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INNOVATIVE APPROACHES TO TEACHING NATURAL SCIENCE IN CAMBODIAN PRIMARY EDUCATION

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ABSTRACT

This study aims to investigate innovative approaches to teaching natural science in Cambodian primary education, focusing on the integration of inquiry-based learning, technology-enhanced instruction, and culturally responsive pedagogy. The research employs a literature-based method, systematically reviewing peer-reviewed journal articles, conference papers, and institutional reports published within the last five years. Data were collected through structured searches using keywords such as "primary science education," "innovative teaching," "Cambodia," "inquiry-based learning," and "ICT in classrooms," followed by thematic content analysis to identify patterns, gaps, and effective strategies. The findings indicate that inquiry-based activities and the use of digital tools enhance student engagement, conceptual understanding, and scientific literacy. Teacher preparedness, pedagogical content knowledge, school infrastructure, and contextual adaptation significantly mediate the successful implementation of these methods. The study identifies a research gap in applying these integrated approaches at the primary level in low-resource, culturally diverse contexts such as Cambodia, where challenges include limited materials, multi-grade classrooms, and insufficient ICT access. The novelty of this research lies in proposing a context-sensitive framework that combines technology, inquiry, and cultural responsiveness tailored to primary school settings, offering both theoretical contributions and practical guidance for policymakers, educators, and curriculum developers. Overall, the study concludes that sustainable improvements in primary science education require systemic coordination of pedagogy, technology, and cultural adaptation, providing a model applicable not only in Cambodia but also in similar global contexts. These insights contribute to the broader discourse on early science education innovation and strategies to enhance scientific literacy in low-resource environments.

Keywords: *Inquiry-based learning, primary science education, Cambodia, culturally responsive pedagogy, educational innovation*

INTRODUCTION

In recent years, the field of primary science education has experienced a marked shift from traditional rote-learning models toward more student-centred, inquiry-based and technology-enhanced pedagogies. The foundational theory underpinning this shift is constructivist learning theory, which posits that children build their own understanding of natural phenomena through active engagement, reflection, and social interaction. When applied to natural science (often referred to as "science of nature" or "natural sciences"), this means that learners are not passive recipients of facts but active constructors of meaning as they observe, experiment, and interpret phenomena in their world. Further, the notion of scientific literacy has become central: children should not only know scientific facts, but also understand how science works, ask questions, design

investigations, and draw evidence-based conclusions. Empirical evidence supports the idea that the integration of interactive technologies and inquiry-based learning enhances students' motivation and outcomes in science education in primary contexts (Soriano-Sánchez, 2025). This theoretical framing is especially relevant for low-resource or emerging contexts, where innovative methods can bridge gaps in infrastructure and teacher preparation (Zhumabayeva et al., 2024). Such a paradigm suggests that primary science teaching in Cambodia could benefit from blending hands-on activities, digital resources, and culturally responsive contexts to support young learners' engagement and understanding.

From a pedagogical perspective, the application of modern educational technologies and culturally responsive teaching constitutes an essential component of innovation in science instruction. Research into the use of Information and Communication Technologies (ICT) in natural science classrooms for primary students indicates a robust positive effect on engagement, motivation, and conceptual learning, including among diverse learners and special-educational-needs populations (Soriano-Sánchez, 2025). At the same time, culturally responsive models such as integrating local environment, indigenous knowledge or community-based phenomena are emerging as effective strategies for making science more relevant and meaningful to students' lived experiences. For instance, approaches like Ethno-SETSaR (which blends indigenous science, environment, society and religion) have shown improvements in creative thinking and problem-solving among pre-service science teachers, hinting at their potential in primary settings (Winarto, 2022). Together, these theoretical bases (constructivism, scientific literacy, ICT integration, cultural responsiveness) provide a strong conceptual framework for exploring how innovative science teaching methods might be implemented in Cambodian primary education settings.

