J-IAMSTEM
Journal of Innovation, Advancement, and Methodology in STEM Education
Vol. 3, No. 2, pp. 191-212, March-April 2026
https://so13.tci-thaijo.org/index.php/j_iamstem

Enhancing Elementary Student Teachers' Scientific Inquiry Skills through Community-Based Laboratory Tools: A Case Study of the KRU-Rak Thin Closed-System Teacher Production Program

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Received: 31 Jan 2026 Revised: 26 Mar 2026 Accepted: 27 Mar 2026

Abstract

The issue of teacher shortages in Thailand persists, particularly in small schools located in remote areas. Many teachers are unwilling to take long-term positions in these areas, resulting in a lack of educational opportunities for students. This study investigates the impact of community-based laboratory tools on the scientific inquiry skills of 67 elementary student teachers within the KRU-Rak Thin Closed-System Teacher Production Program in Thailand. Utilizing a mixed-methods case study design, the research addressed two primary objectives: determining how community-based tools enhance inquiry competencies and identifying the best practices that emerge from their implementation. Data was collected through a scientific inquiry skills test, rubric-based lesson plan evaluations, semi-structured interviews, focus group discussions, classroom observations, and reflective journals. Findings revealed a significant quantitative improvement in participants' inquiry skills, with post-test scores showing statistically significant gains. Qualitatively, the results demonstrated a professional shift in lesson planning from traditional, content-driven instruction to context-responsive inquiry cycles. Student teachers developed critical data collection and interpretation skills through authentic field investigations, such as community walking maps and fishbone diagrams, which effectively reconceptualized the local community as a "living laboratory." The study further identified emerging best practices, including the development of student-designed learning strategies that utilize local ecological phenomena and the implementation of school-community innovation projects that support local income generation. These interventions resulted in transformative changes in participants' professional identity, shifting their roles from mere content deliverers to confident community-based facilitators. By bridging the gap between formal science and community knowledge, the program fosters a more sustainable, culturally relevant, and collaborative approach to science education.

Keywords: scientific inquiry skills, community-based laboratory tools, teacher education, rural contexts, KRU-Rak Thin

1. Introduction

Scientific literacy is widely recognized as a central goal of contemporary education because it enables learners to interpret evidence, make reasoned decisions, and participate responsibly in a science- and technology-rich society. A key component of scientific literacy is scientific inquiry, which involves asking investigable questions, constructing explanations, designing and conducting investigations, interpreting data, and communicating conclusions based on evidence (Bybee, 2014; National Research Council [NRC], 2012; Yuenyong and Narjaikaew, 2009). For elementary education, these capacities are especially important because early experiences with science strongly influence children's curiosity, reasoning, and long-term attitudes toward scientific learning. Consequently, elementary teachers need not only conceptual understanding of science content but also the pedagogical capacity to engage learners in inquiry-oriented processes that are meaningful, developmentally appropriate, and connected to everyday life.

Despite its educational importance, inquiry-based science teaching remains difficult to implement in many teacher education settings. Pre-service teachers often have limited opportunities to experience authentic inquiry as learners, receive insufficient support in designing investigations, and rely heavily on textbook-based instruction rather than evidence-generating learning processes (Crawford, 2014; Windschitl et al., 2008). These challenges become more pronounced in rural and remote contexts, where schools frequently operate under constraints related to budget, laboratory equipment, instructional materials, and access to science-specific teaching support. In such settings, the problem is not simply a lack of resources; it is also a question of how teachers are prepared to transform locally available resources into meaningful scientific learning opportunities.

This issue is highly relevant in Thailand, where educational inequality continues to be associated with the uneven distribution of qualified teachers and learning resources across regions. Small rural schools, in particular, often face shortages of teachers, multi-grade teaching arrangements, and limited access to specialized materials for science learning. Within this context, teacher education cannot rely solely on idealized models of school science that assume the availability of standard laboratory infrastructure. Instead, it must prepare future teachers to design context-responsive instruction by using the materials, knowledge systems, and environmental phenomena available in their communities. For Thai teachers, especially those serving in underserved areas, effective science teaching therefore requires the capacity to connect disciplinary knowledge with pedagogy, contextual knowledge, and resourceful forms of practice.

This need may be understood through the lens of Technological Pedagogical Content Knowledge (TPACK), which has been widely used to explain how teachers integrate different domains of professional knowledge in instructional design. In the present study, TPACK is not interpreted narrowly as the use of digital devices alone, but more broadly as the capacity to connect content knowledge, pedagogical knowledge, and appropriate tools or mediating resources in ways that support learners' understanding (Mishra & Koehler, 2006). In the Thai context, this perspective is particularly significant because teachers in rural and remote schools often need to adapt instruction to conditions in which formal laboratory facilities or advanced technologies are limited. Thus, for student teachers preparing to work in such environments, TPACK involves learning how to transform locally available materials, community knowledge, and environmental contexts into pedagogically meaningful resources for science inquiry. In this sense, TPACK overlaps with pedagogical content knowledge (PCK) by emphasizing how teachers make subject matter teachable, while also extending that knowledge toward flexible and contextually grounded instructional design.

The present study is situated within the KRU-Rak Thin Closed-System Teacher Production Program, a teacher education initiative in Thailand designed to prepare student teachers who are committed to returning to teach in their local or nearby communities, particularly in underserved areas. For international readers, the program may be understood as a context-responsive teacher preparation model that seeks to address educational inequality through local teacher recruitment, targeted professional formation, and school-community engagement. Rather than preparing teachers for generalized placement alone, the program emphasizes professional commitment to local development, responsiveness to rural school realities, and the cultivation of teaching practices that are sustainable within community contexts. As such, the program aligns with broader theories of teacher education that stress constructivist learning, PCK, TPACK, and the situated nature of professional knowledge development.

Constructivist perspectives suggest that teachers develop meaningful professional understanding when they actively engage in experiences that require them to interpret phenomena, test ideas, reflect on evidence, and reconstruct knowledge through interaction with social and material contexts (Piaget & Inhelder, 1969). Similarly, situated learning theory proposes that professional competence develops most effectively when learning is embedded in authentic settings and communities of practice (Lave & Wenger, 1991). Applied to science teacher education, these perspectives imply that student teachers are more likely to develop robust inquiry-oriented practices when they learn through real contexts rather than through abstract discussion alone. This is particularly important in rural teacher preparation, where the context of practice is not peripheral to learning but constitutive of it.

In addition to these individual learning perspectives, the present study also draws on the idea of a whole-school approach. Within this study, the whole-school approach refers not only to classroom-level instructional change, but to the collaborative involvement of multiple actors in supporting teacher learning, including university educators, mentor teachers, partner schools, and community members. Inquiry-oriented teaching is difficult to sustain when it is treated solely as an individual teacher skill. By contrast, it becomes more feasible when schools and communities function together as learning environments in which local problems, local knowledge, and shared educational goals can be integrated into instructional design. For student teachers in the KRU-Rak Thin program, this whole-school orientation is especially relevant because their professional preparation takes place across university coursework, school placements, and community engagement. Accordingly, professional growth in inquiry teaching is shaped not only by what student teachers know, but also by the quality of collaboration and support available across these interconnected settings.

