the courage to take intellectual risks.	4.00	1.00
Metacognition and reflection	Self-reflection	Opportunities for reflection on the learning process.	4.67	0.58
	Self-regulation	Support for self-regulated learning.	3.67	0.58
	Awareness of the learning process	Encouraging student metacognition.	3.67	0.58
Social and contextual contributions	Relevance to real issues	Connecting challenges to social, environmental, and global issues.	3.33	0.58
	Critical awareness	Developing critical awareness in the style of Paulo Freire.	3.67	0.58
	Agents of social change	Encouraging students to become agents of social change.	4.33	0.58
Total average score			3.86	0.75

Validation results by educational psychologists (**Table 19**) show that the SCC-ICBLM prototype obtained an overall average score of 3.86 (SD = 0.75), which is in the valid category. The highest scores were found in the metacognitive and self-reflection aspects, particularly in the self-reflection indicator (M = 4.67; SD = 0.58) and awareness of the learning process (M = 3.67; SD = 0.58), as well as in the integration of the revised Bloom's taxonomy (M = 4.67; SD = 0.58). In contrast, the intrinsic motivation aspect, based on self-determination theory, showed a lower score (M = 3.33; SD = 0.58). These findings indicate a dominant trend that the model has strengths in high-level cognitive and reflective aspects, while the motivational aspect still requires further strengthening.

Table 20. Results of pedagogical expert validation of SCC-ICBLM

Dimensions	Indicators	Description	Responses M	Responses SD
Conceptual clarity	Clarity of model definition	The extent to which the model is explained coherently, systematically, and easily understood.	3.67	0.58
	Alignment of learning objectives	The alignment of the SCC-ICBLM objectives with the expected learning outcomes.	4.33	0.58
	Coherence among components	The integration of syntax elements, social systems, reaction principles, and instructional impacts.	4.33	0.58
Learning syntax	Clarity of stages	The sequence of the phases: challenge orientation, problem identification, information exploration, negotiation and argumentation, synthesis and solution, reflection and evaluation, and product dissemination.	4.33	0.58
	Relevance of activities	The alignment of learning activities with the intended outcomes in each phase.	4.00	1.00
	Roles of teachers and students	Clarity of the teacher's role as a facilitator and students as active learners.	4.67	0.58
Implementation	Accessibility of resources	The suitability of facilities, infrastructure, and media for implementing the model.	4.33	0.58
	Time and learning load	The adequacy of time and distribution of activities according to student abilities.	4.00	1.00
	Flexibility of implementation	The model's adaptability to various classroom contexts and subjects.	4.33	0.58
Pedagogical principles	Student-centeredness	The extent to which the model positions students as the subject of learning.	4.33	0.58
	Authenticity of learning	The degree to which the challenge relates to the students' real-life context.	4.00	1.00
	Collaboration and participation	The extent to which the model facilitates collaboration, communication, and active participation.	4.33	0.58
Evaluation and reflection	Authentic assessment	The appropriateness of the assessment to the learning process and products produced by students.	4.33	0.58
	Student reflection	Opportunities for students to reflect on their learning experiences and project outcomes.	4.00	1.00
	Continuous improvement	Encouraging students to iterate and revise solutions based on feedback.	3.33	0.58
Instructional impact	Development of 21st century skills	The model's effectiveness in enhancing critical thinking, creativity, collaboration, and communication.	4.33	0.58
	Improved learning outcomes	The model's contribution to students' conceptual understanding and skills.	4.33	0.58
	Knowledge transfer	Students' ability to apply knowledge in contexts outside the classroom.	4.33	0.58
Total average score			4.19	0.67

The validation results by pedagogical experts (**Table 20**) show an overall average score of 4.19 (SD = 0.67), which is categorized as highly valid. Aspects with the highest scores include clarity of teacher and student roles (M = 4.67; SD = 0.58), coherence between model components (M = 4.33; SD = 0.58), and development of 21st century skills and learning outcomes (M = 4.33; SD = 0.58, respectively). Meanwhile, the continuous improvement indicator shows a relatively lower score (M = 3.33; SD = 0.58). These findings suggest that the SCC-ICBLM has a clear and coherent pedagogical structure, with strong potential to support student-centered learning and the development of 21st century competencies.

