

Article

Investing in the Lynchpin: Design Principles for Professional Development to Support Youth-Led STEM Programming

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Abstract

Youth-led STEM programming depends on skilled adult facilitators who can support authentic teen leadership, yet professional learning for developing these specialized skills remains understudied. Through three cycles of design-based research, we iteratively developed and studied a professional development model that trained informal educators from museums, libraries, afterschool programs, and schools to launch Teen Science Café programs—a youth-led model where teens organize STEM events. Analysis of data from trainer reflections, trainee interviews, trainee surveys, and implementation tracking across three iterative design cycles revealed six interconnected principles essential for effective professional development: focusing on a committed adult leader; personalized training characterized by mutual respect; learning by doing; establishing accountability that builds momentum; enabling learning from peers and near-peers; and recognizing success to nurture professional pride. Implementing these principles to prepare educators to center youth voice requires substantial, coordinated investment across stakeholders—commensurate with the complexity of developing youth agency and STEM identity in informal settings. From our findings, we contrast this approach with the “efficiency trap,” in which scaled training without sustained support wastes resources when many educators are trained but youth-centered programs fail to materialize.

Keywords: professional development; informal STEM education; youth-led programming; out-of-school time

1. Introduction

An increasingly powerful case is being established for the meaningful contributions out-of-school time (OST) learning affords young people, with growing emphasis on OST programs that incorporate quality science, technology, engineering, and math (STEM) experiences. Teen Science Cafes (TSCs) are a youth-led, adult-supported OST program model, with independently run programs in 135 sites across 36 jurisdictions in the United States, creating opportunities for or teens to develop their identities as people capable of engaging with science, to build leadership skills, and to cultivate confidence in their own ideas and voice (Parrott et al., 2025). This article centers on the adult leader who facilitates these experiences, examining the ways in which their professional development (PD), and the investments required to support it, enables youth to authentically lead.



Academic Editor: Amber Simpson

Received: 26 January 2026

Revised: 19 March 2026

Accepted: 30 March 2026

Published: 2 April 2026

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1.1. The Importance of Skilled Adults

Ways to more meaningfully center youth voice in STEM programming have been of increasing interest in programs in OST settings, including traditional afterschool programs as well as museums, science centers, libraries, and other settings serving youth outside the traditional school day. Approaches designed to let young people take ownership of their learning, lead programs, and see themselves as capable in STEM have demonstrated positive impacts on interest development, science identity, and long-term STEM engagement (National Research Council [NRC], 2009; Falk et al., 2016; Xing et al., 2015). However, research often focuses on youth outcomes, while under-examining a critical enabling condition: the skilled adults who make such programming possible.

Efforts to meaningfully center youth voice in STEM programming require adults who possess specific competencies for facilitating teen leadership—skills that are distinct from those needed for adult-led programs delivered to teens. Research into youth-adult partnerships as a way to elevate youth leadership has identified the importance of adult mentors who possess specific competencies, skills, and mindsets to be successful at letting youth lead (Zeldin et al., 2013). Programs aiming to be “for teens, by teens” require adults become skilled at facilitating teen leadership rather than simply leading themselves. Adults serving as mentors must create systems, practices, and a program culture that enables youth to take increasing authority for programming, while providing scaffolds that enable them to learn the practices of leadership in a supported way without undermining their ownership (Larson et al., 2005). Recent research has begun to examine the dynamics of facilitation in informal STEM settings, finding that facilitators must continuously navigate tensions between supporting learner interests and introducing content learning goals, and that effective facilitation requires careful attention to how adults constrain or support youth thinking rather than simply leading it (Hladik, 2022; Sager et al., 2024). These are distinct skills that need to be explicitly included in training for adults (Bowers et al., 2015; Camino, 2000).

Research on positive youth development programs underscores that program quality hinges on staff capacity, as young people benefit most when surrounded by caring adults who foster supportive environments, provide mentorship, and create genuine opportunities for leadership (Agans et al., 2015; Bowers et al., 2015). Yet, while the literature emphasizes the importance of adults in youth leadership development, far less is currently known about the essential characteristics of preparation that adults need in order to effectively support and enable youth leadership.

1.2. The PD Investment Gap

In informal STEM education specifically, adult facilitators occupy a unique position. Unlike formal classroom teachers or parents, they typically work in opt-in environments where youth are choosing to participate. Moreover, their role requires a combination of knowledge about STEM content, youth development, program development, and pedagogy to foster genuine engagement and empowerment from their learners. The literature on reflective practice in informal science education has begun to address how educators develop professional expertise, particularly in museum settings (Martin et al., 2019), but the specific preparation needed for adults to effectively support youth-led programs remains understudied.

Despite the critical role that frontline educators play in delivering quality youth programming, the informal STEM education field has historically treated PD as an afterthought (National Research Council [NRC], 2009). Given the small budgets and stretched resources in afterschool programs, museums, libraries, and community organizations, credentialing and ongoing PD are often seen as luxuries, particularly for entry-level staff. Increasing

research into PD for educators has become an area of focus, with new models of reflective practice explored in a variety of science settings (Cian & Kastelein, 2025; Martin et al., 2019; Peterman et al., 2021). These practices, however, have not been widespread and were often spurred by specific grant-funded initiatives, rather than an ongoing investment in educator PD.

The realities of the informal STEM education workforce compound this challenge. The staff who engage directly with youth frequently occupy lower tiers of organizational hierarchies. These roles are often part-time, with limited benefits and wages, for which it is difficult to hire and retain staff with the ideal skill sets (Afterschool STEM Hub, 2025). High turnover creates a persistent challenge for building institutional capacity and has been characterized as “a systemic challenge to the entire field” (Asher, 2012). When PD resources are scarce, they tend to be concentrated on full-time staff and supervisors rather than the frontline workers who directly engage with youth. A review of the state of the afterschool education workforce documented barriers and a general lack of PD opportunities for adults who interact directly with youth (Afterschool STEM Hub, 2025).