Within this broader perspective, community-based laboratory tools provide a promising approach for strengthening scientific inquiry skills. Community-based laboratory tools refer to the use of locally available materials, environmental phenomena, cultural practices, livelihood-related knowledge, and community spaces as resources for scientific investigation and science teaching. Rather than positioning the laboratory as a fixed physical room with specialized equipment, this approach expands the meaning of laboratory experience to include field-based exploration, contextual observation, community interviewing, evidence gathering from real settings, and the transformation of local resources into learning materials. Such an approach may be especially valuable in rural and resource-constrained settings because it reduces dependence on formal laboratory infrastructure while making scientific inquiry more relevant, feasible, and socially meaningful.

Previous studies have shown that inquiry-based science teacher education is strengthened when pre-service teachers engage in active investigation, collaborative reflection, and practice-based lesson design. Research has also indicated that context-based and community-linked pedagogies can improve relevance, learner engagement, and teachers' awareness of local knowledge systems. However, relatively limited research has examined how community-based laboratory tools can be used systematically within teacher education programs to strengthen elementary student teachers' scientific inquiry skills, particularly in rural and underserved contexts. Moreover, there remains a need to better understand how such approaches contribute not only to measurable improvement in inquiry competence, but also to the emergence of practical models or best practices that can inform teacher education and school-community collaboration more broadly.

To address this gap, the present study examined the implementation of a professional development program designed to enhance elementary student teachers' scientific inquiry skills through community-based laboratory tools within the KRU-Rak Thin Closed-System Teacher Production Program. The study contributes to the literature by presenting a contextualized model of inquiry-oriented science teacher preparation that is responsive to rural schooling conditions and grounded in collaboration among teacher education institutions, schools, and communities. It also offers insight into how student teachers can learn to design science instruction that reflects local cultural, environmental, and economic contexts while maintaining the core principles of scientific inquiry.

2. Research Questions

- How do community-based laboratory tools enhance the scientific inquiry skills of elementary student teachers within the KRU-Rak Thin Closed-System Teacher Production Program?
- How do best practices emerge from implementing community-based laboratory tools in the KRU-Rak Thin program for enhancing scientific inquiry skills?

3. Conceptual Framework

The conceptual framework of this study integrates three complementary perspectives: constructivist learning theory, situated learning, and teacher professional development. Constructivist theory explains that learners develop understanding by actively constructing knowledge through interaction with ideas, materials, and social contexts (Piaget & Inhelder, 1969). In science teacher education, this means that student teachers strengthen inquiry competence when they engage directly in questioning, investigating, interpreting evidence, and reflecting on their practice.

Situated learning further suggests that professional knowledge develops most effectively when learning is embedded in authentic contexts and communities of practice (Lave & Wenger, 1991). From this perspective, community-based laboratory tools are not merely alternative teaching materials; they are mediating resources that connect science concepts to local environments, local knowledge, and real problems in schools and communities. These tools enable student teachers to learn inquiry not as an abstract procedure, but as a contextual and socially meaningful practice.

The framework also draws on scholarship on effective teacher professional development, which emphasizes content focus, active learning, collaboration, coherence, and sustained engagement over time (Desimone, 2009; Darling-Hammond et al., 2017). In the present study, the professional development program served as the mechanism through which community-based laboratory tools were introduced, practiced, reflected upon, and translated into lesson planning and classroom implementation.

Based on this framework, the study assumes that participation in a contextualized professional development program using community-based laboratory tools will enhance student teachers' scientific inquiry skills, improve the quality of inquiry-based lesson design, and strengthen their capacity to create culturally and pedagogically relevant science learning in rural school contexts.

4. Literature Review

4.1 Scientific Inquiry Skills

Scientific inquiry skills refer to the abilities required to engage in the practices of science, including identifying problems, asking investigable questions, constructing hypotheses or explanations, designing investigations, collecting and analyzing data, interpreting evidence, and communicating findings (NRC, 2012). These skills are central to scientific literacy because they promote reasoning, problem solving, and the evaluation of claims based on evidence (Bybee, 2014).

Recent perspectives on science education emphasize that inquiry is not a rigid sequence of steps, but a dynamic and iterative process through which learners construct explanations and revise ideas in light of evidence (Crawford, 2014; Windschitl et al., 2008). For this reason, preparing elementary teachers to use inquiry-based teaching requires opportunities for authentic investigation and reflection rather than only theoretical instruction.

However, pre-service teachers often enter teacher education with limited experience in authentic inquiry, largely because prior science learning has frequently emphasized memorization and teacher-directed procedures (Lotter et al., 2007). Strengthening inquiry competence in teacher preparation programs is therefore essential if future teachers are to design science learning that is active, evidence-based, and meaningful for children.

4.2 Community-Based Laboratory Tools

Community-based laboratory tools are instructional resources derived from local environments, cultural practices, and community knowledge that can be used to support science investigation. These may include natural materials, local ecological systems, traditional practices, simple apparatus created from low-cost materials, or community issues that can be examined scientifically. In contrast to conventional laboratory models, this approach emphasizes accessibility, contextual relevance, and sustainability, especially in settings where formal laboratory facilities are limited (Aikenhead and Elliott (2010); Bang and Medin (2010); Gruenewald (2003); Gay (2010).

This approach is consistent with place-based and culturally responsive education because it positions local knowledge and lived experience as legitimate foundations for learning (Bang & Medin, 2010; Gay, 2010; Gruenewald, 2003). In teacher education, community-based laboratory tools can help student teachers connect scientific concepts to everyday realities, thereby increasing the relevance of inquiry and reducing dependence on expensive materials.

For rural teacher preparation, such tools are especially valuable because they support feasible, context-sensitive science teaching. When student teachers learn to use available local resources for investigation, they are better prepared to teach in schools with limited infrastructure while still maintaining meaningful inquiry experiences for learners.

4.3 Teacher Professional Development for Inquiry-Based Science Teaching

Teacher professional development is most effective when it is sustained, collaborative, content-focused, and grounded in active learning experiences (Desimone, 2009; Guskey, 2002). In science education, professional development that explicitly addresses inquiry practices can strengthen teachers' pedagogical content knowledge and their capacity to facilitate student-centered learning.

For pre-service teachers, professional development can be embedded in coursework, field experiences, and collaborative lesson design. These activities are particularly powerful when they are connected to authentic school and community contexts. Community-based professional learning models therefore offer an important pathway for preparing teachers to design inquiry-based science experiences that are both pedagogically sound and locally relevant.

