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Research Article

Examining After-School STEM Programs: Insights and Recommendations

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Abstract: Effective after-school Science, Technology, Engineering and Mathematics (STEM) programs require multiple elements and instructional practices that intentionally support engagement and growth of all learners across varied early learning contexts. This study contributes to the current literature by examining instructional quality across eight early learning environments and changes made following the implementation of a Dimensions of Success (DoS)-informed observation process. Using pre-and post-observation data of informal early learning STEM centers, the study investigates patterns across four key dimensions of practice: environment, engagement, knowledge, and relationships. Analyses include both dimension-level trends and site-level mean scores to capture variation within and across programs. Findings indicate overall positive gains in instructional quality following receiving feedback obtained from the observation process, suggesting that communicating results of structured, research-based observational frameworks can support improvement in STEM-focused early learning and out-of-school settings. However, because observational feedback was not accompanied by sustained professional development or ongoing coaching between observation cycles, growth was uneven across sites and dimensions. These results highlight the potential for greater and more consistent improvement when observation-based feedback is coordinated with continuous, targeted professional support. This work can inform effective change by educators, program leaders, and policymakers to support engaging informal STEM experiences. By examining areas for growth and change that are aligned with research-based practices for informal early childhood STEM experiences and instructional improvement, educators, program leaders, and policymakers can make more informed choices when seeking to enhance equity, inclusion, and instructional quality in after-school STEM programs.

***Keywords*:** Science, Technology, Engineering and Mathematics (STEM), early childhood, equity, informal settings

1. Introduction

High-quality early learning environments play a critical role in supporting children's cognitive, social, and academic development, particularly in the foundational areas of Science, Technology, Engineering and Mathematics (STEM). Research consistently demonstrates that early exposure to well-designed, developmentally appropriate STEM experiences contributes to children's problem-solving abilities, perceptions about their place in STEM, conceptual understanding, and long-term academic trajectories (Allen et al., 2020; Roberts et al., 2024). However, the quality of these experiences varies widely across early learning afterschool settings, and educators often receive limited support in implementing intentional, inquiry-driven STEM instruction.

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Observation-based frameworks have emerged as a promising approach for examining and improving instructional quality in early childhood and out-of-school learning environments. The Dimensions of Success (DoS) framework provides a research-based tool for assessing key aspects of learning environments, including organization, instructional practices, student engagement, relationships, and opportunities for youth voice. Rather than functioning solely as an evaluative measure, the DoS framework is designed to support reflective practice and professional learning, making it particularly well-suited for formative improvement efforts. After observations by certified DoS observers, sites receive reports about areas of success and feedback for areas to focus on and grow to improve the STEM learning environment.

Within early learning and after-school contexts, professional learning models that emphasize observation, feedback, and reflection have been shown to promote instructional coherence and intentionality (Liu et al., 2024; Mizyed & Eccles, 2025; Schachter et al., 2019). Yet, empirical research examining how structured observation processes influence instructional quality across diverse early learning settings remains limited. There is a need for studies that examine changes in practice across multiple dimensions of instruction and interaction, rather than focusing narrowly on structural features or isolated outcomes. In addition, studies are needed on the changes when observational feedback is shared with learning cites.

This study addresses this gap by examining changes in instructional quality across eight early learning environments following implementation of a DoS-informed observation process. Using pre-and post-observation data, this study explores patterns of change across environmental, engagement, knowledge, and relational dimensions of practice. By analyzing both dimension-level trends and site-level mean scores, the study provides insight into how a structured observational framework may support improvement in STEM-focused early learning settings. This work contributes to the growing body of research on understanding STEM in early childhood and out-of-school contexts (Erol & İvrendi, 2025; Maiorca et al., 2023; Roberts et al., 2018; Wang & Mihai, 2025). Findings from this study have implications for educators, program leaders, and policymakers seeking to strengthen the quality of STEM learning experiences through observation-based professional support.

2. Literature review

2.1 *Afterschool STEM programs*

STEM represents a broad, interdisciplinary approach to education and careers that emphasizes critical thinking, problem-solving, and innovation. Enhancing and expanding the quality of STEM education is a top priority in the United States. There is a critical need to develop thinkers who can meet the increasing demands of a STEM-focused world. The National Research Council (NRC) (2009) and the United States Federal Government's "Educate to Innovate" initiative (The White House, 2009) led to significant investments to integrate STEM programs across both the private and public sectors, including after-school programs, weekend activities, and summer sessions. After-school programs have become vital in providing STEM learning experiences, especially for underrepresented populations. No matter what children's future aspirations are, all children need to develop STEM literacy and be informed citizens (Mohr-Schroeder et al., 2020). After-school programs offer hands-on learning opportunities to complement traditional classroom instruction. After-school STEM programs develop students' abilities to question, problem-solve, work collaboratively, and solve complex challenges that extend beyond a single discipline into the real world. It is vital for all students, regardless of their future, to develop STEM literacy to become informed citizens (Mohr-Schroeder et al., 2020).