The validation results by educational technology experts (**Table 21**) show an overall average score of 3.89 (SD = 0.57), which is in the valid category. The highest scores were found in the interactivity and learning engagement aspects, specifically in the indicators of student engagement through technology (M = 4.33; SD = 0.58) and learning media interactivity (M = 4.33; SD = 0.58), as well as in the model scalability aspect (M = 4.33; SD = 0.58). In contrast, the use of innovative technology and learning analytics showed relatively lower scores (M = 3.33; SD = 0.58, respectively). These findings indicate a dominant trend that SCC-ICBLM is ready for implementation with support from existing learning technologies. However, there is still room for development in technological innovation and the use of learning data.

DISCUSSION

The findings of this study indicate that the development of the SCC-ICBLM has a strong conceptual and pedagogical foundation and offers clear distinctions from existing learning models. Unlike conventional challenge-based learning, which primarily emphasizes contextual problem-solving and the achievement of solution products (Rådberg et al., 2020; Suwono et al., 2019), the SCC-ICBLM explicitly positions socio-cognitive conflict as a core mechanism in the learning process. This integration enables the learning process to be oriented not only toward solving challenges but also toward the reconstruction of knowledge through the exchange of arguments, the evaluation of evidence, and the scientific negotiation of meaning.

Conceptually, SCC-ICBLM expands the challenge-based learning framework by incorporating the principle of socio-cognitive conflict, which has often been treated as a separate or unstructured discussion strategy (Butera et al., 2019; Roselli et al., 2022). In SCC-ICBLM, conflict over differing perspectives is not viewed as an obstacle to learning, but rather as a learning resource systematically designed during the negotiation and argumentation stages. This approach aligns with social cognitive development theory, which emphasizes that cognitive imbalances arising from social interactions can encourage reflection, conceptual clarification, and the development of higher-order reasoning (Alt & Kapshuk, 2023; Roselli et al., 2022).

Table 21. Results of validation by educational technology experts on SCC-ICBLM

Dimensions	Indicators	Description	Responses M	Responses SD
Instructional design appropriateness	Model integration with instructional design principles	The alignment of the SCC-ICBLM syntax with instructional design theory (e.g., Gagné, Dick, and Carey).	3.67	0.58
	Clarity of learning flow	The sequence and consistency of the learning stages in the model.	4.33	0.58
	Connectedness of objectives, activities, and evaluation	The alignment between learning objectives, strategies, media, and assessments.	4.00	1.00
Utilization of technology	Integration of learning media	The extent to which the model effectively utilizes digital/non-digital media.	4.33	0.58
	Utilization of digital platforms	The connectivity of SCC-ICBLM with a learning management system, collaborative applications, or online technologies.	3.67	0.58
	Technological innovation	The model's supports the use of new technologies (AR, VR, simulations, virtual laboratories, etc.).	3.33	0.58
Accessibility and inclusivity	Access to learning resources	The availability of digital/physical resources for all students.	3.67	0.58
	Inclusivity	The model's ability to ensure all students can participate, including those with special needs.	3.67	0.58
	Affordability	The cost-efficiency and ease of implementation of the technology used.	3.67	0.58
Interactivity and engagement	Student engagement	The model's ability to increase engagement through technology.	4.33	0.58
	Media interactivity	The extent to which media and technology support two-way interaction.	4.33	0.58
	Technology-based collaboration	Technological support for teamwork, idea sharing, and online/offline discussions.	3.67	0.58
Evaluation and feedback	Technology-based assessment	Utilization of digital tools for formative and summative assessments.	4.00	0.00
	Real-time feedback	Ability to provide immediate feedback through media/technology.	3.67	0.58
	Learning analytics	Utilization of learning analytics to monitor student progress.	3.33	0.58
Sustainability and scalability	Flexibility of adoption	The model's ability to be implemented across various learning contexts.	3.67	0.58
	Scalability	The model's potential for application at the classroom, school, or broader scale.	4.33	0.58
	Sustainability of innovation	The model's capacity to support ongoing innovation with educational technology.	4.33	0.58
Total average score			3.89	0.57

From a pedagogical perspective, the SCC-ICBLM is specifically designed to address the needs of science learning at the secondary school level, which differ from those in higher education. At the high school level, students still require a clear learning structure, argumentative scaffolding, and explicit guidance in managing scientific differences of opinion (Governor et al., 2025; Lombardi et al., 2022; Schoute et al., 2024). The analysis of needs, student characteristics, and learning contexts indicates that although students' collaborative participation is high, their scientific argumentation skills and scientific literacy are still moderate. This condition indicates that social interactions in the classroom are not entirely directed towards building evidence-based arguments and in-depth conceptual understanding.