5. Methodology

5.1 Research Design

This study employed a mixed-methods case study design to investigate how community-based laboratory tools enhanced the scientific inquiry skills of elementary student teachers within the KRU-Rak Thin Closed-System Teacher Production Program and how best practices emerged through program implementation. A mixed-methods approach was appropriate because the study sought to examine both measurable changes in participants' inquiry-related competencies and the meanings, experiences, and practices associated with their professional learning. The case study design was used because the research focused on a bounded program situated within a specific teacher education context in Thailand, where participant development was shaped by the interaction of coursework, field experiences, school placements, and community engagement.

The study was guided by an interpretive-pragmatic orientation. Quantitative data were used to identify changes in scientific inquiry skills and lesson planning quality before and after participation in the program, while qualitative data were used to explain how those changes occurred and what forms of practice emerged during implementation. In this way, the integration of data sources enabled the researchers to examine both outcomes and processes of teacher learning in context.

5.2 Research Context and Participants

The study was conducted within the KRU-Rak Thin Closed-System Teacher Production Program at Phuket Rajabhat University, Thailand. The program is intended to prepare student teachers for service in local or nearby communities, particularly in rural and underserved settings. This context made it especially relevant for examining how elementary student teachers could be prepared to design inquiry-based science learning in schools where formal laboratory facilities and instructional resources may be limited.

Participants were 67 student teachers enrolled in the Elementary Education and Early Childhood Education programs under the KRU-Rak Thin program. All participants were in a phase of preparation that required them to engage in professional learning related to school-based teaching, contextual lesson design, and community-linked educational practice. They were selected through purposive sampling because they represented the target population of the program and were directly involved in the professional development activities examined in this study.

5.3 Conceptualization of Scientific Inquiry Skills

In this study, scientific inquiry skills were conceptualized as the abilities required to engage in evidence-based scientific investigation and to design learning experiences that support such investigation. Drawing on the science practices perspective of the National Research Council, scientific inquiry skills in this study included five interrelated dimensions:

(1) identifying and formulating investigable questions,
(2) constructing explanations or tentative hypotheses,
(3) designing appropriate procedures for investigation,
(4) collecting, organizing, and interpreting data or evidence, and
(5) drawing and communicating evidence-based conclusions.

These dimensions were used to guide the development of the quantitative assessment, the lesson plan rubric, the observation focus, and the qualitative coding framework. The framework also reflected the nature of inquiry as a dynamic and iterative process rather than a fixed sequence of steps. Thus, the study viewed scientific inquiry skills not only as cognitive competencies but also as practical and pedagogical capacities enacted through field-based and classroom-based experiences.

5.4 Professional Development Program

The intervention examined in this study was a professional development program designed to strengthen student teachers' scientific inquiry skills through the use of community-based laboratory tools. The program was developed collaboratively by university instructors, mentor teachers, and community-linked educational partners to ensure both pedagogical soundness and contextual relevance. Its design was informed by constructivist learning theory, situated learning, TPACK, and a whole-school perspective emphasizing collaboration across university, school, and community contexts.

5.5 The program consisted of five interconnected phases.

First, a needs assessment phase was conducted to identify participants' prior strengths and limitations in scientific inquiry, science lesson design, and the use of local resources for teaching. This phase also included contextual analysis of partner schools and communities to identify available materials, local knowledge, environmental issues, and school-community learning opportunities relevant to elementary science.

Second, a design phase was undertaken to develop learning experiences, tools, and support mechanisms for the program. This included the preparation of workshops on scientific inquiry processes, examples of community-based science activities, lesson design guidance, and shared criteria for evaluating inquiry-oriented lesson plans.

Third, an implementation phase engaged student teachers in workshops, collaborative lesson planning, community exploration, school-based practice, and reflective learning tasks. During this phase, participants examined local materials and phenomena, visited community sites, interacted with local informants, and designed science learning activities that treated communities as living laboratories for inquiry.

Fourth, a classroom and field application phase enabled participants to translate their learning into practice by designing and implementing lesson plans in partner schools. They were encouraged to create inquiry-based learning experiences that reflected local cultural, environmental, and economic contexts.

Finally, an evaluation and reflection phase involved the collection and analysis of pre- and post-program evidence, followed by reflective discussion on effective practices, challenges, and implications for future teacher preparation.

5.6 Research Instruments

5.6.1 Scientific Inquiry Skills Test

Quantitative data on scientific inquiry skills were collected through a pre- and post-test developed by the research team based on the scientific practices framework of the National Research Council and related scholarship on inquiry-based science learning. The test was designed to assess the five dimensions of scientific inquiry skills identified in the conceptual framework of the study: question formulation, explanation or hypothesis construction, investigation design, data interpretation, and evidence-based conclusion.

The instrument consisted of 30 items with a total score of 30 points. The test was structured to assess participants' understanding and application of scientific inquiry processes in authentic elementary science learning contexts. The items included questions that required participants to identify investigable questions, select or propose appropriate procedures for inquiry, interpret evidence, and draw reasoned conclusions based on data.

The instrument was reviewed by experts in science education and teacher education to ensure content validity and alignment with the purposes of the study. The Index of Item-Objective Congruence (IOC) was 1.00, indicating that all items were fully congruent with the intended objectives. The reliability coefficient of the instrument was 1.00. These results indicated that the instrument demonstrated a very high level of content validity and internal consistency for use in the study.

The instrument used in this study was a researcher-developed Scientific Inquiry Skills Test (SIST) grounded in the inquiry practices framework of the National Research Council (2012). The test consisted of 30 items scored on a 30-point scale and covered five dimensions: (1) formulating investigable questions, (2) constructing explanations or hypotheses, (3) designing investigations, (4) interpreting data and evidence, and (5) drawing evidence-based conclusions. The items included multiple formats, such as selecting the most appropriate investigable question from a classroom scenario, identifying weaknesses in an investigation design, interpreting simple data displays, and justifying a conclusion based on evidence.

5.6.2 Rubric-Based Evaluation of Lesson Plans

To examine changes in participants' capacity to design inquiry-oriented science instruction, lesson plans were evaluated using a rubric developed for the study. The rubric focused on the quality of lesson design rather than the superficial presence of activity steps. It included the following dimensions:

(1) clarity and relevance of inquiry learning objectives,
(2) quality of investigable questions or problem situations,
(3) appropriateness of investigation design and opportunities for evidence generation,
(4) integration of community-based laboratory tools and local resources,
(5) contextual relevance to local cultural, environmental, or economic conditions, and
(6) alignment of assessment strategies with inquiry learning outcomes.

Each dimension was scored on a four-level scale ranging from 1 (limited) to 4 (highly effective). The rubric was used to assess lesson plans before and after the program to identify improvement in inquiry orientation and contextual responsiveness. To strengthen the credibility of scoring, lesson plans were independently reviewed by evaluators with expertise in science teacher education, and discrepancies were discussed to improve scoring consistency.