Recent studies highlight that primary science education in Cambodia faces persistent constraints stemming from inadequate teacher preparation, limited instructional materials, and a lack of school-level infrastructure. Specifically, teacher-training for inquiry-based science instruction remains weak, limiting educators' confidence and ability to adopt student-centred, hands-on methods in the classroom (Pichchenda, 2024). In addition, many Cambodian primary schools continue to employ teacher-centred, lecture-style approaches with minimal laboratory or experimental resources, thereby restricting students' opportunities to engage in active scientific inquiry (Thy et al., 2023). The absence of sufficient and context-appropriate teaching aids and science equipment further inhibits the implementation of innovative methods in natural science instruction (Run et al., 2025). External factors such as high pupil-teacher ratios, multi-grade classes and rural school isolation compound teacher constraints and reduce effective contact time for science learning (Savrin et al., 2023). Moreover, teachers report low self-efficacy and limited professional development opportunities related to science pedagogy, making sustained innovation difficult (Pov & colleagues, 2024). Collectively, these interconnected issues create a gap between the intended curriculum goals for scientific literacy and the realities of classroom practice in Cambodian primary settings.

Despite growing interest in active, inquiry-based and technology-enhanced science pedagogy, there remains a significant gap in evidence concerning how such innovative approaches are adapted and applied at the primary school level in Cambodia. Many recent studies in Cambodia focus on upper secondary or teacher-education contexts rather than early years of primary education (Mel, 2023). There is scarce research investigating how primary school teachers in Cambodia implement constructivist or student-centred natural science methods, especially in low-resource rural schools. The literature rarely addresses how children's engagement, scientific process skills, and conceptual understanding in primary-grade natural science respond to culturally responsive, hands-on and digital modalities in the Cambodian context. Moreover, there is a shortage of longitudinal or large-scale quantitative studies tracking the effects of innovative teaching methods on pupils' scientific literacy outcomes in Cambodian primary schools.

In addition, existing research often overlooks the systemic and contextual barriers that prevent full adoption of innovative natural science teaching in Cambodian primary schools. For instance, while teacher quality is frequently mentioned as a concern, the specific pedagogical content knowledge for natural science and how it influences classroom implementation remains under-studied in primary settings (UNESCO, 2023). Furthermore, there is limited empirical work exploring the interaction between instructional materials, school infrastructure (e.g., labs or digital tools), and teaching method adaptation in Cambodia's varied geographic and socioeconomic contexts. Consequently, the body of evidence lacks nuanced insights into how innovation in natural science teaching must be tailored to Cambodia's primary-school realities such as multi-grade classrooms, teacher workload, materials scarcity, and local cultural practices. Without filling these gaps, efforts to propose or scale up innovative methods risk being generic and non-responsive to the unique Cambodian primary science learning environment.

This study introduces a unique contribution by focusing specifically on primary-level natural science education within Cambodian context, which has been largely under-researched compared to secondary or teacher education levels (Sok & Heng, 2024). It explores how innovative, culturally-responsive, and technology-enhanced pedagogies can be tailored to the realities of Cambodian rural and urban primary schools—something seldom addressed in existing literature. It also examines the interplay of hands-on inquiry, digital tools, and local environment in a combined model seldom attempted in previous Cambodian science education research (Pichchenda, 2024; Pang et al., 2022). Moreover, the research seeks to map how teacher pedagogical content knowledge for natural science and school infrastructural constraints jointly mediate learning outcomes in primary settings offering a systemic lens missing in prior studies. In doing so, it aims to provide actionable insights for low-resource contexts, thereby bridging the gap between generic innovation discourse and contextualised practice in Cambodia's primary science education system.

The primary objective of this study is to evaluate how innovative teaching approaches—comprising inquiry-based learning, digital tools integration, and culturally-relevant contextualisation impact the engagement and scientific literacy of primary school students in Cambodia. A second objective is to identify the specific teacher- and school-level factors (such as pedagogical content knowledge, resource availability, class size, and infrastructure) that facilitate or hinder the adoption of these innovative methods in Cambodian primary natural science teaching. A further aim is to develop a context-sensitive framework for implementing such pedagogies in Cambodian primary schools, drawing on evidence from both urban and rural settings. Ultimately the study intends to offer recommendations for policy-makers, teacher training institutions, and school leaders in Cambodia to enhance the quality and relevance of primary science education.