SCC-ICBLM responds to these conditions through a structured learning syntax, ranging from real-issue challenge orientation, information exploration, negotiation, and argumentation based on socio-cognitive conflict, to reflection and dissemination of learning products. Each stage is designed to facilitate students' balanced cognitive, social, and metacognitive engagement. Thus, socio-cognitive conflict does not arise incidentally but becomes an integral part of the learning cycle that supports the continuous development of scientific argumentation skills and scientific literacy.

Furthermore, integrating socio-cognitive conflict into the challenge-based learning framework further strengthens the relevance of SCC-ICBLM to the demands of the independent curriculum and the development of 21st century competencies. This model not only encourages mastery of chemical concepts but also develops critical thinking, scientific communication, collaboration, and self-reflection skills. These findings reinforce previous research emphasizing the importance of contextual learning and argumentative dialogue in improving scientific literacy (Díez-Palomar et al., 2022; Sengul, 2019; Suwono et al., 2023; Wattanasupinyo & Sangpradit, 2021), while also demonstrating that strengthening scientific argumentation requires a pedagogical design that consciously utilizes differing perspectives as a learning resource (Chen et al., 2016; Lara et al., 2025).

Thus, the SCC-ICBLM can be viewed as a learning model that not only combines two existing approaches but also transforms them into a more comprehensive pedagogical framework that is appropriate for the secondary school context. The model's primary contribution lies in the clarity of the pedagogical mechanisms that connect contextual challenges, socio-cognitive conflicts, and the development of scientific argumentation and scientific literacy in an integrated manner. This aspect has not been explicitly addressed in many previous studies. From a theoretical perspective, this study advances pedagogical research by reconceptualizing socio-cognitive conflict as a deliberately designed pedagogical engine, rather than an incidental outcome of group interactions. This repositioning offers a better framework for understanding how scientific argumentation and scientific literacy can be systematically developed through structured learning design.

This study has several limitations that need to be considered. First, the study only covers the three initial stages of the ADDIE model: analysis, design, and development. Therefore, the SCC-ICBLM prototype has not been tested through direct classroom implementation and has not provided empirical evidence of its effectiveness. Second, the prototype validation remains limited to expert assessments in educational psychology, pedagogy, and educational technology, without field trials involving teachers and students, so the dynamics of model implementation have not been fully revealed. Third, the study participants came from a single geographic region, Bali Province, limiting the generalizability of the study results. Furthermore, the integration of digital technology and authentic assessment in each stage of the SCC-ICBLM has not been explored in depth.

CONCLUSION

The research results indicate that the development of the SCC-ICBLM prototype is supported by empirical needs and relevant learning contexts at the secondary school level. Although students' perceptions of chemistry learning are high, their scientific argumentation and scientific literacy skills remain moderate, necessitating more structured, context-based pedagogical support. This finding is reinforced by the high level of student collaborative participation and the school environment's and teachers' readiness to support innovative learning.

Expert validation indicates that the SCC-ICBLM prototype is highly valid from the perspectives of educational psychology, pedagogy, and educational technology. Therefore, the SCC-ICBLM can be concluded as a theoretically and pedagogically sound learning model prototype for further development, serving as a basis for further research to test its implementation and effectiveness in improving secondary school students' scientific argumentation and scientific literacy skills.

Further research is recommended to test the implementation and effectiveness of the SCC-ICBLM through direct classroom application using an experimental or quasi-experimental design, to obtain empirical evidence on improvements in students' scientific argumentation skills and scientific literacy. Furthermore, future research should involve a more diverse group of participants from various regions and educational levels to increase the generalizability of the findings and test the model's adaptability in different learning contexts. The integration of digital technologies, such as virtual laboratories, collaborative platforms, and technology-based authentic assessments, also needs to be explored in more depth to enrich the learning experience and strengthen the pedagogical support of the SCC-ICBLM. Furthermore, qualitative research examining the dynamics of socio-cognitive conflict and students' argumentation processes during learning is important for enhancing theoretical understanding and further developing this model.

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AI statement: The authors stated that AI-assisted tools were used solely for language editing purposes and did not influence the study design, data analysis, interpretation, or research conclusions.

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