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Research Article

Enhancing Cambodian STEM Educators' Pedagogical Competence Through Integrating the Next Generation Science Standards, Cognitive Apprenticeship, and Claim–Evidence–Reasoning

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Abstract:

Background: Cambodian STEM educators require professional learning that supports inquiry-based teaching, scientific reasoning, and the classroom application of the Next Generation Science Standards (NGSS) and Claim-Evidence-Reasoning (CER) framework.

Aims: This study examined changes in educators' pedagogical knowledge, scientific reasoning, and instructional competencies following an integrated professional development program.

Methods: A quantitative single-group pre-test-post-test design was employed with 30 Cambodian STEM educators. Participants completed a two-day workshop structured through six Cognitive Apprenticeship processes: modeling, coaching, scaffolding, articulation, reflection, and exploration. They also engaged in authentic engineering design activities using creative circuits aligned with NGSS and CER. Data were collected before and after the workshop using a 14-item questionnaire rated on a five-point Likert scale. Descriptive statistics (means and standard deviations) were used to analyze the responses.

Results: Mean scores increased across all 14 items, with the overall mean rising from 1.98 at pre-test to 3.62 at post-test. Higher post-test ratings were observed for understanding NGSS three-dimensional learning, constructing CER-based scientific explanations, designing NGSS-aligned lessons, and applying science and engineering practices.

Conclusion: The findings indicate that participation in the workshop was associated with improved self-reported knowledge and pedagogical competencies. However, because the study did not include a comparison group, the observed changes cannot be attributed solely to the intervention. The integrated approach offers a promising model for future STEM teacher professional development in Cambodia, although further research using controlled designs and classroom-based outcome measures is needed.

Keywords: Claim-Evidence-Reasoning (CER), Cognitive Apprenticeship, Next Generation Science Standards (NGSS), Scientific Literacy, STEM Education.

1. INTRODUCTION

Scientific literacy has become a fundamental objective of contemporary Science, Technology, Engineering, and Mathematics (STEM) education as societies continue to experience rapid scientific, technological, and digital transformation (Kumar, 2025). In the twenty-first century, learners are expected not only to acquire scientific knowledge but also to interpret scientific information critically, evaluate evidence, construct logical explanations, and apply scientific understanding to solve authentic real-world problems. Consequently, modern STEM education has shifted its emphasis from the memorization of scientific facts toward cultivating learners who can think scientifically, communicate evidence-based arguments, and make informed

The success of STEM education depends substantially on educators' ability to facilitate inquiry (Kruatong et al., 2022), scientific investigation (Safitri et al., 2024), evidence-based reasoning (Diola et al., 2025), and authentic problem-solving (Siregar et al., 2025). Contemporary STEM educators are expected not only to communicate disciplinary knowledge but also to guide learners in analyzing evidence, constructing scientific explanations, connecting concepts across disciplines, and applying scientific knowledge to real-world situations (Hurt et al., 2023; Joseph & Nwankwo, 2024; Sanura, 2026). These competencies are fundamental to scientific literacy, which extends beyond knowledge of scientific facts to include the ability to interpret information (Mohamad et al., 2022), evaluate evidence (Stamatios et al., 2023), justify conclusions, and make informed decisions (Mohamad et al., 2022; Wangmo et al., 2025). However, developing these competencies among teachers remains challenging (Davut et al., 2025), particularly in educational systems where

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inquiry-oriented and student-centered STEM instruction is still emerging (Kruatong et al., 2022).

In Cambodia, STEM education has received increasing attention as part of national efforts to strengthen human capital, technological innovation, and sustainable economic development (Cendana et al., 2025; Heng & Sol, 2023; Koem & Bon, 2025; Vann, 2023). Curriculum reforms and teacher-development initiatives have sought to improve the quality of science and mathematics education. Nevertheless, Cambodian educators continue to experience challenges related to teacher preparation (Vann, 2023), professional qualifications (Joseph & Nwankwo, 2024), instructional resources, curriculum implementation (Yang et al., 2021), and the use of inquiry-based pedagogy (Davut et al., 2025; Tep et al., 2026). Many educators have limited opportunities to experience scientific inquiry from a learner's perspective or to practice facilitating scientific argumentation and evidence-based explanations. Consequently, classroom instruction may remain predominantly teacher-centred, with an emphasis on knowledge transmission rather than investigation, reasoning, and authentic problem-solving (Jayaram et al., 2026).

