Journal of Higher Education and Learning
ISSN 2998-7679
Vol. 2, No. 4, 2025
Published by STSL Press

Original Paper

Best Practices in Science Education: A Review of Current Research and Insights for Teacher Preparation

Susan L. Zimlich

Southeastern Louisiana University

Abstract

Best practices in science education emphasize inquiry-based teaching as essential for improving student learning and teacher preparation. Research consistently shows that student-centered models such as the 5E Learning Cycle and argument-driven inquiry outperform traditional direct instruction in developing scientific reasoning, conceptual understanding, and positive attitudes toward science. However, implementation remains limited by teachers' perceptions of time constraints, curriculum mandates, inadequate professional development, and misconceptions about inquiry teaching. To prepare teachers who can effectively use these methods, teacher education programs must integrate inquiry pedagogy throughout teacher preparation rather than confining it to isolated courses. Effective strategies include explicit modeling, co-teaching, extended clinical residencies, and structured reflection. Administrative support and access to high-quality instructional materials further strengthen teachers' ability to implement inquiry approaches. Drawing from experience as a university supervisor, the author notes that while high-quality curricula have expanded inquiry opportunities, challenges in fidelity and access persist. Sustained institutional support, collaboration, and early exposure are critical for fostering lasting change in science education.

Keywords: Inquiry-based teaching; Science education, Teacher preparation, Preservice teachers, 5E Learning Cycle, High-Quality Instructional Materials (HQIM)

Introduction

Science is a process that helps you in "constructing new knowledge and understanding the world around" (Dolenc & Kasanis, 2020, p. 127). The foundation for many people's future as scientists is built during their K-12 education. Research in science education has highlighted the critical importance of inquiry-based teaching methods and their impact on both student learning outcomes and teacher preparation. This article first examines current literature on effective science education practices, with particular attention to teacher preparation programs and the implementation of inquiry-based methodologies. Secondly, the perspectives of an experienced university preservice teacher supervisor are included.

Research consistently demonstrates the superiority of student-centered, inquiry-based approaches in science education compared to traditional direct instruction methods. Student-centered teaching approaches, particularly inquiry strategies and problem-based learning, were most effective at developing elementary students' science skills and fostering positive attitudes toward science. These approaches also demonstrate greater positive impact on science content knowledge acquisition compared to teacher-centered methodologies, with benefits persisting even without formal interventions. These results appear to endure over time (Deehan et al., 2022).

The Role of Inquiry-Based Teaching in Science Education

Research reveals important gaps between teachers' perceptions and actual implementation of inquiry-based instruction. Teachers who lack deep understanding of inquiry methods tend to overestimate their use of inquiry practices, sometimes misidentifying direct instruction as inquiry-based teaching (Lakin & Wallace, 2015). This misalignment suggests a need for more precise professional development in distinguishing inquiry practices from traditional instruction methods. Despite the importance of teacher development in inquiry-based instruction, Lakin and Wallace (2015) note limited research on how teachers' views of inquiry instruction evolve with additional training. This gap in the literature suggests a need for longitudinal studies examining the impact of sustained professional development on teachers' understanding and implementation of inquiry practices.

The implementation of inquiry-based teaching can take various forms, ranging from confirmation inquiry to open inquiry, with structured and guided inquiry serving as intermediate approaches (Fitzgerald et al., 2019). The 5E Learning cycle commonly found in pre-written science curricula, designated as high-quality instruction materials (HQIM) in the state in which the author resides, represents a form of structured inquiry that has shown particular promise. Argument-driven inquiry-based laboratory instruction and the 5E instructional model significantly improved preservice teachers' academic achievement in science (Mukagihana et al., 2022). The effectiveness of inquiry-based teaching comes partly from its ability to engage students as scientists, activating prior knowledge and encouraging questioning (Lakin & Wallace, 2015). This approach initiates learning while allowing for flexible instruction. However, teacher candidates may not always recognize when inquiry methods are being used, highlighting the need for explicit instruction about the nature of scientific inquiry.