Many states aim to improve equity, diversity, access, and STEM outcomes through these after-school networks. Studies recognize the importance of fostering positive STEM attitudes, interests, engagement, and identities (Jakobi et al., 2026; Kidd & Naylor, 1991; Mohr-Schroeder et al., 2020). Graham et al. (2013) supported this, noting that positive STEM attitudes are crucial for increasing participation and persistence in STEM fields. This is particularly important for low-income youth, youth of color, and girls, who are disproportionately likely to leave STEM pathways (Morgan et al., 2016).

A key characteristic of high-quality after-school STEM programs is their emphasis on hands-on learning experiences. Meaning making and acquiring content knowledge through problem-solving and interaction with environments and peers allow real-world STEM practices to be observed in integrated STEM learning environments (McCurdy et al., 2020). Afterschool programs with these areas of emphasis bring STEM concepts to life by encouraging inquiry, problem-solving, and reflection (Cian, 2026; Mohr-Schroeder et al., 2020; Noam & Shah, 2013; National Research Council, 2015; Shah et al., 2018). In 2014, after-school programs in the United States had reached over 10 million participants (Afterschool Alliance, 2015) and such programs continue to operate and reach participants. This substantial participation includes many underrepresented groups, underscoring the program's potential to reduce the achievement gap for low-income youth, youth of color, and girls while offering valuable STEM opportunities. Racial, socioeconomic, and gender inequalities in STEM opportunities and achievement can be counteracted by integrated STEM experiences that empower all students to become capable in STEM (Cian, 2026; Edelen & Bush, 2021). Additionally, after-school programs often provide greater flexibility and are student-centered and interactive, allowing students to take ownership of their learning (Noam & Shah, 2013).

2.2 *STEM afterschool learning opportunities*

Engagement in afterschool STEM programs positively affects STEM career interest and participation in informal STEM activities (Cian, 2026; Sahin et al., 2014; Wulf et al., 2010; Young et al., 2017). The Afterschool Alliance (2015) reported that 70% of parents surveyed said their child's afterschool program offered STEM learning opportunities, and nearly 50% of those (13,709) in United States households considered STEM a factor when selecting a program. Seventy-six percent of parents agree that afterschool STEM helps their child gain interest and skills in STEM. Afterschool STEM learning increases engagement with STEM content, fostering youth voice and choice, building relationships, and applying STEM learning to real-world social concepts-supporting learning, thinking, interest, and identity development at a young age.

Afterschool learning opportunities for prek-3 students require active engagement in math and science, which are critical factors in academic success in STEM (Maltese & Tai, 2010). These factors of active engagement are strong predictors of academic performance (Hughes et al., 2008). The National Research Council (2015) refers to these learning opportunities as a STEM Learning Ecosystem, noting that they occur both in and out of school. The STEM Learning Ecosystem can be defined as an environment in which learners engage with integrated content within a community and culture.

A longitudinal study (Lindahl, 2007) found that student engagement and interest were the most important factors in choosing a science career path. Early learning experiences immersed in a STEM Learning Ecosystem can foster interest in STEM. There is a high level of interest in science among both males and females in middle and high school. Therefore, more focus must be centered on efforts to engage young children in science (Kahle & Lakes, 1983). Efforts to address gaps in science achievement in the United States require intensified early intervention efforts, particularly those delivered before primary grades. If unaddressed, science achievement gaps will emerge by kindergarten (Morgan et al., 2016). Afterschool programs have the potential to create opportunities for young learners to succeed in STEM. The Afterschool Alliance (2015) reported that 70% of parents said their child's afterschool program engaged in STEM activities. Engagement in afterschool programs positively affects STEM early-career interest and participation in informal STEM activities (Allen et al., 2019). STEM interest and engagement are closely linked to STEM identity development (Jakobi et al., 2026), which postulates the importance of a STEM Learning Ecosystem in afterschool programs (National Research Council, 2015).

3. Theoretical framework

3.1 *Transitional space theory*

Winnicott's theory of transitional space (Winnicott, 2021) explores the intermediate space between an individual's inner world and external reality. This theory is pivotal in understanding how individuals, particularly youth, develop their sense of self and relate to the world around them. Initially, in 1951, work on this theory explored potential space with infants. It has since expanded to explore the role transitional spaces have in connecting play to more structured learning experiences. Transitional Space Theory posits that these spaces are where creativity and innovation intersect, making them crucial for engagement in quality STEM programs. Afterschool programs that employ hands-on, innovative practices provide a safe environment where youth can develop self-confidence and experiment with new ideas without external pressures, which then translate into positive impacts on learning in more traditional spaces.