Professional development is therefore essential for strengthening educators' pedagogical knowledge and instructional competencies (Burrows et al., 2021; Hasim et al., 2022; Sanura et al., 2025). However, conventional professional development frequently relies on short-term presentations Sims et al. (2025), or theoretical content delivery, providing limited opportunities for modelling, guided practice, feedback, reflection, and classroom application (Karakose et al., 2026). Recent research also emphasizes the need to reconceptualize teacher professional development as a process that supports teachers' professional agency, reflective practice, and context-sensitive pedagogical decision-making (Barjesteh et al., 2026). Such programs may increase teachers' awareness of an instructional framework without sufficiently preparing them to translate its principles into lesson design and teaching practice (Garba, 2024). Effective professional development should actively engage educators in authentic learning activities, collaborative problem-solving, reflective practice, and the application of newly acquired knowledge to their own educational contexts (Burrows et al., 2021; Janett, 2023). Cambodian STEM educators therefore require a structured professional learning approach that connects curriculum expectations with pedagogical practice and scientific reasoning.

The Next Generation Science Standards (NGSS) provide a relevant framework for addressing these needs by shifting science education from the transmission of isolated facts towards three-dimensional and inquiry-oriented learning (Hardcastle et al., 2021; Mafi, 2022). NGSS integrates Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs). SEPs involve learners in practices such as asking questions, analysing data, developing models, constructing explanations, and communicating scientific findings (Alamodi, 2025). DCIs represent the essential scientific knowledge needed to understand disciplinary phenomena, whereas CCCs help learners identify patterns, systems, cause-and-effect relationships, and other connections across scientific fields (Buntha et al., 2024). Integrating these three dimensions can support deeper conceptual understanding, scientific reasoning, and the transfer of knowledge to authentic problems (Bindal, 2025).

Despite its educational potential, NGSS cannot transform classroom practice through curriculum knowledge alone. Educators must understand how to design three-dimensional learning experiences, facilitate investigation, provide appropriate instructional support, and assess learners' scientific reasoning. Insufficient teacher preparation has been identified as a barrier to the implementation of inquiry-oriented and competency-based STEM curricula, especially in developing educational contexts (Davut et al., 2025). Professional development that merely introduces SEPs, DCIs, and CCCs may therefore be insufficient if educators do not receive structured opportunities to observe their application, practise instructional strategies, receive feedback, and reflect on their performance.

Cognitive Apprenticeship (CA) offers an appropriate instructional model for translating NGSS principles into professional learning experiences (Kumar, 2025). It makes expert thinking visible through six interconnected processes: modelling, coaching, scaffolding, articulation, reflection, and exploration (Matsuo & Tsukube, 2020; Sánchez-Peña et al., 2023). During modelling, facilitators demonstrate the cognitive and practical processes involved in completing a task (Southornwiboon et al., 2025). Coaching and scaffolding provide guidance, feedback, and structured support while participants develop competence (Nketsiah & Motlhabane, 2026). Articulation requires participants to communicate and justify their thinking, while reflection enables them to compare their approaches, evaluate their understanding, and identify areas for improvement. Exploration subsequently encourages independent application and adaptation of acquired knowledge.

Within STEM teacher professional development, CA enables educators to participate in inquiry-oriented learning before implementing similar practices in their classrooms (Ahn et al., 2026). Instead of receiving information passively, educators observe expert demonstrations, engage in guided practice, explain their decisions, evaluate their learning, and explore alternative solutions. Previous research suggests that CA can support conceptual understanding, problem-solving, knowledge integration, and higher-order thinking by situating learning within authentic activities (Nketsiah & Motlhabane, 2026; Southornwiboon et al., 2025), thereby enabling educators to progressively develop the competencies required to implement NGSS-aligned instruction.