Barriers and Challenges in Implementation

Despite its demonstrated effectiveness, implementing inquiry-based science teaching faces several challenges. Teachers' assumptions about inquiry-based teaching present barriers to them implementing inquiry-based strategies, including concerns about time constraints, class size management issues, fears about student learning during exploration, student access to technology due to administrative restrictions, and limited professional development opportunities. Teachers often perceive the preparation time required for inquiry-based lessons as prohibitive, and concerns about classroom management in larger classes can discourage the use of small group activities and laboratory work. Teachers appear to be receptive to inquiry teaching strategies but perceive a disconnect between what they learned in their teacher education coursework (e.g., constructivism) and what they saw in the schools (e.g., direct instruction) (Fitzgerald et al., 2019).

Additionally, many teachers report insufficient professional development in inquiry-based methodologies, with existing training often failing to provide practical, immediately applicable classroom strategies and enough scaffolding of pedagogical knowledge. Somewhat ironically, Fitzgerald et al. (2019) noted that professional development sessions frequently rely on lecture formats rather than modeling the hands-on, inquiry-based approaches they aim to promote.

Professional Development and Administrative Support

Successful implementation of inquiry-based teaching requires sustained support at multiple levels (Deehan et al., 2022; Fitzgerald et al., 2019). Fitzgerald et al. (2019) emphasized the importance of administrative support, including adequate preparation time, reasonable pacing guidelines, and opportunities for peer observation. Teachers benefit from ongoing professional development that is school-based, immediately applicable, and properly paced. Making more experienced teachers available to mentor and model inquiry-based teaching can support teachers who are new to constructivist teaching strategies (Fitzgerald et al., 2019).

Ideally, teachers should not be developing inquiry-based pedagogy skills as an after thought to their initial training, but as part of their initial preparation. The research suggests that clinical practice plays a vital role in helping preservice teachers adjust their understanding of classroom learning and student capabilities (Lammert, 2020).

Programmatic Approaches to Inquiry-Based Teacher Education

Lammert's (2020) comprehensive meta-study of inquiry methods in teacher preparation provides crucial insights into the systematic development of inquiry-based teaching capabilities. The research reveals that inquiry-based teaching strategies are most frequently taught in methods courses for elementary and early childhood certification programs, likely due to the integrated nature of these certification areas and their emphasis on content literacy across disciplines.

The meta-study identifies several key elements of successful inquiry-based teacher preparation. Clinical practice serves as a foundational component, allowing preservice teachers to observe and understand inquiry methods before implementing them independently. However, Lammert notes significant challenges in coordinating clinical experiences with science instruction timing in placement classrooms. Methods courses play a vital role in helping teacher candidates create inquiry experiences, particularly important given their often-limited personal experience with inquiry-based learning from their own preK-12 experience.

Significantly, Lammert (2020) found that exposure to inquiry-based teaching methods prompted fundamental shifts in teacher candidates' perspectives on education. These shifts manifested in increased awareness of student strengths and interests, enhanced content competency, and deeper reflection on fundamental educational questions, including teaching methods, curriculum goals, and educational equity. The research suggests that inquiry-based teaching experiences in teacher education courses are essential for developing critical thinking skills and student engagement strategies. However, Lammert's analysis also revealed persistent challenges in implementation. Teacher candidates require specific support in structuring inquiry learning and managing classroom dynamics during inquiry activities. Many perceive inquiry as impractical within current educational contexts, citing standardized testing pressures and curriculum mandates. While some teacher educators use inquiry-based teaching to help candidates navigate these mandates, concerns about content coverage and time constraints remain prevalent.

A key finding from Lammert's work is that successful implementation of inquiry-based teaching requires program-wide integration rather than isolated course experiences. This comprehensive approach helps shift preservice teachers' understanding of literacy from a discrete skill set to an integrated practice across subject areas. The meta-study concludes that this programmatic approach is essential for developing teachers who can effectively implement inquiry-based methods in their future classrooms.