Exploring new interests, such as STEM, in a supportive, less-structured environment promotes active engagement, critical thinking, and diverse opportunities for low-income youth, youth of color, and girls. STEM projects often allow students to pursue their interests, bridging inner passions with educational structures. Engagement with STEM activities helps youth develop a sense of mastery, a concept that can be understood in relation to Winnicott (2021). These quality learning opportunities allow youth to explore different roles and identities (e.g., scientist, engineer, mathematician) in a low-stakes learning environment, which is critical for self-discovery.

These shared experiences are fundamental to Winnicott's concept of transitional space, fostering social skills and a sense of belonging. By providing opportunities for youth to explore and experiment in a supportive environment, afterschool STEM programs align with Winnicott's theory and facilitate personal and educational growth.

3.2 *Research questions*

This study examines the effectiveness of informal STEM learning experiences in after-school early childhood programs as measured by the criteria of the Program in Education, Afterschool & Resiliency (PEAR) DoS Tool. The research question was: How do informal STEM learning experiences in after-school early childhood programs reflect key dimensions of instructional quality, including learning environment features, activity engagement, STEM knowledge and practices, and youth development in STEM? This includes examining the findings from all observations and examining the change when a second observation is conducted at a site that had previously received written feedback from an observation tool. This study aims to provide valuable insights into early childhood STEM programs in afterschool settings to inform potential areas for support. It also seeks to examine changes made at a site between observations before and after receiving written feedback from an observation tool, such as the DoS Tool. It addresses the challenges that after-school STEM programs face in maintaining effectiveness, including resource limitations and equitable access, and considers strategies to mitigate these barriers.

4. Method

4.1 *Design*

Eight afterschool programs across the southeastern United States used an explanatory sequential mixed-methods evaluation approach to provide STEM learning experiences to PreK through third-grade students. Each of these programs aims to support economically disadvantaged youth by enhancing their academic progress and enriching their lives through quality after-school programs. This study sought to assess the quality of STEM instruction in these early childhood after-school programs. The effectiveness was evaluated for each site using PEAR's DoS observation tool for two lessons, an initial observation and a second DoS observation between 2-3 months after receiving written feedback from the initial observation.

This research aims to investigate instructional environments and practices in after-school STEM programs by evaluating program quality using the PEAR DoS Tool. It aims to identify key findings, challenges, and recommendations to improve program effectiveness, support educator development, and enhance student engagement and learning outcomes in STEM disciplines.

4.2 *Research sites*

This study examined eight early childhood afterschool STEM learning sites offered throughout the Southeastern United States. Among the participants at these sites, 64% identified as female, 27% male, and 9% did not identify. The majority of participants identified as Black (73%), while 18% identified as multiracial and 9% as other. This data indicates that the programs predominantly served participants who identify as either Black or female, reflecting either targeted outreach efforts or the region's demographics supported by the grant. Each site was unique and is described below. The eight early learning environments that varied in size, geographic location, and instructional focus (see Table 1). Site 1, *Growing Minds Learning Center (LC)*, is a four-star, state-accredited program located in a Gulf Coast city serving children from infancy through age 12; observations focused on children ages 4 through Grade 3. Site 2, *Little*

Sprouts Learning Center, located in a major metropolitan area, offers STEM-focused camps and academic support services, with observations involving learners ages 5-10. Site 3, *Blossom Early Learning Center*, situated in a town southwest of a metropolitan area, provides full-day care for children from 6 weeks to age 5 and houses Early Head Start and Head Start programs; observations focused on 4-year-old preschoolers. Site 4, *Sprout & Shine Learning Center*, is a private downtown school serving children from infancy through Grade 12 and guided by the Multiple Intelligences framework; observations were conducted with learners in Grades K-5.

Table 1. Site data

STEM site	Ages served/age of class observed	# Of students pre/post	Type	Location
Growing Minds LC	Birth-12 years/4-8years	16/16	Childcare	Gulf coast urban area
Little Sprouts LC	5-10 years/5-10 years	10/10	STEM camps & tutoring	Urban area
Blossom Early LC	6 weeks-5 years/4-year	11/11	Childcare/Head start	Rural
Sprout and Shine LC	Birth-12th grade/5-11 years	11/12	Private school	Urban area
Bright Beginnings LC	Birth-5 years	7/7	Childcare	Rural
Little Luminaries LC	5-12 years/5-8 years	9/9	Afterschool care	Riverside urban area
Imagine & Grow LC	6 weeks-12/5-8 years	11/10	Afterschool care	Rural
Pathway to Learning LC	4-12 years/4-5 years	10/10	University childcare center	Riverside urban area