For example, in the dimension "quality of investigable questions," a score of 1 indicated questions that were vague, factual, or not investigable through classroom or field-based inquiry; a score of 2 indicated partially investigable questions with limited alignment to the lesson context; a score of 3 indicated clear investigable questions with reasonable connection to inquiry activity; and a score of 4 indicated well-focused, contextually relevant investigable questions that could generate observable evidence and guide meaningful inquiry.

5.6.3 Semi-Structured Interviews

Semi-structured interviews were conducted with 67 participants to gain an in-depth understanding of how they perceived the role of community-based laboratory tools in developing their scientific inquiry skills and professional practice. The interviews explored participants' experiences in using local materials and community knowledge, their confidence in designing inquiry-based learning, their views on the relevance of local contexts for elementary science education, and the challenges they encountered during implementation.

Interview questions were open enough to allow participants to describe their experiences in detail while remaining aligned with the research questions. Interviews also probed changes in professional identity, especially participants' emerging sense of themselves as teachers capable of designing locally responsive science learning.

Semi-structured interviews were conducted with participants after the implementation phase and again after lesson enactment to capture changes in beliefs and practices. Each interview lasted approximately 30–45 minutes and focused on participants' perceptions of inquiry, confidence in using community-based tools, and their views of local knowledge as a resource for science teaching.

Three rounds of focus group discussions were conducted, each involving 8–12 student teachers, to examine collective reflection on effective learning activities and emerging best practices. Classroom observations were guided by an observation protocol focusing on five aspects: (1) use of investigable questions, (2) opportunities for evidence generation, (3) use of community-based tools or contexts, (4) student participation in discussion and interpretation, and (5) reflection on findings.

5.6.4 Focus Group Discussions

Focus group discussions were used to capture shared reflections and collective meaning-making among participants. A total of three rounds of focus group discussions were conducted during the study. These discussions were particularly useful for examining how best practices emerged through collaboration, peer learning, and reflection on field experiences.

Participants discussed the learning activities they considered most influential, the features of effective community-based laboratory tools, and examples of lesson ideas or projects that reflected local school-community realities. Focus groups also generated data on how participants interpreted the educational value of local knowledge and community engagement.

5.6.5 Classroom Observations

Classroom observations were conducted during the implementation of student teachers' lesson plans in partner schools. A total of three rounds of observations were carried out to examine how inquiry-based teaching was enacted in practice over time. The observations focused on how participants introduced investigable questions, facilitated evidence collection, used community-based materials or contexts, supported student discussion, and guided reflection on findings.

Observation records also documented the extent to which the lesson design aligned with inquiry principles and how learners engaged with the activities. These observations were important for triangulating claims made in interviews, focus groups, and lesson plan documents.

5.6.6 Reflective Journals and Student Artifacts

Participants' reflective journals and selected artifacts, such as lesson plans, field notes, community walking maps, and project outputs, were collected as supplementary qualitative data. These materials provided evidence of participants' evolving thinking, their interpretation of community-based inquiry experiences, and the ways in which they translated local information into science teaching resources. Artifacts were especially useful for identifying concrete examples of contextualized learning management strategies and community-linked inquiry practices.

5.7 Data Collection Procedures

Data collection occurred across the major phases of the professional development program. At the beginning of the study, participants completed the scientific inquiry skills pre-test and submitted initial lesson planning work for baseline evaluation. During the program, qualitative data were gathered through classroom observations, interviews, focus group discussions, reflective journals, and participant artifacts. These data documented participants' learning experiences, collaborative processes, and pedagogical development while the program was in progress.

At the conclusion of the program, participants completed the post-test and submitted revised or final lesson plans for rubric-based evaluation. In addition, follow-up interviews and focus group discussions were conducted to capture participants' reflections on how the program influenced their scientific inquiry skills, confidence, perceptions of local knowledge, and approaches to teaching. The collection of data at multiple points enabled the researchers to examine both development over time and the relationship between measurable outcomes and lived learning experiences.

5.8 Data Analysis

5.8.1 Quantitative Analysis

Quantitative data from the scientific inquiry skills test and lesson plan rubric were analyzed using descriptive and inferential statistics. Means and standard deviations were calculated to summarize participant performance before and after the intervention. Paired-sample t-tests were used to examine whether differences between pre- and post-program scores were statistically significant. This analysis enabled the researchers to determine whether participation in the program was associated with measurable improvement in scientific inquiry skills and inquiry-oriented lesson design.

5.8.2 Qualitative Analysis

Qualitative data from interviews, focus groups, observations, reflective journals, and artifacts were analyzed using thematic analysis. The analysis began with repeated reading of the data to achieve familiarity, followed by initial coding of segments related to inquiry development, contextual learning, community engagement, lesson design, and professional identity. Codes were then grouped into broader categories and themes that addressed the two research questions.

Attention was given to themes that explained how community-based laboratory tools supported inquiry development and how best practices emerged during implementation. Examples included the use of local materials as mediating tools for investigation, the integration of community knowledge into lesson design, the development of context-responsive teaching strategies, and changes in participants' confidence and identity as inquiry-oriented teachers.

5.8.3 Integration of Quantitative and Qualitative Data

The study used convergent mixed-methods logic in which quantitative and qualitative evidence were brought together during interpretation. Quantitative results indicated the extent of change in inquiry skills and lesson plan quality, while qualitative findings explained the processes and conditions through which these changes occurred. The integration of data strengthened the overall interpretation by allowing statistical trends to be understood in relation to participants' experiences, practices, and contextual realities.

5.8.4 Trustworthiness, Validity, and Ethical Considerations

Several strategies were employed to enhance the trustworthiness and validity of the study. For the quantitative component, the scientific inquiry skills test and lesson plan rubric were aligned with clearly defined conceptual dimensions and reviewed for content appropriateness. The scientific inquiry skills instrument demonstrated strong evidence of quality, with an IOC of 1.00 and a reliability coefficient of 1.00.

For the qualitative component, data triangulation was achieved with multiple sources, including semi-structured interviews with 67 participants, three rounds of focus group discussions, three rounds of classroom observations, reflective journals, and participant artifacts. Method triangulation was also used to compare patterns across quantitative and qualitative findings.

To strengthen interpretive credibility, the researchers engaged in collaborative review of coding and thematic development. Representative excerpts and artifacts were used to support analytic claims, and themes were checked against multiple data sources before interpretation.