Although CA supports the professional learning process, educators also require a practical structure for constructing and facilitating scientific explanations. The Claim–Evidence–Reasoning (CER) framework addresses this requirement by organising scientific explanations into three connected components. A claim answers a scientific question, evidence provides relevant observations or data supporting the claim, and reasoning explains why the evidence justifies the claim using appropriate scientific principles (Buntha et al., 2024; Jayaram et al., 2026; Sanura et al., 2025). CER moves learners beyond unsupported opinions and factual recall by requiring them to evaluate information, select appropriate evidence, and communicate logical scientific justifications (Hardcastle et al., 2021).

CER is closely aligned with NGSS because constructing explanations and engaging in evidence-based argumentation are central Science and Engineering Practices. Research indicates that CER can support conceptual understanding, scientific communication, critical thinking, and argumentative reasoning (Wangmo et al., 2025). For educators, learning to apply CER may strengthen both their scientific reasoning and their ability to facilitate classroom discourse. However, exposure to the structure of CER alone may not be sufficient. Educators need authentic evidence-generating activities, guided practice, facilitator feedback, articulation of their reasoning, and reflection on the quality of their scientific explanations.

Integrating NGSS, CA, and CER therefore creates a coherent professional development approach (Koem & Bon, 2025; Sims et al., 2025). NGSS identifies the scientific knowledge, practices, and conceptual connections that educators are expected to facilitate. CA provides the instructional processes through which educators observe, practise, articulate, reflect on, and independently apply these competencies. CER provides a practical reasoning structure for constructing and communicating evidence-based scientific explanations. In this integrated approach, NGSS clarifies what should be learned and implemented, Cognitive Apprenticeship structures how professional learning occurs, and CER supports how scientific explanations are developed and justified.

The integration was operationalised in this study through creative-circuit engineering activities. Participants investigated energy changes by designing, constructing, testing, and refining circuits using accessible materials. These activities generated observable evidence that could be analysed through CER while engaging participants in relevant NGSS dimensions. Facilitators modelled the activity and scientific reasoning processes, coached participants during construction and testing, provided scaffolding through structured materials and questions, encouraged articulation of CER explanations, supported reflection on circuit performance and misconceptions, and promoted exploration through independent design refinement. The activity therefore connected curriculum knowledge, pedagogical development, and scientific reasoning within an authentic professional learning experience.

Although NGSS, CA, and CER have individually been applied in science education and professional learning, research examining their systematic integration in STEM teacher professional development remains limited (Hamad et al., 2022). Existing studies have primarily examined NGSS implementation CA, or CER as separate areas of inquiry (Sanura & Rozniza, 2024). Consequently, there is insufficient evidence regarding how these complementary approaches can be combined (Heng & Sol, 2023; Tep et al., 2026), to support educators' curriculum knowledge, scientific reasoning, lesson design, and inquiry-oriented instructional competencies. This gap is particularly evident in Cambodia, where educators continue to require contextually relevant professional development that connects curriculum reform with practical classroom implementation (Davut et al., 2025; Heng et al., 2023).

The novelty of this study lies in integrating NGSS as the learning framework, CA as the professional development model, and CER as the scientific-reasoning structure within an authentic, hands-on program for Cambodian STEM educators. Rather than examining the three approaches independently, the study presents a coherent model that connects curriculum expectations, professional learning processes, and evidence-based scientific explanation. The study contributes context-specific preliminary evidence regarding changes in educators' self-reported knowledge, scientific reasoning, and pedagogical competencies following participation in the program. Accordingly, this study examines changes in Cambodian STEM educators' pedagogical knowledge, scientific reasoning, and instructional competencies after participating in a two-day Cognitive Apprenticeship-based professional development program integrating NGSS and CER. Given the single-group pre-test–post-test design, the study evaluates changes associated with participation and does not seek to establish that the program alone caused the observed changes. Based on this objective, the study addresses the following research question: What changes are observed in Cambodian STEM educators' self-reported pedagogical knowledge, scientific reasoning, and instructional competencies after participating in the program?

This study is grounded in the integration of three complementary components as illustrated in Figure 1. The Next Generation Science Standards (NGSS) as the learning framework, Cognitive Apprenticeship (CA) as the instructional model, and the Claim–Evidence–Reasoning (CER) framework as the structure for scientific reasoning. Together, these components are applied within a professional development context involving Cambodian educators, with the aim of enhancing cognitive complexity in science teaching.

