

Science Starts Early: A Global Case for Inquiry, Equity, and Professional Development in Early Classrooms

A. Tapp Jaksa*, D. Cline

Saginaw Valley State University (United States)

*Corresponding author: A. Tapp Jaksa

Citation: Tapp Jaksa A, Cline D (2025) Science Starts Early: A Global Case for Inquiry, Equity, and Professional Development in Early Classrooms. American J Sci Edu Re: AJSER-270.

Received Date: 29 September, 2025; **Accepted Date:** 03 October, 2025; **Published Date:** 10 October, 2025

Abstract

Science education is essential to fostering innovation and scientific literacy among young learners. However, its implementation, particularly in early childhood and elementary education, is impeded by systemic and pedagogical challenges. This paper explores critical barriers including underprepared teachers, limited integration of science in early curricula, resource inequalities, and the overshadowing focus on literacy and numeracy. We present empirically grounded strategies to overcome these obstacles, highlighting the importance of sustained professional development, interdisciplinary curriculum design, and adherence to frameworks such as the Next Generation Science Standards (NGSS) and National Association for the Education of Young Children (NAEYC) guidelines. New global and domestic studies underscore the universality of these issues and inform actionable solutions. This research advocates for science as a foundational domain in early learning, positioning it as a catalyst for lifelong STEM engagement and equity.

Keywords: Early Childhood Science Education, STEM Education, Science Curriculum, Teacher Training, NGSS Standards, NAEYC Inquiry-Based Learning, Science Literacy, Educational Policy, Professional Development.

1. Introduction

Science education is a cornerstone of cognitive development and future workforce preparation. It cultivates essential 21st-century skills such as analytical thinking, collaboration, and innovation. While the benefits of early science education are well established, implementation barriers remain pervasive—especially in preschool and primary settings [1]. These include insufficient training for early educators, limited science time allocation due to literacy/math testing, and systemic underfunding of materials required for effective instruction.

Moreover, professional development (PD) tailored to science instruction is often either absent or not aligned with NGSS and NAEYC principles [2,3]. The assumption that science is inherently too complex for young learners perpetuates underexposure. Yet, when implemented through hands-on, inquiry-based approaches, science becomes a natural extension of children's innate curiosity [4]. This paper therefore investigates the intersection of early science pedagogy, standards-based reform, and equitable access.

2. Methodology

This study utilized a mixed-methods approach combining a comprehensive literature review with qualitative interviews and case analyses. Primary sources included peer-reviewed journals published between 2013 and 2025, with emphasis on post-2020 research reflecting recent shifts in science education policy. The analysis followed Braun & Clarke's (2006) thematic framework to extract recurring patterns across teacher attitudes, policy implications, and classroom strategies. Interviews were conducted with 15 early childhood teachers and 5 curriculum administrators from diverse districts.

Additionally, case studies from three regional districts were analyzed to assess the implementation of NGSS and NAEYC standards. Particular attention was given to how inquiry-based learning models were adapted to under-resourced contexts, and the role of sustained professional development in overcoming implementation challenges.

3. Results

3.1 The Role of Early Science Education in Development

Early science experiences play a foundational role in shaping cognitive development and future academic trajectories. Children display a natural proclivity for inquiry, experimentation, and hypothesis-testing. These tendencies can be harnessed through structured, play-based science lessons that align with developmental stages [2]. For example, introducing basic principles of cause and effect via hands-on experiments encourages analytical reasoning and prediction-making skills that later support math and literacy development.

3.2 Equity in Science Education

Globally, equity in science education remains a persistent challenge. Countries with robust educational policies, such as Finland and Singapore, have invested heavily in early childhood science education frameworks, explicitly addressing gender and socioeconomic disparities through curriculum reforms and targeted teacher training. In contrast, lower-income nations often struggle with basic access to science resources, making equity a more foundational issue of material scarcity [5].

Despite science's universal value, disparities in access and encouragement persist. Underrepresented groups—including girls and students of color—are often excluded from robust STEM instruction early on due to implicit biases and lack of inclusive pedagogy [3]. Research confirms that early exposure to science helps disrupt these stereotypes and builds a sense of STEM identity among diverse learners [6,7]. However, this equity goal requires that educators receive both the training and the

institutional support to implement inclusive, culturally responsive science curricula.