Moreover, the informal STEM education field has yet to fully grapple with what it means to invest in PD for sustained program implementation. Research on an extensive effort to support informal educators through coaching found that sustainability and spread required far more than a one-and-done training, including flexible pedagogical approaches, ongoing coaching, and structures to support adapting practices to local contexts (Peterman et al., 2021). Unfortunately, such intensive PD projects like those the research highlights are rare. Most budgetary investments leave room for a conventional PD paradigm which, when it occurs, favors efficiency and scale—providing a structured training to as many educators as possible, with the educators expected to implement the ideas on their own. Yet, we contend that, when the principles delivered in a mass training fail to take hold in the understanding and practice of an educator, the resources devoted to that training are effectively wasted. While it may be delivered at scale, it is less likely to make a significant, transformative change in the amount of youth ownership occurring in the OST learning landscape. The true cost of PD must account for whether educators actually build new programs that truly center youth voice and sustain them over time.

1.3. The Teen Science Café Model as a Test Case

TSCs offer a compelling context for studying PD that supports youth-led programming. The program model originated from an NSF-funded experiment to adapt the adult science café concept to be appropriate for teen audiences. To this end, instead of a program delivery model where the organization produces an event for a public audience, the TSC model was centered on a group of Teen Leaders organizing the events, rather than attending programs arranged by the host organization (Hall et al., 2012).

This shift to a teen-led model was essential to its outcomes and ethos. Teen Leaders work closely with their Adult Leader (an informal educator) to plan, organize, and run café events that bring their peers together with STEM professionals. This offers two pathways for teen participants to engage with STEM learning and identity development: a high-engagement role as Teen Leaders, or a casual role as attendees, which offers a low barrier to entry for youth to explore STEM topics. Evaluation documented meaningful impacts on participating teens, including more realistic perceptions of science, increased interest in science careers, and development of leadership skills and confidence (Amanova & Dymond, 2025; Foutz & Luke, 2010; Hall et al., 2012; Hall et al., 2021).

The TSC model is grounded in six Core Design Principles that are all in service of creating genuine youth ownership to create authentically engaging programs (Parrott et al., 2025). Café programs produce (1) highly engaging and interactive events that foster

conversation and activity with STEM professionals. The events themselves are an easy entry for any curious teen, which is a strategy aimed (2) to attract teens with diverse motivations and life experiences—not just those already interested in science. This requires programs to (3) identify, vet, and guide guest STEM professionals (presenters at each event) to successfully engage with teens. Finding experts and other support for the program is accelerated by (4) the cultivation of strong community relationships. And, as we have emphasized, at the center of the TSC model is that (5) teens should take ownership of the program, which requires the sustained effort of (6) a committed adult leader to support the teens, community, and scientists.

Since its founding with three TSC sites in New Mexico, the model has spread to a national network of 135 sites across 34 states, Washington DC, and Puerto Rico as of 2025. Achieving this level of spread required the Teen Science Café Network (TSCN), as the national entity that supports the infrastructure, scale, and sustainability of TSCs as a collective group, to grapple with strategies to train and prepare adult leaders at new sites to do this work. Further, the work is adapted to take place across the spectrum of informal learning settings, from large, urban museums to rural, community-based afterschool programs, and every venue in between. This presented a question of how to structure a professional training program by which a national hub could effectively prepare such a diverse group of on-the-ground educators to successfully launch and sustain genuinely youth-led programs.

1.4. Theoretical Framework

The PD model developed and studied here draws on three established traditions in adult and professional learning, each of which helps explain both the design decisions that emerged across iterative cycles and the mechanisms by which the model supported educator growth. First, the model reflects core principles of andragogy, a theory of adult learning which proposes that adult learners are most effective when training acknowledges their existing professional identities, connects directly to their immediate practice context, and treats them as capable, self-directed individuals rather than passive recipients of instruction (Knowles, 1980). A PD model designed to work across a variety of informal STEM education settings must be designed to train educators who come with differing professional backgrounds, prior knowledge, and institutional constraints. This theory undergirds the approaches of the project's iteration cycles, always foregrounding ways to work with informal educators' incoming expertise and perspectives, rather than asserting a fully standardized approach of content delivery.

Second, the PD model is grounded in experiential learning theory (Kolb, 1984), which holds that skills are most effectively developed through cycles of concrete experience, reflection, and application. This PD initiative was premised on educators learning to support youth-led programming primarily by establishing new programs and doing the work in real-world contexts. The model would embody a commitment to embedded, practice-based learning, rather than purely theoretical or conceptual understanding. This further distinguishes the approach from conventional one-time training models that prioritize the transfer of information over the development of practice.

Finally, the approach is consistent with the established tradition of reflective practice in the field of informal science education (Martin et al., 2019; Tran et al., 2019), which emphasizes that professional expertise develops through sustained cycles of action and reflection, supported by a more experienced practitioner. This tradition, alongside sociocultural perspectives on learning as a process embedded in relationships and shared practice (Lave & Wenger, 1991), suggests that professional growth is not an individual achievement but one shaped by the communities, mentors, and peer networks within which practitioners

develop their expertise. Effective PD must therefore create intentional structures to foster those relationships to maximize the potential of the educator's professional learning.

1.5. Our Research

This context motivated a multi-year research initiative, funded by the National Science Foundation, to develop and study an effective PD model for informal educators seeking to start TSC programs, implemented alongside an effort to expand the number of TSC programs nationwide. Using an iterative Design-Based Research (DBR) approach, we sought to address the central question: What are the critical ingredients of an integrated and successful PD program for informal STEM educators who work at the lower end of organizational hierarchies and come from diverse institutional backgrounds?

The PD initiative was led by the leadership of the TSCN, who managed the training process, created training materials, and hired the staff who did any recruitment or training activities. The fundamental structure of the PD approach was grounded in the six TSC Core Design Principles (of which teen ownership is critical). It was led by trainers, called Resource Guides, who were paid staff selected from people with experience as adult leaders of TSC programs. And its explicit goal was to build the confidence and skills among adult leaders that were applied by successfully launching and, in the future, sustaining new TSC programs at their organizations. Beyond these pillars, the team was open to experimenting to find what tactics and strategies Resource Guides could use to be most successful.