A comprehensive meta-analysis by Mukagihana et al. (2022) revealed several key insights about effective science instruction for preservice teachers. The study found that argument-driven inquiry and 5E instructional models significantly enhanced teacher candidates' learning outcomes through the development of cognitive skills and construction of long-term knowledge. The researchers identified that linking science to social issues produced even larger effect sizes than traditional inquiry-based teaching or problem-based learning approaches, particularly in developing critical thinking and problem-solving capabilities. The meta-analysis highlighted the importance of authentic learning environments and extended instruction time. Including instructional technology and material design courses improved teacher candidates' attitudes and practical skills. The researchers found that argumentation practice enhanced concept development, potentially improving future teaching capabilities. However, findings regarding guided inquiry were mixed, with some results showing comparable effectiveness to traditional instruction methods, suggesting implementation quality may be a crucial factor.

Based on their analysis, Mukagihana et al. (2022) recommended a combination of approaches, including argumentation, 5E instructional models, and collaborative learning strategies like jigsaw activities to develop science process skills. They emphasized that effective learning occurs when new knowledge requires adjustment of existing understanding, highlighting the importance of active learning through questioning, collaboration, and problem-solving.

Preservice Teacher Development and Challenges

Research suggests several critical factors affecting preservice teachers' development as science educators. Teacher preparation programs play a crucial role in developing effective science educators. Bergman and Morphew (2015) found that even a single well-designed science content class for elementary teacher candidates can increase their self-efficacy and outcome expectations. This finding is particularly significant given that efficacy beliefs influence teachers' willingness to try innovative strategies and their perception of whether teaching science is challenging or manageable (Fazio et al., 2020). Key interventions that support teacher candidates' learning of inquiry-based methods, including hands-on scientific investigation, collaborative lesson planning, field-based teaching, reflective practices, and explicit discussion of science pedagogy (Menon & Azam, 2020). Other interventions to support preservice teachers in gaining competence with inquiry-based pedagogical strategies are use of scenarios (Dongque & Enshan, 2022; Wang, 2020), practice in developing scientific models (Dongque & Enshan, 2022), modeling by mentor teachers and methods instructors (Dabney et al., 2020; Wang, 2020). Their findings emphasize the importance of prior science experiences in shaping teacher candidates' attitudes and abilities. These prior experiences can shape whether they view science as fun or stressful, relevant or abstract, and engaging or boring. Teacher candidates' backgrounds significantly influence their approach to science teaching. Dabney et al. (2020) found that many current teacher candidates, having experienced education under *No Child Left Behind* or the *Every Student Success Act* that followed, may lack substantive elementary science experience. Their K-12 experiences and university prerequisites likely emphasized lecture-based instruction rather than inquiry methods, potentially limiting their exposure to effective science teaching models.

Several studies highlight the importance of practical experience in developing teaching competency. Wang (2020) demonstrated that Inquiry-based Pedagogical Instruction (IPI), which includes explicit modeling and scaffolding, resulted in higher scores on pedagogical and scientific content knowledge compared to direct instruction approaches. Murphy et al. (2015) emphasized the role of co-teaching and reflection in development, noting that imitation extends beyond simple modeling to include learning from struggles and continuous practice improvement.

While science HQIM can help teacher candidates implement more inquiry-based teaching, there are additional skills needed. Teacher candidates need an understanding of how there is coherence and scaffolding across teaching units (Dongque & Enshan, 2022). Common challenges faced by teacher candidates include classroom management during hands-on activities, responding effectively to student questions, and accessing necessary resources and technology. Teacher candidates realize that they will need to adjust their teaching for the developmental levels of the students they are teaching (Dolenc & Kazanis, 2020; Menon & Azam, 2020). Many recognize the need for probing questions for students to think deeply but find themselves unprepared for the depth of content knowledge required to answer student questions effectively. Preservice teachers need to develop skills in academic feedback to help students revise their models, and to learn how to address student understanding of cross-cutting concepts as falling into the categories of correct, ambiguous and incorrect (Dongque & Enshan, 2022). They have to develop confidence in being able to change things in the moment when they encounter issues during teaching (Dolenc & Kazanis, 2020).