The study was conducted in accordance with ethical principles for educational research. Participants were informed about the purposes of the study, the voluntary nature of participation, and the confidential handling of research data. Consent was obtained prior to data collection, and identifying information was removed or anonymized in reporting the findings.8. Findings

This section presents the findings in relation to the two research questions. The first part addresses how community-based laboratory tools enhanced the scientific inquiry skills of elementary student teachers. The second part explains how best practices emerged from the implementation of community-based laboratory tools within the KRU-Rak Thin Closed-System Teacher Production Program. The findings are drawn from both quantitative and qualitative data, including pre- and post-test scores, lesson plan evaluations, semi-structured interviews with 67 participants, three rounds of focus group discussions, three rounds of classroom observations, reflective journals, and student artifacts. These sources were used to triangulate the interpretation of participants' learning and professional development

To further illustrate these attitudinal changes, several participants explicitly described increased confidence in inquiry-based teaching, stronger appreciation of local knowledge, and a growing sense of professional identity as context-responsive educators. One participant explained, "Before joining this program, I was not confident in teaching science through inquiry because I thought experiments required formal laboratory equipment. After working with community-based laboratory tools, I realized that inquiry can begin with simple observations, local materials, and meaningful questions from students' everyday lives" (Interview participant). Similarly, another participant noted, "I used to think that science teaching had to rely mainly on textbooks or school materials, but this program showed me that community knowledge is also an important learning resource" (Interview participant). This transformation also extended to professional identity, as reflected in the statement: "This experience changed the way I see myself as a teacher. I no longer think that my role is only to deliver content. I feel that I should design learning based on students' contexts, community resources, and the real conditions of the school" (Interview participant). Together, these accounts reinforce the view that the program influenced not only participants' instructional skills but also their beliefs, values, and professional self-understanding.

6.Findings

Findings revealed how community-based laboratory tools of the KRU-Rak Thin Closed-System Teacher Production Program enhanced the scientific inquiry skills of elementary student teachers. The section will clarify 1) community-based laboratory tools enhanced the scientific inquiry skills of elementary student teachers, and 2) best practices and transformative outcomes resulting from the implementation of community-based laboratory tools.

6.1 Community-based laboratory tools enhanced the scientific inquiry skills of elementary student teachers

The findings demonstrate that community-based laboratory tools enhanced the scientific inquiry skills of elementary student teachers through the following four dimensions: 1) improvement in scientific inquiry skills, 2) improvement in inquiry-oriented lesson planning, 3) development through authentic field investigation, and 4) reconceptualization of the community as a learning laboratory.

6.1.1 Improvement in scientific inquiry skills

The quantitative findings indicated that the student teachers' scientific inquiry skills improved after participation in the professional development program. As shown in Table 1, the mean score increased from 62.4 on the pre-test to 81.7 on the post-test, with the difference reported as statistically significant at the .01 level. This finding suggests that the program effectively strengthened participants' inquiry-related competencies. The improvement is consistent with the overall design of the intervention, which combined inquiry workshops, collaborative lesson planning, field-based investigation, and contextual application in partner schools

Table 1 Pre- and Post-Test Scores of Scientific Inquiry Skills (n = 67)

Measure	Mean	SD	Interpretation
Pre-test	62.4	7.8	Moderate baseline level of scientific inquiry skills
Post-test	81.7	5.9	Higher level after program participation
Statistical result	–	–	Significant difference at $p < .01$

Table 1 showed that the participants' scientific inquiry skills increased substantially after the intervention. The higher post-test mean indicates that the community-based laboratory tool approach contributed to measurable gains in inquiry competence.

6.1.2 Improvement in inquiry-oriented lesson planning

The rubric-based evaluation of lesson plans also showed notable improvement. Before the intervention, lesson plans were largely content-driven and tended to emphasize teacher explanation rather than student questioning, investigation, and evidence-based reasoning. After the intervention, the lesson plans more consistently reflected inquiry cycles, including questioning, hypothesizing, data collection, interpretation, and reflection. They also demonstrated stronger alignment with local school and community contexts, suggesting that participants were better able to connect science content with authentic local resources and lived experiences. As shown in Table 2, the lesson plans shifted from content-oriented teaching toward more inquiry-based and context-responsive instructional design after the intervention.

Table 2 Summary of Changes in Lesson Plan Quality

Aspect of lesson planning	**Before the program**	**After the program**
Inquiry orientation	Mostly content transmission	More explicit use of inquiry cycles
Student questioning	Limited	More opportunities for investigable questions
Evidence generation	Minimal	Greater emphasis on data collection and interpretation
Contextual relevance	Weak or generic	Stronger integration of local school and community context
Use of community resources	Limited	More purposeful use of local materials and knowledge

6.1.3 How inquiry skills developed through authentic field investigation

The qualitative findings explain how these improvements occurred. Evidence from interviews, observations, reflective journals, and student artifacts showed that community-based laboratory tools enabled participants to engage in inquiry through authentic field investigation rather than through abstract discussion alone. One of the clearest examples was the production of a community walking map, which required student teachers to observe real settings, collect and verify field data, interpret local information, and transform those data into a systematic visual representation. This artifact functioned as concrete evidence that the participants were applying inquiry skills in an authentic community context Three interrelated processes were especially visible.

First, participants developed systematic observation and data collection skills. During field visits, they documented roads, households, water sources, public facilities, shops, agricultural areas, and other community landmarks. Their observations became more focused and evidence-based over time, suggesting development in noticing, classification, and recording.

Second, they developed interviewing and contextual interpretation skills. The student teachers did not rely solely on visible physical features; they also interviewed community members to understand place names, local meanings, and the social functions of different sites. This allowed them to compare observed evidence with local explanations and refine their understanding through data verification.

Third, they improved in data organization and representation. The walking maps showed that the participants were able to convert raw field notes, sketches, and oral accounts into a coherent representation using legends, directional markers, and categorized spatial information. This suggests that inquiry development extended beyond data collection to include analytical organization and evidence-based communication

Figure 2 presents an example of a community walking map produced by student teachers during field investigation. The artifact illustrates how participants collected, verified, organized, and represented community data through observation, interviewing, and contextual interpretation.

Figure 1. Example of a community walking map created by student teachers as evidence of field-based inquiry

The walking map demonstrates that scientific inquiry skills were enacted through authentic fieldwork rather than discussed only at a conceptual level.

Table 3 demonstrates that scientific inquiry skills were enacted through real community investigation, not merely reported as perceptions by participants.

In addition to community walking maps, student teachers also produced analytical artifacts such as fishbone diagrams to identify local problems, trace contributing causes, and consider feasible responses. These artifacts indicate that inquiry development extended beyond observation and data collection to include problem analysis, interpretation, and evidence-based decision making.

Table 3 Qualitative Evidence of Scientific Inquiry Skill Development

Inquiry skill dimension	Evidence from field-based learning
Observation	Participants recorded physical spaces, utilities, environmental features, and community resources during field visits
Data collection	Field notes, route tracing, sketches, and community interviews were used to gather evidence
Data verification	Information from observation was cross-checked with community members
Interpretation	Participants identified local meanings, functions, and relationships among places
Representation	Community walking maps transformed field data into organized visual evidence

Figure 2. Fishbone diagram created by student teachers to analyze community problems and their causes based on field investigation in Ban Tu Tae Ra.