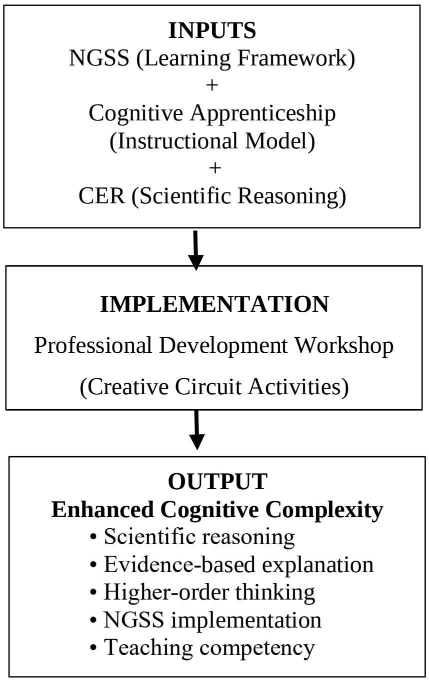

Figure 1. Conceptual Framework

NGSS provides the foundation for three-dimensional learning, emphasizing the integration of Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), and Crosscutting Concepts (CCCs). However, translating these dimensions into classroom practice remains challenging, particularly in contexts where teachers have limited exposure to inquiry-based and reasoning-oriented instruction.

To support implementation, this study adopts Cognitive Apprenticeship, which emphasizes modelling, coaching, scaffolding, articulation, reflection, and exploration. Within the workshop, Cambodian educators engaged in guided, hands-on activities using creative circuits to explore energy concepts. These activities provided authentic learning experiences that made abstract concepts more accessible while supporting gradual development of teaching competence.

The CER framework was incorporated to structure participants' scientific explanations. Through CER, educators were guided to construct claims, support them with evidence derived from circuit activities, and justify their reasoning using scientific concepts. This process helped participants move beyond basic understanding towards more structured and meaningful explanations.

The integration of NGSS, CA, and CER is expected to enhance cognitive complexity, particularly in participants' ability to apply, analyze, and justify scientific concepts. In this study, cognitive complexity is reflected in improvements in teachers' knowledge and pedagogical practices, as measured through a quantitative pre-test and post-test design.

2. MATERIAL AND METHOD

This study employed a quantitative single-group pre-test–post-test design to examine changes associated with participation in the workshop. The design enabled the measurement of changes in participants' knowledge and pedagogical competencies before and after the workshop. A single-group pre-test–post-test approach was considered appropriate (Schoch, 2020), as the study aimed to evaluate learning gains following participation in a structured professional development workshop (Cardellino & Woolner, 2020; Creswell & Guetterman, 2021; Tep et al., 2026).

2.1 Participants

The participants consisted of 30 Cambodian educators selected using purposive sampling, as shown in Table 1.

Table 1. Demographic Characteristics of the Participants (N = 30)

Characteristic	Category	n	%
Gender	Male	15	50.0
	Female	15	50.0
Field of Expertise	Science Education	11	36.7
	Physics	5	16.7
	Biology	3	10.0
	Mathematics	4	13.3
	Chemistry	2	6.7
	Earth Science	2	6.7
	Teacher Education / Others	3	10.0
Educational Level Taught	Primary Education	11	36.7
	Lower Secondary (Grades 7–9)	14	46.7
	Upper Secondary (Grades 10–11)	2	6.6
	Teacher Education / Higher Education	3	10.0
Teaching Experience	≤ 3 years	17	56.7
	4–10 years	8	26.6
	>10 years	5	16.7

Table 1 shows that a total of 30 Cambodian STEM educators participated in the professional development program. The sample comprised an equal proportion of male (50.0%) and female (50.0%) educators, providing balanced gender representation.

Participants represented a wide range of STEM-related disciplines. The largest group specialized in science education (36.7%), followed by physics (16.7%), mathematics (13.3%), biology (10.0%), chemistry (6.7%), and earth science (6.7%), while the remaining participants were involved in teacher education and other related educational fields (10.0%). This multidisciplinary representation reflects the diverse backgrounds of Cambodian STEM educators participating in the workshop.

Regarding teaching level, almost half of the participants (46.7%) taught at the lower secondary level (Grades 7–9), followed by primary education (36.7%). A smaller proportion taught in upper secondary schools (6.6%) or teacher education and higher education institutions (10.0%), demonstrating that the professional development program reached educators across different educational settings.