RESEARCH METHOD

In this study, a literature-based research method is adopted, focusing on a comprehensive review of existing scholarly works to explore and synthesize the state of knowledge on primary-level natural science teaching in Cambodia. The approach begins with systematic searches in multiple academic databases to locate peer-reviewed articles published in the past five years that relate to science pedagogy, inquiry-based learning, and educational innovation in primary schooling. Once identified, selected studies are critically analysed for themes, methodological designs, and outcomes relevant to the research topic (Chigbu, 2023). This method enables the identification of conceptual frameworks, effective practices, and key gaps that the current research can address thereby building a robust theoretical foundation for the investigation. Literature review as a methodology is recognised as not merely summarising previous research but as a purposeful and structured method for mapping the intellectual terrain and guiding new inquiry (Snyder, 2024). Through this desktop research method, data are drawn exclusively from already-published sources rather than primary fieldwork, which aligns with the aim of generating insights into innovative approaches for teaching natural science in Cambodian primary education. The method ensures transparency and reproducibility thereby enhancing the credibility of findings in a context where empirical primary data may be scarce or logistically challenging.

In this literature-based study, data collection involves systematically searching for relevant published sources, including journal articles, conference papers, and institutional reports, focusing on natural science teaching in primary education, particularly in Cambodia and Southeast Asia. Databases such as Scopus, Web of Science, Google Scholar, and ERIC are employed to ensure comprehensive coverage (Chigbu, 2023). Keywords include "primary science education," "innovative teaching methods," "Cambodia," "inquiry-based learning," and "ICT in classrooms." Inclusion criteria are set to limit sources to peer-reviewed publications from the last five years, ensuring contemporary relevance and methodological rigor. Exclusion criteria eliminate non-academic content or studies unrelated to primary science teaching. Selected literature is

then catalogued and coded for themes such as pedagogy type, resource availability, teacher competencies, and student outcomes. This structured approach ensures consistency, replicability, and transparency in capturing evidence relevant to the study objectives. The systematic data collection forms the foundation for synthesising patterns, identifying gaps, and highlighting best practices in Cambodian primary science education.

Data analysis in this study uses a qualitative content analysis approach, which involves organizing, categorizing, and interpreting the information extracted from the selected literature (Snyder, 2024). Each source is examined for recurring themes, pedagogical approaches, technological integration, and contextual factors influencing science teaching in primary schools. Patterns are then synthesized to understand commonalities and divergences across studies, including differences between rural and urban settings, teacher preparedness, and student engagement outcomes. Triangulation of evidence from multiple sources strengthens the validity of conclusions drawn from the literature (Susilawati, 2023). Special attention is given to identifying innovative methods that are empirically supported and culturally responsive. The analysis also involves mapping the limitations and challenges reported in prior studies, providing a contextualised understanding of gaps. Findings are then organized into conceptual frameworks to guide recommendations for implementing effective science teaching strategies in Cambodian primary schools. This systematic analytical process ensures that conclusions are grounded in current evidence while addressing the study's objectives and novelty.

RESULTS AND DISCUSSION

The first major finding from the literature review indicates that inquiry-based learning significantly enhances students' engagement and understanding of natural science concepts in Cambodian primary schools. Studies report that hands-on experiments, observation activities, and group discussions increase motivation and support conceptual learning (Pichchenda, 2024). Integration of Information and Communication Technology (ICT), such as interactive simulations and educational apps, also contributes to improved learning outcomes (Soriano-Sánchez, 2025). Table 1 below summarizes key studies, types of innovative teaching methods applied, and observed student outcomes. Rural schools, however, face challenges including limited digital access and insufficient science materials, which may constrain the effectiveness of these methods. Despite these constraints, evidence suggests that combining inquiry-based activities with culturally relevant content can enhance scientific literacy. The table shows variations in method application, context, and observed outcomes, demonstrating the potential for innovation even in low-resource environments. Such findings highlight the need for teacher training programs that focus on practical implementation of innovative science pedagogy in primary classrooms.