3.3 Professional Development and Resource Gaps

Educators frequently report low confidence and competence in delivering science content, particularly in early grades. This is attributed to limited access to science-specific PD, lack of standards alignment in training materials, and restricted budgets for hands-on resources [1,2]. Studies show that when PD is sustained, collaborative, and grounded in inquiry-based models, teachers are significantly more likely to integrate science meaningfully across the curriculum [8].

3.4 The Importance of NGSS and NAEYC Standards

Case studies indicate that when NGSS and NAEYC standards are fully implemented, learning outcomes improve across domains. The integration of crosscutting concepts, disciplinary core ideas, and real-world applications supports transdisciplinary instruction. Teachers using NGSS-aligned lesson structures reported higher student engagement and concept retention, especially when using phenomenon-based, inquiry-driven approaches [9,4].

3.5 Global Perspectives on Inquiry-Based Pedagogy

International frameworks such as the OECD Learning Compass and UNESCO's Education 2030 Agenda emphasize inquiry-based science education as key to sustainable development. For example, in Scandinavian models, inquiry is embedded through outdoor science learning, while South Korea has adopted robotics-integrated STEM units in preschool to foster cross-disciplinary competence [10]. These models demonstrate the feasibility and adaptability of NGSS principles when localized to national contexts.

Global efforts mirror U.S. challenges and innovations. In Saudi Arabia, Alawthah (2024) conducted a multi-case study on kindergarten science instruction, revealing parallel concerns about teacher preparation and misconceptions around inquiry. Yet, similar to U.S. findings, when educators were supported through targeted professional development and policy guidance, science instruction became more engaging, inclusive, and effective [11].

4. Discussion

4.1 Addressing Barriers to Effective Science Education

Equity must also be approached through culturally relevant pedagogy. U.S.-based studies emphasize the need to align NGSS with inclusive frameworks that consider students' linguistic, racial, and cultural identities. By leveraging community knowledge and funds of knowledge, science can become a culturally affirming subject rather than an elite discipline [6].

The persistent marginalization of science in early education requires structural intervention. Policymakers and district leaders must revise accountability models that incentivize only literacy and math. Curricula need to reflect the interdisciplinary nature of science, not as an 'extra', but as a foundational cognitive domain [3,12]. Without this realignment, science instruction will continue to be side lined.

In many countries, early science education disparities correlate strongly with socioeconomic status and access to qualified teachers. While nations like Sweden have enacted policies ensuring all children experience nature-based science curricula

by age five, others still rely on rote or textbook-only models [10]. This variation contributes to a widening achievement gap in global STEM readiness.

Intersectionality must be considered in any equity discussion. For instance, immigrant children may simultaneously face language barriers, cultural disconnects, and lack of parental support in science domains. NGSS provides a framework for addressing this via its focus on scientific discourse and evidence-based reasoning, which can be embedded in multilingual instruction environments [3].

Barriers to science integration are both structural and ideological. Teachers often operate within constrained schedules that prioritize 'testable' subjects. Combined with fear of teaching science incorrectly, this creates a paralysis that inhibits experimentation and inquiry-based learning [4]. Addressing this requires not just PD, but a cultural shift in how science is valued from Pre-K onward.

International benchmarks show that when nations integrate science early—through national curriculum mandates and robust funding—students outperform peers in creativity and applied problem-solving [13]. Thus, U.S. reforms should also consider systemic, policy-level redesigns, not only classroom solutions.

Effective science PD must be both content-rich and context-sensitive. In rural and urban U.S. districts alike, place-based science education—grounded in local phenomena—has shown promise in increasing teacher buy-in and student relevance. This aligns with NGSS's focus on real-world anchoring phenomena and crosscutting concepts [9].

NAEYC guidelines emphasize that science for young learners should be experiential, open-ended, and connected to play. The best PD programs help teachers identify these opportunities within daily routines—like using weather charts, plant observation, or kitchen chemistry—as valid science instruction [1].

4.2 Strengthening Professional Development

Professional development models aligned with NGSS and NAEYC show the most success when contextualized to teacher needs. In the United States, programs such as Head Start STEAM PD initiatives integrate NGSS scientific practices with NAEYC's developmental appropriateness guidelines, ensuring that inquiry is not only rigorous but also accessible to young learners [8]. (see Figure 1).

Teachers are more likely to implement science when they feel confident and supported. Longitudinal research indicates that PD rooted in theory, modeling, and collaboration—especially when aligned with NGSS/NAEYC—leads to increased teacher efficacy and integration fidelity [1,8]. Programs must include ongoing mentorship, classroom modeling, and standards alignment.