Figure 3. Fishbone diagram created by student teachers to identify possible solutions and prioritize community-based intervention.

6.1.4 Reconceptualizing the community as a learning laboratory

Another important qualitative finding was that student teachers began to understand inquiry as a contextualized and participatory process. Rather than viewing scientific inquiry as something confined to a formal laboratory, participants increasingly recognized that community environments could function as living laboratories in which they could observe, question, verify, interpret, and communicate findings. This shift in understanding was pedagogically important because it expanded the meaning of laboratory experience and made inquiry more feasible in rural and resource-constrained educational settings

These findings indicate that community-based laboratory tools enhanced scientific inquiry skills in both measurable and practical ways. The quantitative gains in test scores were reinforced by qualitative evidence showing that participants performed inquiry through field investigation, community interaction, and artifact production.

6.2 Best practices and transformative outcomes resulting from the implementation of community-based laboratory tools

The findings identify the emergence of best practices and transformative outcomes resulting from the implementation of community-based laboratory tools. The findings will identify 1) Best Practices in Learning Activities Using Community-Based Laboratory Tools, 2) Student-Designed Learning Management Strategies Reflecting Local Contexts, 3) Income-Generating and School-Community Innovation Projects, 4) Changes in Confidence, Attitudes, and Professional Identity

6.2.1 Best practices in learning activities using community-based laboratory tools

The qualitative findings revealed that best practices emerged when student teachers used local materials, environmental phenomena, traditional practices, and community issues as the basis for science learning. These activities were effective because they were accessible, relevant, and feasible in schools with limited formal laboratory infrastructure. Participants learned that science instruction could be grounded in resources already available in students' daily lives, thereby making inquiry more meaningful and sustainable in rural contexts

Table 4 Highlights of Learning Activities Using Community-Based Laboratory Tools

Learning activity	Community-based laboratory tool/resource	Inquiry process involved	Learning value
Community walking map	Local spaces, landmarks, residents' knowledge	Observation, interviewing, verification, representation	Strengthened field-based inquiry and data interpretation
Water filtration project	Locally available materials and water-related community issues	Problem identification, design, testing, revision	Connected science to community problem-solving
Sustainable agriculture activity	Local agricultural practices and environmental resources	Observation, experimentation, contextual application	Linked inquiry to livelihood and environmental learning
Local product development	Community materials and economic practices	Design thinking, testing, reflection	Connected science learning with local economic context

Table 4 shows that the most effective activities were those that combined scientific processes with locally meaningful materials, problems, and community knowledge.

6.2.2 Student-designed learning management strategies reflecting local contexts

Another best practice was the emergence of learning management strategies that reflected local cultural, environmental, and economic contexts. The lesson plans produced after the intervention were more context-sensitive and better aligned with community realities than those prepared before the program. Instead of using generic activities, the student teachers designed inquiry lessons based on local environmental features, community resources, and students' everyday experiences. This contextualization increased the authenticity of the learning process and demonstrated growing pedagogical flexibility among participants

The community walking map also reflects how student teachers translated local environmental and social information into context-responsive teaching resources. This type of artifact demonstrates pedagogical adaptation grounded in local realities.

Figure 4. A community walking map created by a student teacher during field-based inquiry.

Table 5 Examples of Student Teachers' Designed Learning Management Strategies

Contextual focus	Example of strategy	Inquiry feature reflected
Local environment	Using nearby environmental features as sites for observation and investigation	Evidence gathering from real settings
Local culture/community knowledge	Integrating residents' explanations and local practices into science lessons	Multiple sources of evidence
Local economy	Designing activities linked to local products or livelihoods	Problem-based and applied inquiry
School-community context	Adapting lessons to available school and community resources	Feasible and context-responsive inquiry design

These examples indicate that best practice did not emerge from standardized lesson delivery, but from the student teachers' ability to adapt inquiry teaching to the realities of local school-community contexts.

6.2.3 Income-generating and school-community innovation projects

The findings also showed that inquiry-based learning extended beyond classroom activity into school-community innovation projects. The manuscript identifies examples such as water filtration systems, sustainable agriculture activities, and locally relevant product development, which reflected the integration of scientific and engineering design processes with community needs. These projects demonstrated that inquiry learning could contribute to local problem-solving and, in some cases, support community-oriented productive activity. They also illustrated the diversity of student teachers' work and their growing ability to connect science education with practical community development

Table 6 illustrates that the student teachers' work was diverse and extended beyond lesson planning into community-linked innovation and applied inquiry.

Figure 5 illustrates how student teachers translated field-based inquiry into a school-community innovation project. The V-diagram shows the integration of problem identification, contextual analysis, hypothesis formulation, planning, and expected community impact in a locally relevant product development initiative.

Table 6 Examples of School-Community Projects Emerging from the Program

Project type	Community relevance	Inquiry/engineering element	Educational significance
Water filtration system	Responded to local water-related issues	Designing, testing, and improving a solution	Linked science with practical community problem-solving
Sustainable agriculture activity	Connected with local agricultural practices	Observation, experimentation, and contextual adaptation	Integrated environmental science with local livelihood knowledge
Locally relevant product development	Related to community materials or economic practices	Design, trial, revision, and reflection	Connected inquiry with local economic and cultural relevance

Figure 5. V-diagram developed by student teachers for a community-based product innovation project on processed fish snacks linked to local economic needs.

6.2.4 Changes in confidence, attitudes, and professional identity

Finally, best practices also emerged through changes in participants' attitudes toward inquiry-based teaching. Interviews, focus groups, reflective journals, and classroom observations indicated three recurring themes:

(1) increased confidence in using inquiry-based methods,

(2) greater appreciation for local knowledge and community involvement, and

(3) enhanced professional identity as educators capable of tailoring instruction to student needs and local contexts.

These attitudinal shifts were important because they suggest that the intervention strengthened not only participants' technical competence but also their dispositions toward context-responsive and inquiry-oriented teaching

The qualitative evidence further demonstrated that the program influenced student teachers' attitudes toward inquiry-based teaching in three major ways: increased confidence in using inquiry-based methods, greater appreciation of local knowledge and community participation, and a stronger sense of professional identity as context-responsive educators.

One participant explained, "Before joining this program, I was not confident in teaching science through inquiry because I thought experiments required formal laboratory equipment. After working with community-based laboratory tools, I realized that inquiry could begin with simple observations, local materials, and meaningful questions from students' everyday lives."

Another participant emphasized the value of local knowledge: "I used to think that science teaching had to rely mainly on textbooks or school materials, but this program showed me that community knowledge is also an important learning resource."

This shift also extended to professional identity. As one participant stated, "This experience changed the way I see myself as a teacher. I no longer think that my role is only to deliver content. I feel that I should design learning based on students' contexts, community resources, and the real conditions of the school." These excerpts suggest that the intervention influenced not only participants' inquiry skills but also their beliefs, values, and sense of responsibility as future teachers.