This process included iterating on the recruitment strategy for prospective TSC sites and trainee adult leaders to participate in this effort, as will be discussed in the results. In all cycles of testing, prospective trainees completed an interest form with information about their institution and interest in the TSC model. Beyond that, however, the degree and process of introducing, vetting, and selectivity for entering the training process was refined over time. By the final cycle, there was a formalized process, timeline, and structure to select trainees to enter the PD initiative, learn the Core Design Principles and model, and be supported through the creation of a full-fledged TSC program for their community. Because the TSCN is a national network and trainees came from all parts of the United States, all training sessions, coaching, and cohort activities occurred virtually, using asynchronous and synchronous approaches. The specifics of the process and strategies evolved with each PD cycle.

Through three cycles of iterative design, testing, and refinement, we developed and studied a PD model to build skills among informal educators from museums, libraries, afterschool programs, schools, and universities to launch and sustain their own Teen Science Café programs, which embody the TSC Core Design Principles. Most critically, the training needed to develop adults who could support genuine youth ownership while serving as guides and mentors, a central but challenging element.

This research was meant to identify a set of design principles for the PD program created, articulating the attributes of elements that are necessary for PD that enables educators to apply these skills while initiating a new, full-scale program in their institutions. Our concern was beyond measures of educator skill-gain, but what design principles were necessary for skill-building to lead to a solidified program that sustains beyond the training period.

2. Materials and Methods

2.1. Design-Based Research Approach

This work employed a DBR methodology to iteratively develop, test, and refine PD approaches for informal STEM educators who were launching Teen Science Cafés. DBR enables researchers and practitioners to collaboratively study, revise, and construct

theory about educational interventions while those interventions are being implemented in authentic settings (Design-Based Research Collective, 2003; Barab, 2014). Rather than testing a fully formed intervention against a control condition, DBR acknowledges that complex programmatic solutions arise through cycles of design, implementation, observation, and revision, with each cycle informing the next (Cobb et al., 2013).

Researchers and TSCN leadership together conducted three major cycles of design iteration, each following a structured process: (1) collaboratively defining the current challenge and proposed design solutions for process, structure, and content; (2) TSCN leadership and Resource Guides (experienced TSC adult leaders hired to serve as trainers) implemented the design solutions into materials, processes, and experiences, applying them with cohorts of trainee adult leaders; (3) the research team collected and analyzed data about the implementation cycle, adjusting methods and lines of inquiry based on the needs of that cycle; and (4) all stakeholders reconvened for collaborative “data parties” (Bird & Lewis, 2021; Franz, 2018) to interpret findings, identify new or updated challenges, and propose further refinements and solutions for the next cycle.

This collaborative approach was essential to our goals. Rather than program staff developing solutions in isolation and researchers coming in to measure results, we worked as an integrated team. The process brought together researchers’ theoretical expertise, Guides’ practical knowledge of implementation and the barriers “on the ground,” and TSCN leadership’s strategic understanding of network growth, diversity, and scaling concerns. This process also allowed the team to develop systems that were responsive to the significant challenges of training educators during and shortly after the COVID-19 pandemic, which upended many programs through layoffs, budget cuts, and staff turnover (American Alliance of Museums [AAM], 2020; Krantz & Downey, 2021).

2.2. Data Sources

Throughout the iterative cycles, we drew on multiple data sources to understand the PD process and outcomes, adjusted methods based on fit for the concerns and strategies in each round of testing. We leaned more heavily on qualitative methods, as we found that the nuance of the process and the feelings of participants (Resource Guides and trainees) about the process were more critical to understanding success of the adjustments to the process. Methods included:

Participation tracking: Using the program’s relationship management platform (which also evolved and strengthened the quality of data tracked over the cycles of testing), Resource Guides systematically documented adult leader participation in training activities, progress toward program launch milestones, and other training components (as these were added, changed, and removed). The progress and status of the new Café programs was also part of tracking systems, to continue to track sustainability of programs over time.

Resource Guide reflections: Researchers conducted interviews or group discussions with Resource Guides to capture their observations about what was and was not working in the training model, emerging challenges across trainees, and their own learning as mentors. This was the main method in cycle 1, as the team focused on translating the strategies used in customized 1:1 support to something more systematized and scalable for larger groups. Helping practitioners document their intuitive process was a key research focus.

Implementation documentation: In cycles 2 and 3, Resource Guides maintained records of their interactions with trainees, including meeting notes, email exchanges, and progress on key milestones. These records provided insight into the individualized support each adult leader required.

Trainee adult leader reflections: In cycles 2 and 3, we collected individual interviews with adult leaders from the cohorts, exploring perceptions of what they learned, which PD

elements they found valuable, challenges they encountered, ease and difficulty with the TSC principles, and views on program sustainability. In cycle 1, we administered a brief survey to participants, which had low response rate attributed to lack of engagement or follow-through with the PD or program development process.

2.3. Analysis & Development of Design Principles

At the conclusion of each iterative cycle, the research team analyzed data available and provided an internal report summarizing the patterns and themes. Following this analysis, the team engaged TSCN leadership and Resource Guides in an interactive “data party” where we discussed the themes and patterns that each person noticed from the data, and how the findings aligned with their experiences working with trainees. Through that process, the team documented their evolving design strategies in the form of a Journey Map, which developed in complexity over the three cycles, as the team recognized the importance of pre-training and post-training systems and steps that contribute to an overall successful learning experience. See Table 1 for detail on the major design challenges and solutions tested in each of the three cycles, including the substantial evolution of the PD model that occurred over these cycles.

Table 1. Overview of the TSC PD starting challenges and design solutions to test, by cycle.