The participants also varied in their professional experience. More than half (56.7%) had three years of teaching experience or less, indicating that many participants were early-career educators. Approximately one-quarter (26.6%) had between four and ten years of experience, while 16.7% had more than ten years of teaching experience. This variation provided opportunities to examine the applicability of the professional development program across educators with different levels of professional expertise.

2.2 Research Context and Intervention

This study was conducted during a two-day STEM professional development workshop entitled "Exploring Energy Change through NGSS and CER with Creative Circuits", held on 24–25 April 2025 at Phnom Penh Teacher Education College, Cambodia. The workshop was designed based on CA instructional model and aimed to strengthen Cambodian STEM educators' pedagogical knowledge and scientific reasoning by integrating NGSS and the CER framework into an authentic inquiry-based learning experience. Table 2 summarizes how each component of the CA model was implemented during the professional development program.

Table 2. Component of the Cognitive Apprenticeship Model Implementation

Cognitive Apprenticeship Component	Workshop Implementation
Modeling	Facilitators demonstrated the integration of NGSS through a hands-on engineering design activity and modelled the application of the CER framework for constructing scientific explanations.
Coaching	Participants received continuous guidance and feedback while designing, constructing, testing, and troubleshooting paper circuits using LEDs, copper tape, and batteries. Facilitators supported participants in applying NGSS concepts and CER throughout the activity.
Scaffolding	Structured learning materials, guided questions, and step-by-step instructions were provided to support participants' understanding of Science and Engineering Practices (SEPs), Disciplinary Core Ideas (DCIs), Crosscutting Concepts (CCCs), and the engineering design process before independent application.
Articulation	Participants communicated and justified their scientific thinking by constructing CER explanations and presenting their findings during collaborative discussions.
Reflection	Participants reflected on their investigation results, evaluated circuit performance, identified misconceptions, and discussed how NGSS and CER could be implemented in their own STEM classrooms.
Exploration	Participants independently refined their circuit designs, explored alternative solutions, and considered adaptations of the engineering activity for inquiry-based STEM teaching in different classroom contexts.

2.3 Instrument

Data were collected using a structured questionnaire administered as both a pre-test and post-test. The instrument consisted of 14 items designed to measure participants':

a) Knowledge and understanding of NGSS dimensions;
b) Understanding of the CER framework; and
c) Ability to apply these concepts in teaching practices.

Responses were recorded using a 5-point Likert scale. The items were developed to reflect key constructs aligned with the conceptual framework of the study, including science practices, conceptual understanding, and reasoning skills.

2.4 Data Collection Procedure

Data collection was conducted in two phases. The pre-test was administered before the workshop to establish baseline levels of participants' knowledge and understanding. Following the completion of the workshop, the post-test was administered using the same instrument to measure changes in participants' learning outcomes. The workshop consisted of interactive presentations, collaborative discussions, facilitator modelling, guided practice, and a hands-on engineering design activity aligned with NGSS and CER principles.

2.5 Data Analysis

Data were analyzed using descriptive statistics, including means and standard deviations, to summarize participants' responses to the 14 questionnaire items before and after the workshop. Mean differences were calculated to describe the direction and magnitude of the observed changes. Therefore, the analysis was conducted at the item level; no inferential test of participant-level pre-test–post-test differences were performed.

2.6 Ethical Considerations

Participation in the study was voluntary, and participants were informed of the purpose of the research prior to data collection. Confidentiality and anonymity were maintained throughout the study, and all data were used solely for research purposes.

3. RESULTS AND DISCUSSION

3.1 Result

Table 3. Descriptive Analysis Results

	Pre-Test Mean	Std.Deviation	Pre-Test Mean	Std. Deviation	Post-pre test Difference
Knowledge and understanding the concept of NGSS	1.70	.794	3.57	.568	+1.87