Table 1. Summary of Key Findings on Innovative Science Teaching Methods in Cambodian Primary Schools

Study	Method Applied	Con-text	Student Outcome	Challenges	Study
Pichchenda (2024)	Inquiry-based learning	Urban & Rural	↑ Engagement, Conceptual understanding	Limited teacher training	Pichchenda (2024)
Soriano-Sánchez (2025)	ICT & simulations	Urban	↑ Motivation, Understanding	Limited ICT access	Soriano-Sánchez (2025)
Run et al. (2025)	Hands-on experiments	Rural	↑ Scientific skills	Lack of lab equipment	Run et al. (2025)
Winarto (2022)	Ethno-SETSaR approach	Mixed	↑ Problem-solving, Creativity	Curriculum constraints	Winarto (2022)
Mel (2023)	Group discussions	Urban	↑ Collaboration, Engagement	Large class size	Mel (2023)
UNESCO (2023)	Teacher-led workshops	Nation al	↑ Teacher preparedness	Resource disparity	UNESCO (2023)

The second major finding concerns the role of teacher factors and school infrastructure in supporting innovative approaches. Evidence shows that teachers with strong pedagogical content knowledge and confidence in science instruction are more likely to implement hands-on and ICT-based activities effectively (Thy et al., 2023). Table 2 summarizes how teacher preparedness, available resources, and school context affect implementation and student outcomes. Studies highlight that urban schools tend to have better ICT access and materials, while rural schools face challenges including multi-grade classrooms and limited professional development opportunities (Savrin et al., 2023). The synthesis shows that even where resources are limited, culturally responsive approaches such as integrating local environmental knowledge enhance student engagement and learning. These findings underline the need for policy and curriculum support to enable teachers to apply innovative methods consistently. Consequently, addressing teacher training, infrastructure, and contextual adaptation emerges as critical for advancing natural science education in Cambodian primary schools.

Table 2. Teacher and Infrastructure Factors Affecting Science Teaching Innovation

Study	Teacher Preparedness	School Context	Resources Available	Student Outcome	Implementation Barrier
Thy et al. (2023)	High	Urban	ICT & labs	↑ Engagement	Large class size
Savrin et al. (2023)	Medium	Rural	Minimal	↑ Creativity (partial)	Lack of training
Pichchenda (2024)	Medium	Mixed	Basic materials	↑ Understanding	Limited support

UNESCO (2023)	High	National	Workshops, guidelines	↑ Teacher efficacy	Resource disparity
Run et al. (2025)	Low	Rural	Minimal	Limited learning	Multi-grade classrooms
Winarto (2022)	High	Mixed	Local environment	↑ Problem-solving	Curriculum constraints

The synthesis of findings reveals that despite the documented benefits of innovative, inquiry-based and technology-enhanced teaching approaches for primary natural science education in Cambodia, the key determinants of success remain unevenly distributed across school contexts. Recent research demonstrates that teachers' self-efficacy and their capacity to integrate ICT strongly influence the fidelity of innovative practice implementation (Pov et al., 2024). Moreover, the effective use of culturally responsive pedagogy and locally relevant materials buffers the impact of infrastructure deficits, particularly in rural settings where resource limitations are more acute (Da Bou et al., 2025). These results underscore that simply introducing new teaching methods is insufficient; rather, systemic alignment of teacher preparation, school context, resource availability and cultural relevance is necessary to achieve meaningful improvements in student scientific literacy and engagement. By focusing on these interconnected layers, the gap between potential innovation and classroom reality can be bridged more effectively, offering a more sustainable pathway for enhancing primary science education in Cambodia.

Recent systematic reviews have underscored the growing role of digital technologies in supporting inquiry-based science education for young learners. For instance, the review by M. Yun & K. J. Crippen (2023) found that while technology has been widely used in the investigation and data-interpretation phases of inquiry, there remains scant evidence on its use for modeling and explanation processes, particularly in elementary science settings. Meanwhile, J.E. Hinostroza and colleagues (2024) identified seven key roles that digital technologies play in inquiry-based learning (IBL), including scaffolding, visualization, and feedback, yet they also pointed out persistent infrastructure and teacher-training barriers. These findings suggest that even when schools adopt technology-enhanced pedagogies, the depth and quality of implementation vary significantly depending on context, resources, and teacher competence. Collectively, the literature indicates that to move from sporadic to sustained innovation in primary science teaching, we must address the alignment of technology affordances, teacher capacity, and curriculum design—not just introduce devices or apps in isolation.

Another strand of recent literature focuses on meta-analyses of pedagogical models such as inquiry-based learning (IBL) and discovery learning, examining effect sizes in student outcomes. For example, a meta-analysis published by S. Aprilisia (2024) on the TPACK-based discovery learning model for elementary students reported a substantial effect size ($rES = 1.114$; $p < 0.001$), indicating strong promise of technology-integrated discovery approaches. Additionally, another meta-analysis by J.G.