Cycle	Planning: Lessons & Challenges to Address	Design Solutions for This Cycle
Cycle 1 (2020–2022)	• 1:1 Founder-led support (recent strategy) not scalable; need to document and systematize. • Need to shift to Resource Guide-led model. • Mid-COVID: existing programs being eliminated; organizational interest in new initiatives severely curtailed. • Team prioritized strategies that would speed scaling.	• Founders give 1:1 support to two new sites; research documents the process. • Hire first two Resource Guides to build and test a prototype training system. • Resource Guides responsible for recruitment and training. • Flow created to move individuals who express interest into training immediately.
Cycle 2 (2022–2023)	• Consistent communication and clear expectations—with trainees and within the team—is critical. • Balancing recruitment and training overloads Resource Guides; setting goals for numbers of people in training (but not around sustaining) overwhelms attention available for training. • Moving too fast from interest to enrollment leads to abandoned training. Curious individuals is not the same as committed institutions. • Setting expectations for “easy” and “rapid” start-up timelines is unrealistic for trainees. • No new TSCs fully launched within this timeframe.	• Separate recruitment from training; stronger vetting process is added to include organizational leadership commitment. • Resource Guides overhaul training, including articulating a self-guided training stage, followed by a 1:1 coaching stage that surrounds key milestones. Set graduation criteria (3 events). • Relationship management system for tracking trainee progress. • Rolling monthly enrollment; test offering stipends where funding allows.

Table 1. *Cont.*

Cycle	Planning: Lessons & Challenges to Address	Design Solutions for This Cycle
Cycle 3 (2023–2025)	• Greater success launching new sites, but some receiving stipends view participation as a one-off rather than long-term commitment. • Rolling enrollment creates solo cohorts; more staff work, less peer benefit. • Trainees who disengage feel they have failed; need supportive off-ramp options to come back to this work at a later time.	• Formalize training milestones and cohort structure. • Establish off-ramp process for trainees facing outside barriers, with option to re-enroll next cycle. • Create formal graduation and hand-off; transition to full TSCN membership. • Shift to one annual cohort start, aligned with school year planning cycle; timeline of 9 months with flexibility. • Offer stipend and non-stipend tracks, both with full PD and network access.

Ultimately, at the end of the final cycle of implementation and data-gathering, the research team and TSCN leadership convened again to engage in a synthesis process to distill overarching design principles that had emerged from across the four years of experience and research. While the team developed a comprehensive Journey Map that outlined the sequence of tactics and structures the TSCN program used to shepherd trainees through a learning journey, this process was to develop a set of higher-level design principles that characterized how and why the ultimate PD model was successful for supporting most trainees to develop skills and ultimately put them into action with new programs (that sustained) to carry forward, and which might be useful to other programs seeking to achieve similar goals.

In an extended working session and iterative discussion, researchers, TSCN leadership, and Resource Guides considered what were the critical investments and ways of working that made PD more effective? What shifts over the cycles most distinguished strategies that worked and strategies that were ineffective? What distinguishes this approach from conventional PD approaches? Through this process, we articulated six design principles that captured the essential ingredients of our PD model, which were emergent insights from the iterative design work. Each principle represents both a theoretical insight about effective PD with a practical commitment about where to invest resources.

3. Results

We identified six interconnected design principles essential to effective PD that enables informal educators to gain skills to launch and sustain youth-led STEM programs. Each principle represents both a critical ingredient for skill-building and program success, as well as an investment requiring coordinated commitment across multiple stakeholders. The principles work as an integrated system rather than standalone features; removing any single element significantly weakens the model's effectiveness (see Figure 1).

1. Committed Adult Leader.
2. Personalized Training with Mutual Respect.
3. Learning by Doing.
4. Accountability to Build Momentum.
5. Learning from Peers & Near-Peers.
6. Recognition & Nurturing Professional Pride.

Below, we describe each principle in greater detail, including its generalized characteristics relevant to any PD system, illustrating with specific strategies and evidence from the TSCN context, and identifying how it is an investment of time and resources.



Figure 1. Depiction of the six design principles for professional development that enables informal educators to gain skills, launch, and sustain youth-led STEM programs. The diagram uses the visual metaphor of climbing a mountain to illustrate the contributions of each principle to this journey.

3.1. Principle 1: Committed Adult Leader

The foundation of successful PD begins with recruiting the right adult leader. The adult leader serves as the vehicle through which all other principles will be learned, applied, and customized to fit their particular institutional context, and the one who will directly create the conditions for youth to lead. This principle requires getting buy-in from the individual's organization, but focusing support on the specific person who will work directly with youth, and ensuring that individual understands the expectations and process of centering teens as leaders.

This first principle parallels the “Committed Adult Leader” Core Design Principle of the TSC model itself (Hall et al., 2012; Parrott et al., 2025). Both the programmatic and PD frameworks recognize that committed, passionate adults are the lynchpins to building and sustaining any program that authentically centers youth leadership, and recognize that investing in those individuals is critical to program success.

3.1.1. Evidence from the TSCN Test Case

Cycle 1 of the PD model centered on translating the process of one-on-one coaching to a scaled solution, which involved developing training materials and content to rapidly move people from expressed interest to training experiences (see Table 1). This expedited timeline resulted in the majority of people entering training but then “ghosting” the process. Findings from the first cycle revealed that many trainees were just exploring the idea of the program model, rather than committing to implementation. Half of cycle 1 survey respondents indicated that they did not intend to start a program and noted that their initial participation motivations were to learn more about what a TSC is and to get ideas to tweak existing teen programs. There was also indication in the survey data that some trainees were not in roles that would work directly with teens, and realized someone else should have attended. By the end of a training cycle, these participants had neither started a TSC program nor intended to do so.

For cycle 2, the project team established a recruitment and vetting phase in the PD journey, which occurred long before anyone attended training. By cycle 3, a systematic process for recruitment and vetting was refined, which included conversations to assess the prospective site's alignment and identify specific individual(s) to participate in the training. This also introduced a mechanism for obtaining organizational commitment, acknowledging that staff would be investing time to develop, and ultimately maintain, the program. Even an informal process of acknowledgement ensured that an individual trainee and their larger organization were on the same page about the effort.

By the end of cycle 3, the data showed that trainees always reported that all of the TSC program principles, having the "Committed Adult Leader" principle was the easiest to achieve; due to the vetting process, the trainee had entered the PD as that committed leader. As one trainee reflected on their experience, "We did not have an issue with [meeting the principle of] a committed leader. Really, that was me. I was pretty committed. I was frustrated sometimes, but I was committed."