Source: Author

Additional data were collected from four other early learning settings. Site 5, *Bright Beginnings Learning Center*, served preschool-aged learners. Site 6, *Little Luminaries Learning Center*, a Christian ministry-affiliated program located in a riverside city, offers mentoring, after-school care, and STEM activities for children in Grades K-5; observations focused on learners in Grades K-2. Site 7, *Imagine and Grow Learning Center*, a faith-based program in a small town, provides care from 6 weeks to age 12 and hosts a STEM-oriented after-school program for students in Grades K-5; observations centered on learners in Grades K-3. Site 8, *Pathway to Learning Center*, affiliated with a state university in a riverside city, operates as a prekindergarten and after-school program that promotes evidence-based practice; observations focused on children ages 4 and 5.

4.2.1 *Instruments*

The PEAR DoS observational tool was used to assess the quality of STEM learning experiences. Pre-and post-observations were conducted in PreK-3rd grade. However, there was no professional development provided between observations. Sites were provided with findings from the observations but not supported in addressing feedback. The DoS observational tool incorporates the constructs about effective informal learning environments, science practices, and engineering practices that can be observed for effectiveness (Shah et al., 2018).

4.3 *Dimensions of success*

DoS is an overarching framework that defines key aspects and helps improve the quality of the STEM learning experience. The DoS suite of tools allows researchers, practitioners, funders, and other stakeholders to track the quality of STEM learning opportunities and to pinpoint strengths and weaknesses by identifying twelve indicators of STEM program quality in out-of-school time (see Figure 1). The Dimensions of Success observation tool is a validated research tool (Shah et al., 2018), and certified DoS observers evaluated the quality of STEM learning experience.

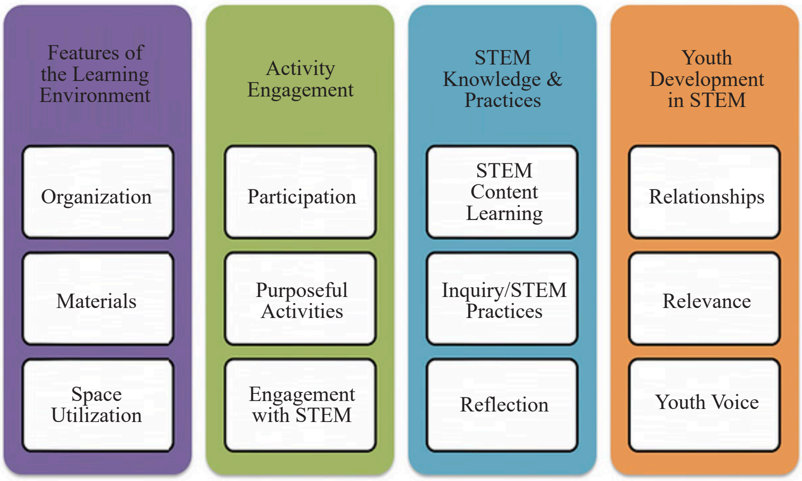

Figure 1. Dimensions of success four domains and twelve dimensions
Source: https://www.pearinc.org/dimensions-of-success
Note: This figure demonstrates the four domains of the DoS observation tool. In addition, each domain displays the indicators used to score it

The DoS suite of tools allows researchers, practitioners, funders, and other stakeholders to track the quality of STEM learning opportunities and to pinpoint strengths and weaknesses by capturing the twelve indicators of STEM program quality in out-of-school time. Three dimensions fall under each of the four domains: *Features of the Learning Environment, Activity Engagement, STEM Knowledge and Practice, and Youth Development in STEM* for a total of 12 dimensions. The Dimensions of Success observation tool is a validated research tool (Shah et al., 2018), and certified DoS observers in the southeastern region of the United States evaluated the quality of STEM learning experience by rating instruction on the 12 dimensions.

The three dimensions in the *Features of the Learning Environment* domain. Refer to the details surrounding preparation for the activity, such as organization, materials and utilization of space. How students are involved in the activity are evaluated using the three dimensions under *Activity Engagement. STEM Knowledge and Practice* examines how students are pushed to make connections, engage in inquiry practices, and understand the content*. Youth Development in STEM* explores student empowerment and voice in the learning, connect the learning to their real-world experiences, and the way they interact with others during the activity.