Table 7 Key Themes in Student Teachers' Attitudes and Professional Development

Theme	Evidence from qualitative data	Interpretation
Increased confidence in inquiry-based teaching	Reflections and interviews indicated greater willingness to ask questions, guide investigations, and interpret findings	Participants became more confident in facilitating inquiry
Appreciation of local knowledge and community involvement	Participants recognized community members and local contexts as valuable educational resources	Inquiry was reframed as socially and culturally grounded
Enhanced professional identity	Student teachers described stronger responsibility and readiness to design context-responsive science lessons	Professional growth extended beyond skill acquisition

These themes suggest that the emergence of best practices depended not only on improved skills, but also on a broader transformation in how student teachers understood their role as science educators.

7. Conclusion and Discussion

The findings show that community-based laboratory tools enhanced scientific inquiry skills through a combination of measurable improvement and authentic practice. Quantitatively, participants demonstrated significantly higher post-test scores after the intervention. Qualitatively, they showed stronger performance in observation, interviewing, interpretation, evidence verification, and representational communication through field-based inquiry activities such as community walking map construction. At the same time, best practices emerged when inquiry learning was grounded in locally available resources, supported through collaboration with schools and communities, and extended into contextualized lesson design and school-community innovation projects. These integrated findings indicate that community-based laboratory tools functioned not merely as supplementary materials, but as a core mechanism for developing inquiry-oriented, context-responsive science teacher preparation in the KRU-Rak Thin program

This study examined how community-based laboratory tools enhanced the scientific inquiry skills of elementary student teachers in the KRU-Rak Thin Closed-System Teacher Production Program and how best practices emerged through the implementation of this approach. The discussion of findings suggests that the intervention was effective not only in improving measurable inquiry competence, but also in reshaping participants' understanding of science teaching as a contextualized, collaborative, and community-responsive practice. These results are important because they show that inquiry-oriented teacher preparation in rural contexts can be strengthened when scientific investigation is grounded in locally meaningful settings rather than limited to conventional laboratory environments.

7.1 Community-based laboratory tools as a mechanism for enhancing scientific inquiry skills

The first major finding of the study was that community-based laboratory tools contributed to significant improvement in student teachers' scientific inquiry skills. The increase in post-test scores, together with the observed improvement in lesson planning quality, suggests that the intervention strengthened both conceptual understanding and pedagogical application of inquiry. This result supports prior scholarship indicating that inquiry competence develops more effectively when learners actively engage in questioning, investigating, interpreting evidence, and reflecting on authentic experiences rather than receiving inquiry as a purely theoretical concept (Crawford, 2014; Windschitl et al., 2008). In this study, inquiry was learned through fieldwork, collaborative lesson design, classroom enactment, and reflective analysis, which likely explains why the improvement was evident in both quantitative and qualitative forms.

More specifically, the qualitative findings suggest that the effectiveness of the intervention lay in its ability to make inquiry visible and practicable. Participants did not simply learn about inquiry as a prescribed sequence of steps. Instead, they enacted inquiry through observing community environments, interviewing local residents, recording and organizing evidence, and transforming field information into meaningful representations such as the community walking map. This indicates that community-based laboratory tools functioned not as supplementary materials, but as mediating resources through which inquiry practices became concrete, accessible, and educationally meaningful. In this sense, the findings extend the literature by showing that inquiry development in teacher education can occur through locally available resources and social interaction, even in settings where formal laboratory infrastructure is limited.

7.2 Inquiry as a situated and constructivist process

A second important interpretation concerns the nature of inquiry learning itself. The findings strongly suggest that student teachers developed scientific inquiry skills because the program positioned inquiry as a situated and constructivist process. This aligns with constructivist theory, which views learning as the active construction of meaning through engagement with ideas, materials, and social contexts, and with situated learning theory, which emphasizes that professional knowledge develops most effectively in authentic contexts and communities of practice. In the present study, the community was not merely a backdrop for teaching practice; it became the site through which inquiry was experienced, negotiated, and understood. This helps explain why participants moved beyond procedural knowledge toward a more interpretive and evidence-based understanding of science learning.

The role of the walking map is especially important in this regard. As an artifact, it demonstrated that participants could transform fragmented field evidence into an organized representation of community space, relationships, and resources. This process required observation, verification, categorization, and synthesis, all of which are central dimensions of inquiry. The walking map therefore represented more than an assignment product; it embodied the process of knowledge construction through authentic inquiry. This finding supports the argument that inquiry-oriented teacher preparation should include tasks that require pre-service teachers to investigate real settings and communicate evidence-based interpretations, rather than relying solely on simulated or decontextualized activities.

7.3 Best practices emerged through contextual relevance, collaboration, and feasibility

With respect to the second research question, the study found that best practices emerged when inquiry-based science teaching was grounded in resources and issues that were locally relevant, pedagogically feasible, and collaboratively supported. The effective learning activities identified in the findings—such as community mapping, water filtration design, sustainable agriculture activities, and locally relevant product development—shared several common features. They drew on materials and problems familiar to students, invited evidence generation and interpretation, and connected scientific learning with local environmental, cultural, and economic conditions. This suggests that best practice in this context was not defined by the sophistication of equipment, but by the strength of the connection between scientific inquiry and the realities of the local community.

This result is consistent with place-based and culturally responsive perspectives, which argue that learning becomes more meaningful when it is connected to lived experience, local knowledge, and community context (Bang & Medin, 2010; Gruenewald, 2003; Gay, 2010). In the context of rural teacher preparation, this insight is especially important. Many pre-service teachers will work in schools where conventional science laboratories are unavailable or under-resourced. The present findings suggest that effective inquiry teaching in such settings depends not on replicating idealized laboratory conditions, but on learning how to mobilize available local resources for scientific investigation. Community-based laboratory tools therefore offer a practical response to structural constraints while also deepening the social relevance of science education.

7.4 Professional development and the emergence of context-responsive teacher identity

Another key contribution of the study is the evidence that the intervention supported not only skill development but also professional identity formation. The qualitative findings showed that participants became more confident in using inquiry-based methods, more appreciative of local knowledge and community involvement, and more aware of their role as educators who must design learning in response to student needs and local realities. This indicates that the professional development program influenced how student teachers understood themselves as future practitioners, not merely what they were able to do in isolated tasks.

This shift in identity can be interpreted through the lens of teacher professional development theory, which emphasizes that effective professional learning is content-focused, collaborative, active, and coherent over time. The present study reflects these characteristics. Student teachers participated in workshops, field-based inquiry, lesson design, school implementation, and reflection across multiple phases, and this continuity appears to have supported deeper professional learning. The findings therefore suggest that inquiry-oriented teacher preparation is most powerful when it is embedded in sustained developmental experiences that connect theory, practice, and context. In this respect, the program did not simply teach inquiry techniques; it cultivated a context-responsive professional orientation toward science teaching.