3.1.2. Investments in PD

This principle recognizes that any training of a new adult leader for these types of goals is a major investment of time, energy, and resources. By identifying a distinct PD stage that comes before the official training stage, it enabled the PD program to evaluate institutional and individual readiness before anyone invested time into training. While it may appear to slow the intake process—no one is moving from "interested" to "in training" immediately—it ensures that when a trainee begins the initial learning stage of PD, they are ready to learn and aware of expectations. While it reduced the number of people who enter training, this was more efficient because it also reduced the amount of time trainers spend "chasing" people who simply are not ready, and lessened the emotional toll for both trainers and trainees when realizing that something is a poor fit.

3.2. Principle 2: Personalized Training with Mutual Respect

Building trainees' skills and knowledge to start youth-led programs is most effective when it has human support, not self-guided processes. One-on-one mentoring from experienced trainers proved critical to success. The evidence (see Section 3.2.1) indicated that this "human touch" was a key mechanism that enabled new programs to overcome challenges practically and adapt the model to their unique institutional contexts without losing sight of core principles.

It was not simply personal support, however. Another critical component was that the trainer approaches their role and interactions with trainees with a spirit of humility. While trainers serve as official experts on the PD skills and programmatic model, it was critical that they explicitly recognize that trainees are experts about their own locations and communities. This created a collaborative and problem-solving relationship between trainer and trainee that centered on mutual respect, rather than a hierarchical dynamic.

3.2.1. Evidence from the TSCN Test Case

The evolution across cycles demonstrates this principle's importance. Cycle 1 experimented with more self-paced, resource-based learning and less intensive human support. This strategy developed out of a focus on a more efficiency-centered PD model to train more people more quickly. But at least half of people completely disengaged with the training process (we could not even obtain survey feedback from them), and of those who provided feedback, the biggest barrier identified was that it was hard to keep up with the pace of training, and that they needed a longer time to learn the strategies and plan. After cycle 1, one clear piece of feedback was wanting to have more one-on-one meetings with Resource Guides to help customize their support. As the iterative testing progressed, Re-

source Guides observed trainees' reactions to the "fire hose" of information and resources, learning that some continued "ghosting" came from who were overwhelmed and feeling as though they had failed at the learning process.

This prompted an overhaul of the training structure, introducing distinct "learning and planning" and "coaching and implementing" stages at the start of cycle 2. Resource Guides became more hands-on and had authority to customize pacing and emphasis based on each trainee's context. They slowed down the learning process and emphasized encouragement and solution-finding to keep trainees feeling empowered and making forward progress, adding a pathway to identify when a trainee needed a temporary "off-ramp," during times of organizational stress, rather than disengaging with a feeling of overwhelm. By the end of cycle 3, 10 of 11 interviewed trainees spoke to the personalized support and customized problem-solving of the Resource Guides, and how it was key to their learning process in the PD, as summarized by this trainee:

"I think the [Resource Guides] were amazing, incredibly engaging, incredibly flexible. I remember one of my first cafes that was supposed to happen in December. It got pushed, and I thought it would be a big deal, and I was really worried. And they were like, 'Oh, it's all right.' But the accountability was still there. They didn't let me off the hook completely, but they still were super encouraging."

3.2.2. Investments in PD

This principle most illustrates the push-pull between a PD model that focuses on "efficient" processes that enable throughput of more trainees in an identical way and a model that centers high-touch and personalized support for each learner. This test case revealed that the "efficient" systems had a higher potential to alienate trainees from the process and cause them to drop out. When training success is not simply "finished all modules" or "reported takeaways," investing in experienced trainers and letting them invest time in trainees is ultimately worthwhile.

The shift toward more humble leadership from trainers is less directly a financial investment, but it does dovetail with giving trainers more time with their trainees. Through personal connections, trainers understand trainees' difficulties and what type of encouragement each learner needs most. This also seemed to enable greater satisfaction in the work for trainers, as they can focus on connecting with people, rather than chasing people.

Notably, in our testing, there has been a further return on investment of this high-touch and mutually respectful PD. During the process of synthesizing cycle 3 findings and constructing these principles, a TSCN manager articulated a productive cycle she had observed: when trainers spend time problem-solving with trainees, they learn about the nuances of the environments in which they work, which they are able to bring back to the national leadership, which is used to refine the recruitment and training strategies. In this way, while it is a significant investment of staff time, this principle fuels a cycle of learning and improvement for the trainer organization.

3.3. Principle 3: Learning by Doing

PD has real impact when skill-building is not abstract, but offers ways for the learner to apply the concepts and techniques to create something tangible (in this case, a youth-centered program designed to last). Since the objective of this PD program is to facilitate specific types of learning opportunities for teens in action, it was essential that the PD model was also fundamentally action focused. That also means giving the learning cycle a sufficient amount of time for the learners to thoroughly apply and solidify what they have learned into practice.

While the theoretical grounding behind what educators learn is important, it is more effective when training is structured to foreground learning how to apply those theoretical principles in practice. The theory can remain largely implicit throughout training and still be successful. This principle recognizes that greatest value in PD resides in developing skills and achieving outcomes, not in being able to name conceptual labels.

3.3.1. Evidence from the TSCN Test Case

In cycle 3's PD strategy, Resource Guides introduced the TSC Design Principles in the training, but did not continually revisit or emphasize that language with trainees. Instead, training, coaching, and materials focus on techniques to put the principles in practice through the milestones of implementation: recruitment of a teen leadership group, finding a scientist, first event planned, first event held, and so on. This further underscored the trainers and trainees focus on learning the skills to live the principles.

When trainees from cycle 3 were asked, in final interviews, to reflect on which of the six TSC Core Design Principles were easy and which were challenging, they needed a refresher on the list of the six principles' labels. However, upon reviewing them, all trainees could instantly describe how they had implemented each principle and which had been easier or more challenging to implement. The evidence was clear that they had lived the principles as a form of program implementation, even if they had not learned to name the principles in the abstract. As one interviewed trainee from the final cohorts articulated, "Even though I probably can't name the six of these [TSC design principles], I could feel their impact on the program [I created]."