	Pre-Test Mean	Std.Deviation	Pre-Test Mean	Std. Deviation	Post-pre test Difference
Knowledge and understanding about Science and Engineering Practices	2.27	.828	3.67	.606	+1.40
Knowledge and understanding about Disciplinary Core Ideas	2.00	.695	3.63	.490	+1.63
Knowledge and understanding about crosscutting Concepts	1.87	.776	3.63	.556	+1.76
Knowledge and understanding about Claim-Evidence-Reasoning (CER) Framework	2.03	.890	3.87	.681	+1.84
Knowledge and understanding of the strategies and teaching approaches to enhance Science	1.97	.890	3.57	.568	+1.60
Knowledge and understanding of the introduction to integrated NGSS and CER in teaching	1.83	.791	3.60	.621	+1.77
Designing lessons based on NGSS dimensions	1.67	.661	3.43	.626	+1.76
Applying Science and Engineering Practices in your classroom	2.27	.907	3.60	.621	+1.33
Identifying and integrating Disciplinary Core Ideas in your lessons	1.97	.765	3.57	.679	+1.60
Ability to Encouraging students to connect ideas using Crosscutting Concepts	2.00	.788	3.53	.571	+1.53
Ability to explaining the concept of the CLAIM in teaching and learning	1.97	.809	3.73	.691	+1.76
Ability to explaining the concept of the EVIDENCE in teaching and learning	2.10	.885	3.63	.669	+1.53
Ability to explaining the concept of the REASONING in teaching and learning	2.07	.868	3.67	.661	+1.60

Descriptive statistics were used to examine participants' knowledge and pedagogical competencies before and after the intervention, was illustrates in Table 3. The pre-test results indicate that participants' initial understanding across all constructs was relatively low to moderate. Mean scores ranged from 1.67 to 2.27, suggesting limited familiarity with NGSS dimensions, the CER framework, and their application in teaching practices. Specifically, the lowest mean score was recorded for designing lessons based on NGSS dimensions (M = 1.67, SD = 0.661), followed by understanding of NGSS concepts (M = 1.70, SD = 0.794). Similarly, participants demonstrated limited ability in explaining CER components, with mean scores of 1.97 (Claim), 2.10 (Evidence), and 2.07 (Reasoning). These findings indicate that prior to the intervention, participants had only a basic level of understanding and limited experience in applying NGSS and CER in instructional contexts.

In contrast, the post-test results show a substantial improvement across all measured constructs. Mean scores increased to a range of 3.43 to 3.87, indicating a higher level of understanding and application. The highest mean score was observed for understanding of the CER framework (M = 3.87, SD = 0.681), followed by knowledge of Science and Engineering Practices (M = 3.67, SD = 0.606). Participants also demonstrated improved ability in explaining CER components, with mean scores of 3.73 (Claim), 3.63 (Evidence), and 3.67 (Reasoning).

The improvements were also observed in pedagogical aspects, such as designing lessons based on NGSS dimensions (M = 3.43, SD = 0.626) and applying Science and Engineering Practices in the classroom (M = 3.60, SD = 0.621). These results suggest that the intervention not only enhanced conceptual understanding but also supported the development of teaching competencies.

Overall, the findings demonstrate a clear and consistent improvement across all 14 items measured in the study. The increase in mean scores indicates that participants progressed from a basic level of understanding to a more advanced level, particularly in applying NGSS dimensions and constructing scientific explanations using the CER framework. These results suggest that the integration of NGSS, CA, and CER through creative circuit-based activities was associated with improvements in both conceptual understanding and pedagogical practices. Furthermore, the improvement in participants' ability to explain and justify scientific concepts reflects the development of cognitive complexity, particularly in higher-order thinking skills such as analysis and reasoning.

3.2 Discussion

This study examined the changes a CA-based professional development program integrating the NGSS and the CER framework in enhancing Cambodian STEM educators' pedagogical knowledge, scientific reasoning, and instructional competencies. The findings showed increases in participants' post-test mean scores across the measured dimensions. These changes suggest that participation in the professional development program was associated with improvements in educators' self-reported pedagogical knowledge, scientific reasoning, and instructional competencies.

3.2.1 Implications

The improvement in educators' understanding of NGSS suggests that the workshop successfully enhanced participants' knowledge of three-dimensional learning, including SEPs, DCIs, and CCCs. Experiencing NGSS through authentic engineering design activities enabled participants to connect scientific concepts with inquiry and problem-solving, rather than viewing science as isolated factual knowledge. This finding is consistent with previous studies reporting that sustained, practice-oriented professional development enhances teachers' ability to implement NGSS-aligned instruction and supports the transition from teacher-centered to student-centered learning.