Soriano-Sánchez (2025) on ICT in primary natural science teaching found that personalized adaptive systems and diversity-responsive designs markedly improved engagement and performance in science among primary pupils. These results point to the potential for robust student-learning gains when pedagogies combine inquiry, technology, and adaptation to learner diversity. However, the literature also emphasises that large effect sizes often occur in well-resourced settings or controlled studies, raising questions about scalability in low-resource and culturally diverse contexts—such as many primary schools in Cambodia.

This study's novelty lies in its dual-focus design, combining culturally responsive pedagogy with inquiry-based and technology-enhanced science teaching specifically at the primary school level in Cambodia. While previous research has addressed secondary or teacher-education contexts, few studies have targeted Cambodian primary classrooms with this integrative approach (Shih, 2024). For instance, although culturally responsive curricula have been reviewed broadly, their application in natural science for young learners remains under-explored (Tanjung et al., 2025). Moreover, recent investigations into innovative science learning tools show promise for 21st-century skills development (Leasa, 2024), yet they seldom connect with the realities of Cambodian rural primary settings. By situating innovation within Cambodia's local cultural, resource, and infrastructural constraints, this study offers new empirical ground. Hence, the potential contribution is twofold: advancing theoretical models of adapted pedagogy and generating practical strategies for low-resource primary contexts.

Furthermore, this research introduces a context-sensitive framework designed to operationalise how teacher pedagogical content knowledge, school infrastructure, and student engagement interact in innovative natural science education in Cambodia. Unlike generic models of innovation in education (OECD, 2023) that focus on broad system metrics, this framework adapts to the specificities of Cambodian primary schools—multi-grade classes, limited labs, and culturally diverse students. Recent studies emphasise that teacher self-efficacy for inclusive and innovative practice significantly impacts implementation outcomes (Pov, 2024). Additionally, research on culturally responsive science pedagogy shows that linking learners' cultural backgrounds, local knowledge and scientific inquiry can enhance science literacy (Rozi, 2025). By weaving together these strands in the Cambodian primary science context, the study aims to fill a gap in both theory and practice. In doing so, it offers a novel roadmap for policy-makers, teacher educators and schools to implement sustainable, innovation-driven science teaching.

The findings of this study hold substantial relevance beyond Cambodia, as they contribute to the global discourse on innovative primary science education in low-resource and culturally diverse contexts. By demonstrating how inquiry-based, technology-enhanced, and culturally responsive pedagogies can be integrated effectively, the study provides a model for other developing countries facing similar challenges in teacher preparedness, infrastructure, and student engagement (Shih, 2024). Insights from this research can guide international education policymakers, teacher-training

institutions, and curriculum developers in designing adaptable strategies that foster scientific literacy and 21st-century skills. Furthermore, the study emphasizes the importance of context-sensitive implementation, showing that innovation is not only about introducing new tools but also about aligning pedagogy with local culture and resources (Tanjung et al., 2025; Leasa, 2024). Such evidence can inform global educational programs, cross-cultural professional development, and comparative studies on primary science learning. Ultimately, the research highlights that achieving meaningful improvements in young learners' scientific understanding requires systemic coordination of pedagogy, technology, and cultural relevance, a lesson applicable across multiple global education systems.

CONCLUSION

This study concludes that the integration of inquiry-based, technology-enhanced, and culturally responsive pedagogies significantly improves primary students' engagement, scientific literacy, and problem-solving skills in Cambodian natural science education. The findings highlight that teacher preparedness, school infrastructure, and contextual adaptation are critical mediating factors for successful implementation. Rural schools face challenges including limited resources, multi-grade classrooms, and insufficient ICT access, yet culturally responsive approaches can mitigate some of these constraints. Evidence also suggests that professional development and targeted teacher training are essential to translate innovative methods into consistent classroom practice. The analysis underscores that sustainable improvements require systemic coordination among pedagogy, technology, and cultural relevance. By bridging gaps between theory and practice, the study provides a framework for low-resource contexts to adopt effective science teaching strategies. Overall, these conclusions offer actionable insights for policymakers, educators, and curriculum developers seeking to enhance primary science education. The study contributes both theoretically and practically to global discussions on innovation in early science education.

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