3.3.2. Investments in PD

This principle is fueled by the investment of the participant and their organization in the learning and application process. Trainees need to devote far more time and effort than it takes to sit in a workshop, as they are taking the learning and applying it in their work. This connects to the need for buy-in from both individual trainees and their supervisors to do this work. In most cases, a learning-by-doing approach also requires that the training organization invest in a longer timeline for the learning process. For the TSC learning process, we found that a cycle of at least 9 months was necessary to learn and apply all of the elements to establish a new program. This is a slower and longer investment by trainers, but the reality is that extending support through the entirety of the process and its bumps (rather than an arbitrary end date) is critical to success.

3.4. Principle 4: Accountability to Build Momentum

A key element of the PD model was establishing clear expectations for what trainees will create and/or achieve to be considered "training graduates," with an emphasis that the expectation is that they will engage in new professional practices—not simply learn ideas or concepts. Setting clear expectations serves two key functions. First it holds trainees accountable for making tangible progress, as well as providing clear guardrails and achievable milestones to build trainees' confidence that they are on track. Particularly for a complex training objective (like building a youth-led program) that is a long process, this breaks the journey into smaller steps of achievement.

The second function is that accountability structures build momentum that is essential for program sustainability after intensive support ends. For training that aims to help organizations build new and lasting programs, continued close support through the production of a "critical mass" of the target type of youth experience needs to be prioritized. Whether trainees excel or struggle in getting initial programs off the ground, the momentum created by the repeated learning-by-doing cycle creates a foundation for independent continuation.

3.4.1. Evidence from the TSCN Test Case

This strategy was first tested in cycle 2 when the TSCN experimented with offering stipends for a small group of new trainee sites; stipends introduced the need for formal MOUs with clear deliverables to release funding. At that stage, the TSCN leadership established a core expectation that a trainee would produce three TSC events, alongside several mid-point accomplishments, to “graduate” as a full-fledged TSC program (and receive full stipends). Within this framework, Resource Guides could maintain flexibility, as needed, to support trainees through unexpected barriers. But the core principle remained firm: trainees must have enough real-life practice to be capable of continuing independently.

The rationale for requiring three events was grounded in the team’s experience in cycle 1 about the trajectory and momentum that was necessary for an adult leader to get in a rhythm with structures and processes that work. Ensuring that trainees actually put their plan into action, while supported by Resource Guides was key. But implementing one or two events could feel like a one-off experiment, rather than established practice. But by three complete events, the rationale was that trainees would have a better established foundation (and routine) of practice to fuel their independent work at the next stage.

And while the structure was born out of a legal requirement, results from cycle 3 and reflections from Resource Guides highlighted that it was a useful structure to motivate all trainees (regardless of whether they received a stipend), offering them clear goalposts and a clearly defined metric of completion. By the end of cycle 3, sites who had participated without a stipend (but were held to the same accountability expectations) had the same graduation rate as those whose accountability came with a financial incentive. This further illustrates that the combination of an initial commitment and the structure of milestones (but not the motivation of money) were important to sustained success.

3.4.2. Investments in PD

The investment in this principle largely dovetails with Principle 3 (Learning by Doing). By incorporating expectations and processes to achieve multiple milestones toward full-scale implementation, it requires the PD program to invest in its trainers to operate on a longer time scale per trainee and per cohort, to be able to support the learning and implementation process.

3.5. Principle 5: Learning from Peers and Near-Peers

PD gains extra strength when it leverages opportunities for peer and near-peer learning. Using a cohort-based model is a natural way to enable trainees to learn within a group of peers who are navigating the same challenges simultaneously. Even when trainees come from diverse settings and geographies, a cohort learning model offers a likeminded community for sharing ideas, challenges, and solutions.

Opportunities to learn from near-peers offer a different set of benefits. We define near-peers as other educators who have already succeeded in developing and sustaining the programs that trainees are learning to create. Professionals who are similar to trainees, but just a little further ahead in their journey of developing this type of programming, provide realistic models that the strategies they are learning (and perhaps struggling with) can be achieved and are thriving in other locations.

3.5.1. Evidence from the TSCN Test Case

The PD model established by cycle 3 incorporated both dimensions: training cohorts move through the process together and have opportunities to connect with more experienced adult leaders. From the start, Resource Guides were selected exclusively from current or past TSC adult leaders, ensuring that trainees’ primary contact was from experienced

role models. This near-peer expertise proved essential for credibility and practical wisdom. Using a cohort model was a strategy that evolved over the cycles (see Table 1), with cycles 2 and 3 testing strategies that had groups of trainees starting at roughly the same time and participating in group meetings and training sessions designed to build community and enable peer learning alongside their individual coaching relationships.

In the data gathered from trainees after cycle 3, over 70% of interviewed trainees noted that the experiences of interacting with and learning with others was critical to their learning. Responses were a Venn diagram of those who emphasized the value of learning with their cohort peers, those who emphasized the value of learning from the Resource Guides or other more experienced adult leaders, and those who indicated both were of value. It was a near-universal sentiment that indicated the mix of strategies met the most people where they were. In fact, the most frequent request to further enhance the learning experience (suggested by over half of trainees interviewed) after cycle 3 was to broaden interaction with near-peers, beyond the Resource Guides, reiterating the value of learning from those who are a few steps ahead of the learner.

An important consideration, however, is that not every trainee will want these types of peer learning experiences. While our data indicates they are valuable to the vast majority, at least one member of cycle 3 did not connect with the socially grounded learning, instead feeling confident to independently use the amassed resources and get to work. This emphasized the importance of allowing flexibility, while offering the connections that are beneficial to most learners.

3.5.2. The Investments in PD

Cohort-based learning requires coordination to start groups of trainees at roughly the same time, which can require slower and more deliberately timed cycles. It requires a shift in view of PD as being an isolated, on-demand experience to one that centers on the excitement possible with a shared starting and ending point. In some ways, however, this can create more efficiencies for the trainer leading the process, as they are managing larger groups of trainees who are all at roughly the same stage of program development, which is easier than continually context-switching for trainees at very different stages.