7.5 Implications for TPACK, whole-school collaboration, and rural teacher education

The findings also have implications for understanding TPACK in the Thai teacher education context. In this study, the enhancement of inquiry-based lesson planning suggests that student teachers were not only improving their knowledge of science content or pedagogy in isolation; they were learning to integrate content, pedagogy, and contextually available tools in ways that made science learning possible in rural school settings. From this perspective, community-based laboratory tools may be understood as part of a broadened TPACK framework in which "technology" is interpreted not narrowly as digital devices, but as the purposeful use of tools, materials, and mediating resources to support learning. The findings thus suggest that TPACK for rural Thai teachers should include the capacity to transform local resources into pedagogically meaningful inquiry opportunities.

In addition, the study reinforces the importance of a whole-school approach. Best practices did not emerge from the efforts of student teachers alone. They developed through collaboration among university instructors, mentor teachers, schools, and community members. This collaborative dimension helped bridge the gap between university-based teacher preparation and the realities of school practice. It also suggests that inquiry-oriented science teacher education in rural contexts should be supported as a shared institutional and community responsibility rather than as an individual teaching skill. Such a perspective is particularly relevant to the KRU-Rak Thin program, whose broader mission is to prepare teachers who can work meaningfully within and for their local communities.

7.6 Contribution of the study

The main contribution of this study lies in demonstrating that community-based laboratory tools can serve as a viable and pedagogically robust model for inquiry-oriented science teacher preparation in rural and underserved settings. The study contributes to the literature in three ways. First, it provides evidence that inquiry skills can be significantly enhanced through a mixed model of workshops, field experiences, contextual lesson design, and reflective practice. Second, it shows that authentic community engagement can function as a powerful mechanism for inquiry development by enabling pre-service teachers to investigate real environments and generate evidence-based representations. Third, it highlights that the outcomes of such interventions extend beyond technical competence to include changes in confidence, professional identity, and appreciation of local knowledge. Together, these contributions suggest that community-based laboratory tools are not merely a pragmatic substitute for formal laboratories, but a distinct and valuable pedagogical approach in their own right.

7.7 Limitations and directions for future research

Although the findings are promising, several limitations should be acknowledged. The study focused on one teacher education program in a specific institutional and regional context, which may limit the transferability of the findings to other settings. In addition, the study measured development within the duration of the intervention and did not examine long-term retention of inquiry skills or the subsequent classroom practices of participants after graduation. Future research could therefore explore how graduates continue to use community-based laboratory tools in their professional teaching, how this approach affects elementary students' science learning outcomes, and how similar models might be adapted in other teacher education programs or subject areas.

Overall, the intervention was effective because it treated inquiry as a socially situated, evidence-based, and context-responsive process. By positioning communities as learning laboratories and local resources as legitimate tools for scientific investigation, the program enabled student teachers to develop inquiry competence in ways that were meaningful for their future work in rural schools. This interpretation strengthens the central argument of the study: that community-based laboratory tools offer a practical, theoretically grounded, and educationally significant pathway for enhancing scientific inquiry skills in elementary teacher education.

5. References

Aikenhead, G. S., & Elliott, D. (2010). An emerging decolonizing science education in Canada. *Canadian Journal of Science, Mathematics and Technology Education, 10*(4), 321–338. https://doi.org/10.1080/14926156.2010.524967

Allen, D., & Tanner, K. (2006). Rubrics: Tools for making learning goals and evaluation criteria explicit for both teachers and learners. *CBE—Life Sciences Education, 5*(3), 197–203. https://doi.org/10.1187/cbe.06-06-0168

Bang, M., & Medin, D. (2010). Cultural processes in science education: Supporting the navigation of multiple epistemologies. *Science Education, 94*(6), 1008–1026. https://doi.org/10.1002/sce.20392

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Bybee, R. W. (2014). NGSS and the next generation of science teachers. *Journal of Science Teacher Education, 25*(2), 211–221. https://doi.org/10.1007/s10972-014-9381-4

Cook, K., & Buck, G. (2010). Photovoice: A community-based socioscientific pedagogical tool. *Science Scope, 33*(7), 35–39.

Crawford, B. A. (2014). From inquiry to scientific practices in the science classroom. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research on science education* (Vol. 2, pp. 515–541). Routledge. https://doi.org/10.4324/9780203097267

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). SAGE.

Darling-Hammond, L., Hyler, M. E., & Gardner, M. (2017). *Effective teacher professional development*. Learning Policy Institute. https://doi.org/10.54300/122.311

Desimone, L. M. (2009). Improving impact studies of teachers' professional development: Toward better conceptualizations and measures. *Educational Researcher, 38*(3), 181–199. https://doi.org/10.3102/0013189X08331140

Gay, G. (2010). *Culturally responsive teaching: Theory, research, and practice* (2nd ed.). Teachers College Press.

Gruenewald, D. A. (2003). The best of both worlds: A critical pedagogy of place. *Educational Researcher, 32*(4), 3–12. https://doi.org/10.3102/0013189X032004003

Guskey, T. R. (2002). Does it make a difference? Evaluating professional development. *Educational Leadership, 59*(6), 45–51.

Koh, J. H. L. (2013). A rubric for assessing teachers' lesson activities with respect to TPACK for meaningful learning with ICT. *Australasian Journal of Educational Technology, 29*(6), 887–900. https://doi.org/10.14742/ajet.228

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge University Press.

Lotter, C., Harwood, W. S., & Bonner, J. J. (2007). The influence of core teaching conceptions on teachers' use of inquiry teaching practices. *Journal of Research in Science Teaching, 44*(9), 1318–1347. https://doi.org/10.1002/tea.20191

Mishra, P., & Koehler, M. J. (2006). Technological pedagogical content knowledge: A framework for teacher knowledge. *Teachers College Record, 108*(6), 1017–1054. https://doi.org/10.1111/j.1467-9620.2006.00684.x

National Research Council. (2012). *A framework for K–12 science education: Practices, crosscutting concepts, and core ideas*. National Academies Press. https://doi.org/10.17226/13165

Piaget, J., & Inhelder, B. (1969). *The psychology of the child*. Basic Books.

Vibulphol, J. (2015). Thai teacher education for the future: Opportunities and challenges. *Educu Journal, 43*(1), 1–16.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Harvard University Press.

Windschitl, M., Thompson, J., & Braaten, M. (2008). Beyond the scientific method: Model-based inquiry as a new paradigm of preference for school science investigations. *Science Education, 92*(5), 941–967. https://doi.org/10.1002/sce.20259

Yuenyong, C., & Narjaikaew, P. (2009). Scientific literacy and Thailand science education. *International Journal of Environmental and Science Education, 4*(3), 335–349.