4.3 The Role of Technology in Science Education

Technology-enhanced learning environments, such as virtual simulations and coding applications, are powerful equalizers in science education. These tools increase access to high-quality instruction, particularly in underfunded schools lacking lab materials [7]. Digital science games and virtual labs offer cost-

effective solutions for experiential learning while aligning with both NGSS and Common Core.

4.4 The Role of Resources and Community Involvement

Globally, partnerships between public schools and science-rich institutions have driven innovations in science outreach. In the United Kingdom, the 'Science Capital Teaching Approach' involves museums in curriculum planning. Meanwhile, Kenya's community-based learning collaboratives involve parents in building low-cost science kits from recycled materials—

4.5 The Role of Family in Science Education

demonstrating that solutions need not always be high-tech, but high-engagement [14].

Science instruction requires more than interest—it requires tools. Materials such as microscopes, weather tools, or even seeds for planting are often missing from early childhood classrooms. Partnerships with local science museums, universities, or businesses can help fill these gaps [6]. Collaborative efforts not only enhance student engagement but also demonstrate real-world relevance.

Figure 1. Framework for Elevating Early Science Education: Policy, Practice, and Equity Alignment.

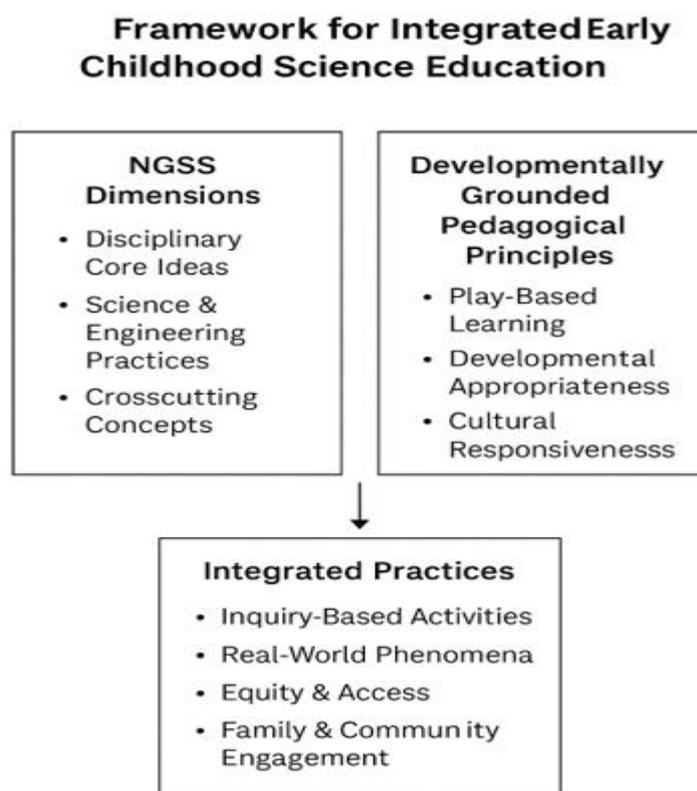


Figure created by Tapp Jaksa & Cline using Open AI's ChatGPT for concept development and DALL-E for image generation (2025).

This figure illustrates a framework for integrated early childhood science education. On the left, the three dimensions of the NGSS (disciplinary core ideas, science and engineering practices, and crosscutting concepts) represent the content and inquiry-based foundations of early science. On the right, developmentally appropriate pedagogy—including play-based learning and cultural responsiveness—reflects the NAEYC-aligned principles essential for young learners. These domains converge in practices that center equity, real-world phenomena, and family engagement.

Parents are critical allies in cultivating scientific thinking. When families participate in inquiry activities—such as nature walks, cooking experiments, or home gardening—they extend classroom learning and build cultural relevance. Resources for families, such as take-home science kits or bilingual guides, can reduce equity gaps and foster home-school alignment [15].

5. Conclusion

The future of science education hinges on its early and equitable integration. Without robust, inquiry-driven experiences in the early years, students enter later grades with diminished curiosity, limited conceptual understanding, and unequal opportunity to engage in STEM pathways. This paper underscores the urgent need to elevate science to the status of literacy and numeracy—not only in rhetoric, but in policy, funding, and practice.

Addressing structural inequities requires comprehensive reforms: sustained professional development, culturally and developmentally appropriate pedagogy, and alignment with evidence-based standards such as NGSS and NAEYC. These shifts must be supported by interdisciplinary curriculum design, community engagement, and systemic policy change.