Dolenc and Kazanis (2020) found that incorporating student interests into inquiry lessons helped teacher candidates build confidence and motivation while making lessons more effective. They feel more successful in teaching when the students are engaged, and teacher candidates recognize that there are many student-centered teaching strategies that can achieve student engagement (Menon & Azam, 2020).

Wang (2020) demonstrated that Inquiry-based Pedagogical Instruction (IPI) helps teacher candidates develop greater competence in addressing unfamiliar material and filling gaps in their scientific content and pedagogical knowledge compared to direct instruction approaches. Both IPI and direct instruction of science teaching methods contributed to teachers' sense of belonging in the science education community, potentially enabling them to promote positive views of science to their students.

The implementation of inquiry-based methods requires significant adaptation of traditional teaching approaches. Dongque and Enshan (2022) emphasized the importance of purposeful concept sequencing and scaffolding in implementing the 5E Learning cycle, particularly for cross-cutting science concepts. Sengul (2021) noted the need to modify the 5E learning cycle to accommodate both student teacher practice and online learning environments.

Supporting Successful Implementation

Research indicates several key factors that support successful implementation of inquiry-based science teaching. Murphy et al. (2015) emphasize the importance of co-teaching experiences, including co-planning, co-practice, and co-evaluation. These collaborative approaches help bridge the gap between theory and practice while providing emotional support during the learning process.

Clinical experiences prove crucial in developing inquiry-based teaching skills. Lammert (2020) emphasizes that methods courses help preservice teachers create inquiry experiences, particularly important given their often limited exposure to inquiry-based teaching in their own education. Experiencing inquiry-based teaching helps Teacher Candidates encourage children's natural curiosity, make real world connections, and help dispel the excuse that schools have a lack of resources to do hands-on science (Fazio et al., 2020). However, timing challenges persist in aligning clinical practice with classroom teachers' science instruction schedules.

Dolenc and Kazanis (2020) found that incorporating student interests into inquiry-based lessons increased teacher candidates' confidence and motivation while making lessons more effective and engaging for students. Their research showed that contextualizing science within students' career aspirations helped elementary students recognize the relevance of science to their future.

Inquiry-based teaching experiences have shown to shift preservice teachers' understanding of learner support, leading them to focus more on student strengths and interests (Lammert, 2020). Additionally, this approach helps teacher candidates feel more competent in their content knowledge. However, teacher candidates require specific support in structuring inquiry learning and managing classroom dynamics during inquiry activities.

Structural Challenges and Political Context

Preservice teachers often perceive inquiry as impractical due to standardized testing emphasis and curriculum mandates in the current political context (Lammert, 2020). Time pressures for content coverage remain a significant concern, as even though science is tested in the state in which the author resides, emphasis is generally placed on instruction in reading, writing and math. Research indicates that inquiry teaching can effectively span interdisciplinary content areas, with most teacher research on inquiry-based strategies occurring in methods courses for elementary and early childhood certification (Lammert, 2020). However, there are concerns about some districts' attempts to subsume science education entirely within literacy instruction, as reading about science cannot substitute for hands-on scientific exploration. Lammert (2020) found that inquiry necessitates reconceptualizing literacy not as an isolated skill set but as an integrated practice across subject areas. This integration requires support at the program level rather than in isolated courses or modules.

The literature strongly supports inquiry-based teaching as a best practice in science education, while acknowledging the challenges of implementation. Successful adoption of these methods requires a comprehensive approach that includes well-designed teacher preparation programs, ongoing professional development, and administrative support. Future research might focus on strategies for scaling these practices effectively, particularly in early elementary grades where research is currently limited (Deehan et al., 2022). Use of technology might be needed to make on-going learning communities for teachers implementing inquiry-based teaching strategies.