Achieving high scores on these 12 indicators across the four domains (*Features of the Learning Environment, Activity Engagement, STEM Knowledge and Practice, and Youth Development in STEM*) indicates that the facilitator has effectively demonstrated a high-quality approach to after-school STEM learning opportunities (Papazian et al., 2013). Each of the 12 Dimensions of Success is rated on a four-point scale. As described in Shah et al.'s (2018) validation paper, the four points are defined by the degree to which there is evidence during the learning experience to support the essential features of the respective dimension:

• Compelling Evidence (score of four): the existence of compelling and consistent evidence supporting the presence of practices and/or interactions defined by the dimension.

• Reasonable Evidence (score of three): the presence of clear evidence of the dimension, although the evidence is less consistent than the evidence that would merit a score of four.

• Inconsistent Evidence (score of two): the presence of weak evidence supporting the dimension definition.

• Evidence Absent (score of one): minimal or no evidence in support of the dimension definition.

4.4 *Data collection*

A DoS-certified observer conducted each pre-observation and post-observation. To become a DoS-certified observer, individuals must complete an official PEAR DoS Observation Training, which typically lasts two days and covers the DoS framework, observation techniques, and scoring procedures. After training, participants must pass a certification test that involves watching video clips of STEM learning activities and scoring them based on the DoS rubric. They are guided in scoring by information obtained in the training, detailed commentary, and examples. To achieve certification, their scores must match expert ratings, demonstrating reliability and consistency in observations. Additionally, DoS certification requires recertification or refresher training every two years to ensure observers maintain accuracy and stay up to date with DoS guidelines. Both DoS observers has completed both the initial and recertification processes and hold a valid certification. Observations of every learning experience required the observer to compile field notes and provide a score for each dimension and specific feedback from the observation using the DoS Observer Rating Sheet and Feedback Report in order to justify their final score decisions.

4.5 *Data analysis*

Each DoS observation included detailed notes and scoring across the four domains and 12 indicators of the Dimensions of Success. Scores were analyzed quantitatively by calculating the mean and range scores. Qualitative notes were analyzed within each domain to provide more detailed explanations of the scores and to identify common elements across programs. Because the DoS instrument was used, traditional coding wasn't a part of this analysis process. Instead the field notes justifying the categories, and the criteria descriptions that were part of the DoS Observer Rating Sheet and Feedback Report were used in the analysis of the experience. Internal reliability was met via the training and field notes on prior observation tools in the training and certification process.

5. Results

The results were examined holistically to identify the mean state of each dimension across the 8 sites (See Table 2). Organization was the highest-ranking dimension across both observations for all eight sites with a mean score of 3.69 out of 4. Space Utilization and Relationships were second highest, with a mean score of 3.5 out of 4. The lowest ranking dimension was relevance with youth voice being second to last. When examined by domain, the highest-ranking domain was STEM Knowledge and Practices (3.44). Activity and Engagement had a mean of 3.02 and Youth Development in STEM scored a mean average of 2.77. The lowest mean was STEM Knowledge and Practices (2.67).

Table 2. Mean scores in dimensions

Dimension	Mean score	Rank order	Domain
Organization	3.6875	1	Features of the learning environment
Materials	3.125	5w	
Space utilization	3.5	2*	
Participation	3.375	4	Activity engagement
Purposeful activities	2.875	6	
Engagement with STEM	2.81	7	
STEM content learning	2.625	9*	STEM knowledge & Practices
Inquiry into STEM practices	2.625	9*	
Reflection	2.75	8	
Relationships	3.5	2*	Youth development in STEM
Relevance	2.375	12	
Youth voice	2.4375	11	

Source: Author

In addition, pre-and post-DoS observations were analyzed to examine changes in instructional quality across eight early learning settings following implementation of the DoS process (see Figure 2). This process includes the initial observation and sharing the observation and feedback with each site in the written DoS feedback format. How each site chose to use the feedback prior to the post observation was unknown. Overall, results indicated positive shifts across multiple dimensions, with the most substantial gains observed in instructional and interactional domains rather than structural features of the learning environments.