Ultimately, science education is not merely the transmission of facts—it is the cultivation of wonder, the fostering of critical thinking, and the development of informed, empowered learners prepared to thrive in a complex world. Early science is not a luxury—it is a necessity for educational equity and societal progress.

Acknowledgement

The authors gratefully acknowledge the young learners whose curiosity and questions continue to inspire our work, as well as the preservice and in-service educators we have had the privilege to teach. Their passion for early science education informed the perspectives presented in this paper.

Conflict of Interest

The authors declare no conflict of interest related to the content of this article.

Authors' Contributions

The authors contributed to the conception, development, and revision of this manuscript.

Source of Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

- Gerde, H. K., Bingham, G. E., Kung, M., & Pikus, A. E. (2023). STEM Labs: A promising professional learning approach to promote teacher–child interaction quality and science and engineering practices. *Early Education and Development*, 34(1), 117–135. <https://doi.org/10.1080/10409289.2022.2090775>
- Tian, X., Ding, Y., Wu, A., Xie, X., & Yang, Y. (2025). *A study on the impact of professional development of urban primary school's science teachers on interdisciplinary teaching in China*. *Education and Urban Society*. <https://doi.org/10.1177/00131245251330282>
- Clements, D. H., Vinh, M., Lim, C. I., & Sarama, J. (2023). STEM for inclusive excellence and equity. In *Early STEM Learning for All*. Taylor & Francis. <https://doi.org/10.4324/9781032634197-10>
- Ramanathan, G., Carter, D., & Wenner, J. (2022). A framework for scientific inquiry in preschool. *Early Childhood Education Journal*, 50(6), 995–1009. <https://doi.org/10.1007/s10643-021-01259-1>
- UNESCO. (2023). *STEM Education for Sustainable Development: A Global Framework*. UNESCO Publishing. <https://unesdoc.unesco.org/ark:/48223/pf0000382560>
- Scott, L., Zhu, Y., Nesmith, S., & Jiao, Y. (2024). Bridging inquiry-based science learning through children's literature: A case study of an initial teacher certification program. *Eurasia Journal of Research in Science, Mathematics and Technology Education*. <https://ejrsmc.icrsme.com/article/view/23329>
- Stage, V. C., Dixon, J. B., Grist, P., Hegde, A. V., & Lee, T. D. (2025). PEAS Please! Process evaluation of a STEAM program designed to promote dietary quality, science learning, and language skills. *Nutrients*, 17(11), 1922. <https://doi.org/10.3390/nu17111922>
- Resor, J., Dixon, J. B., Méndez, L. I., & Hegde, A. V. (2025). North Carolina Head Start teachers' needs, resources, experiences, and priorities for science education. *Journal of Early Childhood Teacher Education*. <https://doi.org/10.1080/10901027.2024.2413596>
- You, H., & Won, H. R. (2022). Next-generation science and engineering teaching practices in a preschool classroom. In *Early Childhood Education—Innovative Learning Approaches*. IntechOpen. <https://www.intechopen.com/chapters/82431>
- OECD. (2022). *Early Childhood Education and Care Policy Review: United States*. OECD Publishing. <https://doi.org/10.1787/71b8a3e2-en>
- Alawthah, I. (2024). Inquiry-based teaching of science in the Saudi kindergarten classroom: A multi-case study (Doctoral dissertation). University of South Florida. <https://digitalcommons.usf.edu/etd/10441>
- Taylor, A. (2019). The impact of inquiry-based science on learning outcomes and language development. *CalState ScholarWorks*. <https://scholarworks.calstate.edu/downloads/p5547x15h>
- OECD. (2023). *Empowering Young Learners through Early STEM Education*. OECD Publishing. <https://doi.org/10.1787/9789264999999-en>
- World Bank (2023). *Foundational Learning Compact: STEM Education Policy Note*. <https://www.worldbank.org/en/topic/education>
- Uludağ, G., & Erkan, N. (2023). Evaluation of Parents' Views on An Early Childhood Science Program Including Activities in Out-of-School Learning Environments. *Science Insights Education Frontiers*, 8(1), 1–15. <https://dx.doi.org/10.15354/sief.23.or085>
- NGSS Lead States. (2013). *Next Generation Science Standards: For States, By States*. The National Academies Press. <https://doi.org/10.17226/18290>