The Author's Perspective

Current Trends in School Implementation

Recent changes in school-based science education implementation reveal both promising developments and persistent challenges. The adoption of commercially developed HQIM inquiry-based curricula has facilitated greater incorporation of inquiry-based teaching in schools, though the fidelity of implementation varies across classrooms. However, some teachers modify inquiry lessons into direct instruction formats, potentially diminishing the intended benefits of the inquiry-based approach.

The transition to extended clinical experiences in teacher preparation programs, particularly two-semester residency models, has enhanced preservice teachers' access to curriculum materials and educational technology. This expanded access has proven beneficial in supporting teacher candidates' ability to plan and execute inquiry-based lessons, as the foundational structure is already inquiry-oriented rather than requiring complete lesson development from scratch. However, teacher preparation programs may struggle to give teacher candidates experience with high-quality curricula prior to the two-semester residency without outside interventions such as a grant to purchase curricula or support from a state department of education. Publication companies may have separate representatives for K-12 versus post-secondary that limit education preparation provider’s access to K-12 materials, as well as whether there are funds available to purchase curricula across multiple grade levels. This can be further complicated when surrounding schools and districts use curricula from different companies. Even when there is access to teacher manuals, there may still be student resources (e.g., online simulations) that are not available.

While improved over the years prior to districts obtaining HQIM for science, several significant limitations persist in the implementation of effective science education. Content siloing in elementary education means that not all preservice teachers gain experience teaching science. More concerning is the practice in some districts of delaying formal science instruction until third grade or attempting to substitute literacy instruction using science-related texts for hands-on science experiences. This approach fundamentally misunderstands that reading about science cannot replicate the experiential learning that comes from doing science.

Resource accessibility presents another challenge, particularly for teacher candidates who may lack access to the electronic resources available to full-time classroom teachers. To address this limitation, some teacher preparation programs have implemented on-campus micro teaching or peer teaching experiences, providing opportunities for practice when clinical placements do not offer adequate science teaching exposure.

One notable advantage of current curriculum implementations is their inclusion of anticipated student responses and common misconceptions, which helps prepare teacher candidates for classroom realities. However, the structure of inquiry-based curricula, which often distributes inquiry processes across multiple lessons, can create challenges for teacher candidates attempting to fit these experiences into traditional lesson plan templates; even when given a lesson template specially for inquiry-based teaching. This challenge parallels similar issues in planning direct instruction lessons that cycle between modeling and guided practice when given a prescriptive curriculum. Additionally, teacher candidates who have grown up with primarily direct instruction may still take an inquiry-based lesson provided from curricula and try to turn it into a direct instruction lesson.

These observations suggest that while progress has been made in supporting inquiry-based science education through curriculum adoption and extended clinical experiences, significant work remains in ensuring consistent and effective implementation across educational settings. Future efforts might focus on addressing the gaps in early elementary science education and developing more flexible frameworks for lesson planning that better accommodate inquiry-based approaches. Additionally, as the students who are currently in the K-12 schools exposed to inquiry-based HQIM become teacher candidates, they may come better equipped to implement inquiry teaching having experienced when they were children.

Conclusions and Future Directions

The literature presents compelling evidence for inquiry-based science education while acknowledging implementation challenges. Research consistently demonstrates that student-centered, inquiry-based approaches improve both content knowledge and science process skills. However, successful implementation requires systematic support at multiple levels, from teacher preparation programs through classroom practice.

Effective teacher preparation emerges as a critical factor, with studies showing the importance of explicit modeling, hands-on experience, and sustained support throughout preparation programs. Meta-analyses indicate that combining multiple approaches—including argumentation, 5E instructional models, and social issue integration—produces optimal results in developing teacher candidates' capabilities.

Key challenges persist, including resource limitations, time constraints, and alignment with standardized testing requirements. Additionally, many preservice teachers lack personal experience with inquiry-based learning, necessitating careful scaffolding during their preparation. The research suggests that addressing these challenges requires a comprehensive approach incorporating extended clinical experiences, technology integration, and ongoing professional development.