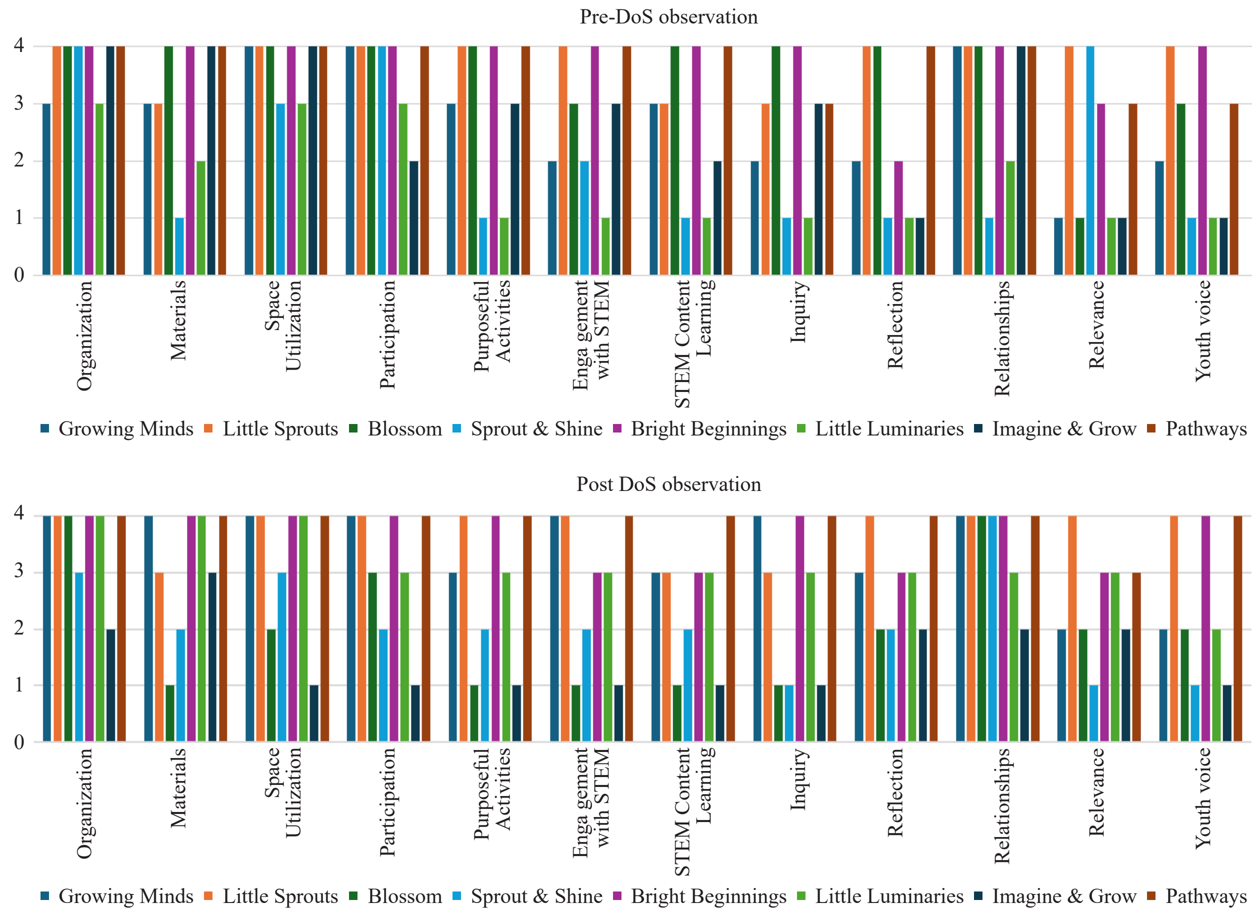

Figure 2. Overall mean for DoS pre and post observations using the DoS observation tool (Authors' own work)

5.1 *Features of the learning environment*

Across sites, the Features of the Learning Environment (Organization, Materials, and Space Utilization Dimensions) received the highest mean score both holistically and during pre-observations, suggesting that foundational classroom structures and routines were largely in place prior to the DoS intervention. Post-observation data show these dimensions were maintained or modestly improved, indicating stability rather than substantial change. These findings suggest that the DoS process did not primarily influence environmental management but instead supported changes in how instruction was enacted within existing structures. Other domains had greater variability within them, therefore dimensional data is grouped and described below.

5.2 *Instructional intentionality and STEM engagement*

More pronounced changes were observed in dimensions associated with instructional intentionality and STEM learning, including Purposeful Activities, Engagement with STEM, STEM Content Learning, and Inquiry. Pre-observation scores in these areas demonstrated greater variability across sites, with several settings showing limited evidence of inquiry-based instruction or explicit STEM content integration. Post-observation data show consistent increases across sites, indicating greater alignment among activities, learning goals, and STEM concepts. Observations documented increased use of questioning, hands-on exploration, and opportunities for students to engage in problem-solving and investigation.

5.3 *Reflection and relationships*

Relationships, which is in the domain of Youth Development in STEM, scored highest throughout the entire set observations. Improvements were also evident in Reflection and Relationships, suggesting enhanced instructional interactions following the DoS process. Pre-observation data indicated that opportunities for reflection were inconsistently embedded within instruction. In contrast, post-observations showed more frequent instances of students being prompted to explain their thinking, make connections to prior experiences, and revisit learning goals. Similarly, gains in the Relationships dimension reflect stronger teacher-student interactions, characterized by increased responsiveness, encouragement, and affirmation of student ideas.