Similarly, participants demonstrated improved competence in applying the CER framework when constructing scientific explanations. The integration of CER throughout the hands-on investigation encouraged educators to formulate evidence-based claims and justify their reasoning using scientific concepts. Therefore, these findings support previous research by Buntha et al. (2024) indicating that CER promotes scientific argumentation, critical thinking, and evidence-based reasoning, all of which are fundamental components of scientific literacy. As future classroom practitioners, educators who are confident in using CER are more likely to facilitate meaningful scientific discourse and inquiry among their students.

Although CA was not measured directly, it provided the pedagogical structure that guided the professional development program. Through modelling, coaching, scaffolding, articulation, reflection, and exploration, participants actively experienced the instructional strategies expected in inquiry-based STEM classrooms. Consequently, these findings are consistent with Janett (2023), who argued that effective professional development extends beyond traditional lecture-based instruction by actively engaging educators in collaborative problem-solving, providing timely feedback, encouraging reflective practice, and supporting the adaptation of newly acquired pedagogical approaches to their own classroom contexts. This instructional design likely contributed to the observed improvements by creating an authentic and supportive learning environment that encouraged both conceptual understanding and pedagogical application.

The findings also have important implications for teacher professional development in Cambodia and other developing education systems. These findings are consistent with previous studies, which suggest that implementing innovative teaching approaches and providing continuous professional development for educators are essential for strengthening STEM teaching competencies (Jayaram et al., 2026; Tep et al., 2026). In particular, integrating the NGSS and the CER framework within a CA instructional model offers a practical and sustainable approach to supporting inquiry-based STEM teaching (Janett, 2023; Tep et al., 2026). Such programs can better prepare educators to implement competency-based curricula that emphasize scientific inquiry, problem-solving, and evidence-based reasoning, thereby contributing to the broader goal of improving scientific literacy.

3.2.2 Limitations

Despite these promising findings, several limitations should be acknowledged. First, the study employed a one-group pre-test and post-test design without a comparison group, limiting the ability to attribute improvements solely to the intervention. Second, the relatively small sample of 30 participants may limit the generalizability of the findings to other educational contexts. Third, the study measured immediate learning outcomes following the workshop and did not investigate the long-term implementation of NGSS- and CER-based instructional practices in participants' classrooms. Future studies should employ larger samples, include comparison groups, and examine the sustained impact of professional development on classroom practices and student learning outcomes.

The combination of NGSS and CER within an experiential professional development model offers a practical strategy for improving educators' capacity to foster scientific literacy. Rather than focusing solely on theoretical knowledge, the program enabled participants to experience, practice, and reflect on inquiry-oriented teaching approaches that can be transferred to their own classrooms. These outcomes highlight the importance of designing professional development that integrates pedagogical frameworks with authentic scientific investigations.

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3.2.3 Research Contribution

The study contributes to the growing body of STEM education research by demonstrating how an instructional model grounded in CA may support the implementation of NGSS and CER in teacher professional development. The proposed approach offers a promising framework for strengthening STEM education in Cambodia and other contexts seeking to enhance educators' competencies for competency-based and inquiry-driven science education.

3.2.4 Suggestion

Future research should investigate the long-term impact of such programs on teachers' classroom practices and students' scientific literacy to further validate their effectiveness of emerging of NGSS, CA, and CER with different group of participants.

4. CONCLUSION

These findings indicate that the integrated professional development approach offers a promising model for supporting inquiry-oriented STEM teaching in Cambodia. However, because the study employed a single-group pre-test–post-test design without a comparison group, the observed improvements should be interpreted as changes associated with participation rather than definitive causal effects of the program. Overall, the study demonstrates the potential value of combining curriculum, pedagogical, and scientific-reasoning frameworks within authentic STEM teacher professional learning.

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6. AUTHOR CONTRIBUTION STATEMENT

MN contributed to the conceptualization, methodology, investigation, data curation, formal analysis, visualization, and writing of the original draft. SJ contributed to the conceptualization, methodology, supervision, validation, project administration, writing, review, and editing, and overall coordination of the research. MN and SJ have read and agreed to the published version of the manuscript.

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