Trainers who serve as near-peer resources must be drawn from an existing pool of experienced educators already doing the work. That creates a much smaller pool of qualified candidates. Arguably, however, this component will become less of an investment over time, as the network of professionals trained, doing, sustaining, and enthusiastic about this work grows. This broad incorporation of peer learning creates a mindset that no one is doing this work alone. As the community grows, there is an increasingly bigger pool of human resources to draw upon, and eager to share, such that each person can be expending less and still “give back” to the larger group.

3.6. Principle 6: Recognition and Nurturing Professional Pride

Throughout training and especially upon completion, it is critical to celebrate and recognize adult leaders’ achievements in launching their programs. In addition to celebrating genuine accomplishment of the trainee, this serves two strategic functions. First, it offers the chance to provide a pathway to ongoing professional growth. At this transition, a PD can offer how to get further support and/or introduce them to a larger community of practice. This emphasizes their identity with a community of practice to encourage sustainability.

Second, this is a moment to celebrate their accomplishment on behalf of their organization. By celebrating what trainees accomplish to their organizations, an external PD program leverages its political capital (which may be as from a nationally recognized organization) to potentially improve adult leaders’ standing and/or program sustainability.

The goal is helping adult leaders feel pride in specialized skills they have developed, and not take their achievement for granted.

3.6.1. Evidence from the TSCN Test Case

After an impromptu trial strategy (in cycle 2) of sending a “graduation” packet in the mail to trainees who completed the process, developing a group of Teen Leaders and hosting three or more TSC events at their site, the Resource Guides received a strongly positive response to this recognition. In cycle 3, the TSCN established an official “graduation” process, which includes a mailed certificate and program materials from the broader TSCN. In the final PD model, this formal process officially marks trainees’ transition from learners to full-fledged TSCN members, introducing additional ways to receive PD and access resources, some of which may bring additional institutional cachet, such as: mini-grants, specialized training sessions, opportunities to present at conferences, and promotional support from the national hub.

This principle was developed alongside the expansion of PD resources for the ongoing Network membership; the growth of both PD programs together meant that trainees were being handed off into an active and growing professional community. The Network maintains an active social media presence that regularly amplifies member programs, raising visibility to decision-makers within their institutions and to community members. This strategic promotion provided adult leaders with external validation they could leverage in conversations with supervisors about resources, program sustainability, and the value of their work with youth.

3.6.2. Investments in PD

Of all the principles for PD, this largely leverages the existing political capital of the national network, organization, or hub that is leading the training initiative and/or their funding source. It requires the least additional time or energy from staff, but simply adds on to the overall process of tracking progress and creates new systems to celebrate and recognize people. During the training process, hiring trainers who are well-suited to the skillset of encouraging and celebrating participants is also important.

3.7. *The Ecosystem of Investment: The “Efficiency Trap”*

These six principles do not operate in isolation; they require coordinated investment across an ecosystem of stakeholders to ensure youth-centered programming is truly possible. Program sustainability depends on alignment among:

- **Network/Hub level:** Providing infrastructure, employing trainers, maintaining online platforms and communication channels, organizing convenings.
- **Trainer level:** Investing time and expertise in personalized support, drawing on experience to customize training, bringing lessons learned back to improve the model.
- **Organizational level:** Allowing staff to participate in extended training, committing resources to launch and maintain programs (even if on minimal budgets), providing institutional support for a new initiative.
- **Adult leader level:** Dedicating time, effort, and emotional energy to learning new skills and championing the program within their institution and community.

Our iterative design process revealed that when investment from any of these levels decreased—often in pursuit of greater “efficiency” or trainee throughput—corresponding success at launching real, sustained, youth-leading programs declined. This illuminates what we term the “efficiency trap”: an assumption that PD scaled to reach many educators without a corresponding increase in time or funding is more cost-effective. Our experience demonstrates that when preparing educators with the unique skillset of supporting youth

agency and identity-building, such models waste resources by treating PD as a numbers game. Completing training does not equate to launching authentically youth-led programs, with strategies and support systems that sustain for the long haul.

4. Discussion

4.1. Transferability of Design Principles for Youth-Centered Professional Development

The six design principles that emerged from our iterative research with the TSCN add to growing insights from prior research into PD across informal STEM education contexts. These principles—recruiting committed adult leaders, personalized training with mutual respect, learning by doing, accountability structures, peer and near-peer learning, and recognition systems—represent a coherent framework rather than standalone interventions. While developed specifically in the context of building educators' skills to create and sustain youth-led programming, they speak to broader strategies that are important for preparing informal educators to facilitate identity-affirming STEM experiences.

Our findings align closely with recent research from [Peterman et al. \(2021\)](#) regarding several essential elements in successful PD programs for informal educators. In both projects, the role of the trainers to embody interactional principles and a sense of community were important to success. Further, the importance of accountability, trainer modeling, and a process of mutually supportive peer learning were also relevant. Both frameworks reject deficit-oriented models of PD in favor of approaches that honor what educators bring to their work while supporting genuine growth. However, our model differed in an important respect by taking a more macro approach, centering skill development in the real work of developing and sustaining a substantial youth-led program. Rather than a micro focus on developing specific facilitation techniques, trainers coached trainees across a variety of professional skills they needed, as prompted by the realities of their context, their teens, and their community assets.

These findings both confirm and extend the established principles of adult and professional learning. The personalized, context-sensitive nature of the PD model reflects andragogical principles ([Knowles, 1980](#)); adult educators came with existing professional identities and expertise, and the model's success depended on building from and respecting those assets. Similarly, the centrality of learning by doing—with skill development embedded in the real work of launching programs—is consistent with experiential learning theory ([Kolb, 1984](#)), confirming that abstract instruction alone is insufficient for developing the kind of flexible, adaptive practice that youth-led facilitation requires. Resource Guides shifted focus away from teaching theoretical frameworks and toward applying skills within the concrete work of launching a café series, with direct skill-building emerging as trainees worked through the real problems and roadblocks of supporting teens to lead. Regardless of educators' institutional contexts or areas of expertise, the most universal skill gain reported was learning how to “let go”—allowing teens to become authentic leaders of their programs. This type of shift has been identified as a persistent challenge in the contrast between adult- and youth-driven approaches ([Larson et al., 2005](#)).