5.4 *Relevance and youth voice*

Changes in Relevance and Youth Voice, two elements within the domain of Youth Development in STEM, had more variability across sites but demonstrated an overall upward trend from pre-to post-observation. Post-observation data suggest increased opportunities for student choice, participation, and real-world connections; however, these dimensions remained among the lowest relative scores across settings. This variability indicates that while progress was made, fostering student voice and relevance may require ongoing and sustained instructional support beyond a single intervention cycle.

5.5 *Cross-site trends*

Despite differences in program type, age range, and institutional affiliation, post-observation results revealed greater convergence across sites, particularly in inquiry, engagement, and relational dimensions. This pattern suggests that the DoS process supported more consistent instructional practices across diverse early learning environments.

5.6 *Summary of dimensional findings*

When examining all the data the areas of relationships, organization and space utilization consistently ranked highest. When examining the pre and post observations collectively, the results indicate that participation in the DoS process was associated with improvements in instructional quality, particularly in dimensions related to purposeful STEM engagement, inquiry-based learning, and teacher-student interactions. Structural features of classrooms remained stable, while instructional and interactional practices showed the greatest growth from pre-to post-observation.

5.7 *Site-level mean comparisons*

Figure 3 presents the mean DoS observation scores for each site at pre-and post-observation. Overall, six of the eight sites demonstrated increases in mean DoS scores following participation in the DoS process, indicating broad improvement in instructional quality across settings.

The largest gains were observed at Little Luminaries Learning Center and Growing Minds Learning Center, where post-observation means increased substantially relative to pre-observation scores. These sites showed notable improvement in instructional and interactional domains, suggesting that the DoS process may have been particularly effective in supporting intentional practice in these contexts.

Moderate gains were evident at Sprout & Shine Learning Center and Bright Beginnings Learning Center, both of which demonstrated upward shifts in mean scores while maintaining relatively strong baseline performance. Little

Sprouts Learning Center and Pathway to Learning Center showed consistently high mean scores across both observations, with minimal change, indicating sustained high-quality practice rather than marked growth.

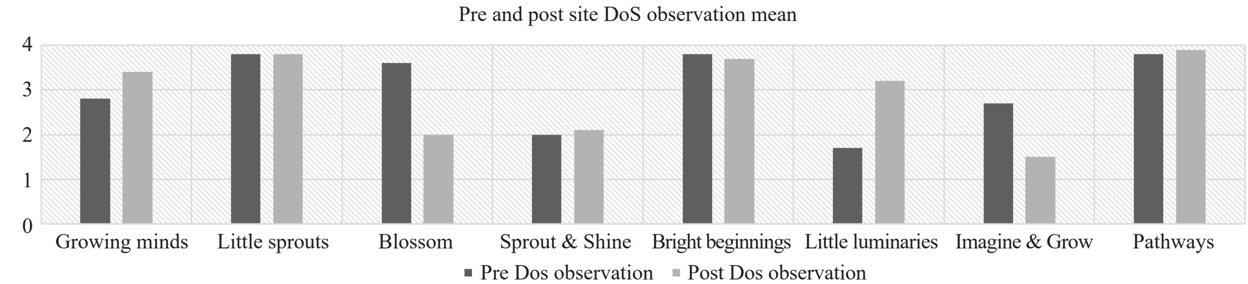

Figure 3. Pre and post site DoS observation mean (Authors' own work)

Two sites, Blossom Early Learning Center and Imagine & Grow Learning Center, demonstrated slight declines in mean scores from pre-to post-observation. These decreases may reflect contextual variability, implementation differences, or changes in observed instructional focus rather than a systematic reduction in quality. The teachers at both sites noted that the second observation day had been challenging and the observations were conducted late in the day. Notably, both sites maintained mean scores within the mid-range of the DoS scale.

5.8 *Summary of site-level trends*

Taken together, the site-level mean comparisons indicate that participation in the DoS process was associated with slight overall positive movement across the sites, while also highlighting variability in the magnitude and direction of change. These findings underscore the importance of considering contextual factors and implementation conditions when interpreting site-level outcomes.

5.9 *Limitations*

There are several limitations to this study. First, findings only represents what was observed at these eight sites, in the specific classrooms and lessons observed. While it provides insight into these classrooms, it can't be generalized beyond these observations. In addition, it only notes observational data directly taken from within the DoS framework. Statistical tests of the data were not conducted, due to the limited n. There is a limitation of causal inference, because other reasons might explain the changes between pre and post observations. This research may note the changes, but the main focus is on the state of the lessons as an overview of STEM education in these eight informal learning spaces. There is also a potential bias given the paid observational roles. However, the observers external consultants and were not a part of the grant. Therefore, their role was to observe free from bias, without the bias that might come if they were part of the grant writing team. Student outcome data was not collected, so this only reports on the observations and what occurred during the activity. Finally, while sites were spread across multiple sites and locations, they were all located within the southeastern United States which could have cultural impacts on the results. Due to the limited number of sites and observations, the only quantitative data obtained was descriptive statistics.