Future research should focus on longitudinal studies examining the evolution of teachers' inquiry implementation skills, particularly as they transition from preparation programs to classroom practice. Additional investigation is needed regarding the effectiveness of various professional development models and the impact of institutional support structures on sustained inquiry-based teaching practices.

The literature ultimately suggests that while inquiry-based science education presents implementation challenges, its benefits for student learning and teacher development justify continued investment in developing and refining support systems for this approach. Success requires commitment at both institutional and individual levels, with particular attention to providing teachers the tools, training, and support needed to effectively implement inquiry-based methods in their classrooms.

References

Bergman, D. J., & Morphew, J. (2015). Effects of a science content course on elementary preservice teachers' self-efficacy of teaching science. *Journal of College Science Teaching, 44*(3), 73-81.

Dabney, K. P. et al. (2020). Preservice elementary teachers and science instruction: Barriers and supports. *Science Educator, 27*(2), 92-101.

Deehan, J., MacDonald, A., & Morris, C. (2022). A scopint review of interventions in primary science education. *Studies in Science Education, 60*(1), 1-43. https://doi.org/10.1080/03057267.2022.2154997

Dolenc, N. R. & Kazanis, W. H. (2020). A potential for interest driven learning to enhance the inquiry based learning process. *Science Educator, 27*(2), 121-128.

Dongque, J. & Enshan, L. (2022). Designing a coherence- & concept-based modular course to facilitate students' understanding of crosscutting concepts. *National Association of Biology Teachers, 83*, 291-297. https://doi.org/10.1525/abt.2021.83.5.291

Fazio, C., Di Paola, B. & Battaglia, O. R. (2020). A study on science teaching efficacy beliefs during pre-service elementary training. *International Electronica Journal of Elementary Education, 13*(1), 89-105.

Fitzgerald, M., Danaia, L., & McKinnon, D. H. (2019). Barriers inhibiting inquiry-based science teaching and potential solutions: Perceptions of positively inclined early adopters. *Research in Science Education, 49*, 543-566. https://doi.org/10.1007/s11165-017-9623-5

Lakin, J. M., & Wallace, C. S. (2015). Assessing dimensions of inquiry practice by middle school science teachers engaged in a professional development program. *Journal of Science Teacher Education, 26*, 139-162. https://doi.org/10.1007/s10972-04-9412-1

Lammert, C. (2020). Becoming inquirers: A review of research of inquiry methods on literacy preservice teacher preparation. *Literacy Research and Instruction, 59*, 191-217. https://doi.org/10.1080/19388071.2020.1730529

Menon, D., & Azam, S. (2020). Investigating preservice teacher's science teaching self-efficacy: An analysis of reflective practices. *International Journal of Science and Mathematics Education, 19*, 1587-1607. https://doi.org/10.1007/s10763-020-10131-4

Mukagihana, J., Nsanganwimana, F., & Aurah, C. M. (2022). Effect of instructional methods on pre-service science teachers learning outcomes: a meta-analysis. *Education and Information Technology, 27*, 2137-2163. https://doi.org/10.1007/s10639-021-10696-9

Murphy, C., Scentlebury, K., & Milne, C. (2015). Using Vygotsky's zone of proximal development to propose and test an explanatory model of conceptualizing coteaching in pre-service science teacher education. Asia-Pacific *Journal of Teacher Education, 43*(4), 281-295. http://dx.doi.org/10.1080/1359866X.2015.1060291

Sengul, O. (2021). Preservice science teachers practice teaching online through 4E instructional model. *Journal of College Science Teaching, 51*(1), 5-11.

Wang, J. (2020). Compare inquiry-based pedagogical instruction with direct instruction for pre-service science teacher education. *International Journal of Science and Mathematics Education, 18*, 1063-1083. https://doi.org/10.1007/s10763-019-10010-7