However, our findings extend these frameworks in an important way: in the context of supporting genuine youth agency, the adult's professional development is not simply about acquiring new skills, but about fundamentally renegotiating their relationship to authority in the learning environment. Research on informal STEM facilitation has found that navigating when and how to constrain or support youth thinking rather than directing it is among the most complex dimensions of this work ([Hladik, 2022](#); [Sager et al., 2024](#)). Our findings suggest that PD models must be explicitly designed to support this shift in educators' relationship to authority, rather than assuming that it follows naturally from general development of facilitation skills.

4.2. Practical Implications: Professional Development as Program Development

This foundation of learning by creating a program could be an important strategy to advance high-investment PD in an increasingly resource-constrained education landscape. While organizations may be reluctant to invest in the professional development of educators for their own sake, there may find it easier to justify supporting staff to create highly compelling (or fundable) programs than to support PD as a standalone activity. When skill-building is embedded in launching something tangible that offers value to the organization (e.g., a new teen program, a community partnership, a visible offering), it may be easier to obtain the needed buy-in. The PD becomes justified by the program outcome.

4.3. Systemic Conditions for Sustainable Investment

The ecosystem of investment that we described requires coordinated commitments from training organizations, host institutions, peer mentors, and adult leaders themselves. This mirrors what research on PD in informal science education has argued more broadly: that meaningful growth in educator practice requires sustained institutional commitment, not isolated training events (Tran et al., 2019; Martin et al., 2019). This, in turn, raises important questions about sustainability and scale. What would enable these multilayered investments to become standard practice rather than exceptional effort?

One consideration is helping funders recognize that effective PD for OST educators, particularly when they are seeking to advance authentically youth-centered work, cannot be delivered effectively at scale, without a substantial financial investment. The efficiency trap we described is likely to waste resources, if one's metric for success is seeing more and more authentic youth leadership programs operating on the ground. Helping funders understand tradeoffs between breadth and depth of reach is critical to making the case for intensive PD, even when per-person costs appear high.

Recognizing that the landscape of investment by organizations in their educators' professional development is largely lacking, it may fall upon national networks, professional associations, and other larger entities to be hubs and catalysts for affordable pathways to get much-needed and high-quality training models (embodying principles like those we discuss here) integrated into educators' daily work. Such training models gain systems and processes over time, operating with greater efficiency—if never reaching the throughput of a large-scale, self-directed, online course. It is these organizations that sit at the boundary between institutions delivering programs to youth and larger-scale funders, that may have the right mix of expertise and access to continue offering these resources. But this requires sustained commitment, with structures that persist beyond grant cycles.

4.4. Limitations and Future Directions

Our research focused on one specific model, Teen Science Café programs, which were developed across diverse, informal education settings. While we believe the design principles transfer to other youth-centered contexts, further application and testing across more program models would strengthen these claims. Our work concentrated on adult development rather than youth outcomes. Although we have evidence of teen impacts from earlier evaluation (Foutz & Luke, 2010; Hall et al., 2021), understanding the mechanisms by which adult leaders' implementation practices influence youth identity development remains an important frontier. Emerging research on facilitator-youth dynamics in informal STEM settings has begun to examine how adult facilitation practices shape youth STEM identity and engagement (Wade-Jaimes et al., 2023; Hladik, 2022), pointing toward productive directions for connecting adult professional learning outcomes to youth experience.

In parallel with this work, our team is exploring the question of how training and the spread of this network of TSC sites has impacted real-world implementation of the design

principles, including the principle of youth leadership. From this work, we will be better able to address how thoroughly and deeply members of the network are able to implement the design principles, and test assumptions about which principles trainees and new sites struggle to implement most fully.

5. Conclusions

To be effective, youth-centered STEM programming requires adult-centered investment. Skilled adult leaders create conditions for teens to develop agency, confidence, and STEM identity, but developing those adult capacities demands substantial, coordinated support. Our six design principles work as an integrated system, requiring alignment across multiple stakeholders and sustained commitment beyond typical training timelines. By making visible the true costs of preparing educators to do this work meaningfully (in time, expertise, relationships, and institutional commitment), we aim to shift conversations about PD in informal STEM education. These investments are commensurate with both the complexity of youth-centered facilitation and the importance of expanding youth voice in STEM.

Author Contributions: Conceptualization, J.S.; methodology, J.S.; formal analysis, J.S., A.P., B.J. and R.K.; investigation, R.K. and J.S.; data curation, R.K.; writing—original draft preparation, J.S.; writing—review and editing, J.S., A.P., B.J. and R.K.; visualization, J.S. and A.P.; supervision, J.S. and A.P.; project administration, J.S. and R.K.; funding acquisition, J.S. and A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Science Foundation, grant numbers 2005815 and 2424451.

Institutional Review Board Statement: The study was conducted in accordance with the Declaration of Helsinki, and approved by the Institutional Review Board of Ethical & Independent Review Services (study ID 20097, 4 June 2020).

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: The data presented in this study will be made available by the authors on request.

Acknowledgments: The authors would like to thank Angelina Ong who assisted with data collection and analysis in early iterations of the PD model. We thank the Teen Science Café Network’s Resource Guides and Managers, especially Katey Ahmann and Sheila James, who contributed throughout the design research process. We thank the adult leaders who participated in the professional learning for their dedication to youth-centered programming. Finally, we acknowledge the leadership of Michelle Hall and Michael Mayhew; their vision for expanding youth-led science programming across the country lit the spark for this project and research.

Conflicts of Interest: Our affiliations are with our companies. STEM Next Opportunity Fund is a private, non-profit organization in the US. J. Sickler Consulting is a private company in the US. We all declare that there are no conflicts of interest with this work. It was funded entirely by the National Science Foundation, and they had no role in the study.

Abbreviations

The following abbreviations are used in this manuscript:

TSC	Teen Science Café
TSCN	Teen Science Café Network
OST	Out of School Time
PD	Professional Development
STEM	Science, Technology, Engineering, and Mathematics

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