6. Discussion

Overall, the informal STEM learning programs examined in this study are of significant educational and scientific importance, as they provide insight into how informal learning environments can support high-quality STEM experiences in early childhood settings. They also share insight into areas that could use additional focus. By using the DoS framework to examine instructional quality across multiple sites, this study contributes empirical evidence to ongoing efforts to strengthen STEM learning beyond the traditional classroom.

Findings of the four domains were similar to findings of the validation studies conducted by Shah et al. (2018). Their two studies also found Features of Learning Environment to be the highest scoring domain. Reflection and Relationships mean scores were higher for these eight sites than the mean scores for these dimensions in the prior studies. They also showed a substantial amount of growth across the eight sites between the pre observation and the post observation. Afterschool STEM programs that encourage inquiry and reflection are beneficial to learners identities and connection with the learning experience (Mohr-Schroeder et al., 2020; Noam & Shah, 2013; Shah et al., 2018).

Results from DoS observations across all pre-and post-observation sites confirmed that participation in the DoS-informed process was associated with improvements in instructional quality, particularly in domains such as instructional intentionality, STEM engagement, inquiry, and teacher-student relationships. This supports prior studies that found that observations, feedbacks, and reflections have been shown to promote professional development with coherence and focus (Liu et al., 2024; Mizyed & Eccles, 2025; Schachter et al., 2019). While structural features of learning environments (e.g., organization, materials, and space utilization) were largely stable across observation periods, notable gains were observed in how learning experiences were designed and enacted, suggesting that observation-based professional learning may be especially effective in supporting pedagogical change rather than surface-level adjustments.

Importantly, improvements were evident across diverse program contexts, including community-based centers, faith-based programs, and university-affiliated settings, suggesting that the DoS framework may serve as a flexible, context-responsive tool for instructional improvement. At the same time, variability in gains, particularly in dimensions related to youth voice and relevance, highlights the complexity of fostering student-centered practices in after-school early childhood settings and suggests a need for sustained, iterative support.

The two sites that demonstrated slight declines in mean scores could be reflections of the challenges of the day that the teachers noted, but it also may reflect contextual variability, implementation differences, or changes in observed instructional focus. This further highlights the needs for multiple observations and perhaps interviews with teachers and students about experiences in STEM education before and after the DoS observation tool and feedback were shared. While overall there were slight positive shifts, it creates the question of how the shifts might have been enhanced through systematic communication with teachers about the observation findings, rather than leaving findings for each site to communicate in the way they decide to do it. In addition, professional development or coaching around the individual findings of the observation might provide targeted support to further improve the effectiveness of each site. Observations and evaluations can be helpful, but how they are used and communicated are key in effecting significant change.

7. Conclusion

This study examined informal STEM learning experiences in after-school early childhood programs through observations guided by the DoS framework. Relationships, organization and space utilization were found to be the strongest areas across all observations of sites.

Findings from pre-and post-observations indicate that structured, observation-based professional learning can support improvements in instructional quality across diverse early learning contexts as stand-alone tools. Gains were most evident in domains related to instructional intentionality, inquiry-based STEM engagement, and teacher-student relationships, underscoring the value of reflective practice in informal learning environments. These elements connect to Winnicott's (2021) theory of transitional space, as students are engaging their inner identities within these positive spaces and experiences, which may then support their transition to and connection with STEM learning in more traditional settings, such as classrooms.

The results highlight the importance of moving beyond structural considerations toward a deeper focus on how STEM learning experiences are designed, enacted, and experienced by young learners. While many programs demonstrated strong organizational foundations at baseline, the DoS process appeared to support educators in leveraging these structures to create more purposeful, engaging, and relationally rich STEM experiences. At the same time, continued variability in dimensions related to youth voice and relevance suggests that fostering student-centered STEM learning is an ongoing process that may require sustained professional support. Findings suggest that while observational tools can make a difference, it begs the question as to the amount of improvement one might see if the tools were used to provide targeted coaching and or professional development.

These findings contribute and strengthen the growing body of research on instructional quality and professional learning in early childhood and after-school STEM contexts. By demonstrating the utility of the DoS framework across varied program types, this study offers practical implications for educators, program leaders, and policymakers seeking scalable approaches to improving informal STEM education. Future research should examine the long-term impact of observation-based professional learning, explore connections between instructional quality and student outcomes, and investigate how sustained engagement with the DoS framework supports the development of equitable and inclusive STEM learning environments.

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Conflict of interest

The authors declare no competing financial interest.

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