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Recommendations from 20 Years of Professional Development of Early-Career Scientists and Engineers

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Abstract

The Professional Development Program (PDP) was a highly impactful and innovative program that was run by the Institute for Scientist & Engineer Educators for twenty years, from 2001–2020. The program trained early-career scientists and engineers to teach effectively and inclusively, while also developing participants' skills in leadership, collaboration, and teamwork. In this paper, we summarize important aspects of the PDP and some of the program's major outcomes, describe legacies of the program, and share recommendations based on two decades of experience. A large section of this paper details aspects of the PDP that we consider essential to the program but that might not be apparent from other documentation of the program. Recommendations for others interested in professional development of STEM graduate students and postdoctoral scholars are: 1) invest in establishing program culture; 2) prepare participants pursuing all STEM career paths for inclusive teaching; 3) focus on teaching and learning authentic STEM practices of participants' fields; 4) provide authentic and challenging contexts for practicing professional skills; 5) model all aspects of what participants are expected to do; and 6) provide opportunities for growth and becoming a collaborator within the community.

Keywords: engineering educators, equity & inclusion, professional development, science educators, STEM identity, STEM practices

1. Introduction

The Professional Development Program (PDP) was developed and led by the Institute for Scientist & Engineer Educators (ISEE), and from 2001–2020 innovated and built a community focused on preparing early-career scientists and engineers to be effective and inclusive in their professional practices. PDP training was focused on teaching STEM, but was applicable to mentoring, leading small teams, collaborating, and other important professional skills.

In May 2022, a group of 80 PDP alumni gathered in Hilo, Hawai‘i for a reunion conference, “Advancing Inclusive Leaders in STEM: 20 Years of the PDP.” Major goals of this conference were to share perspectives on the benefits of PDP training and to develop a set of recommendations for future professional development programs based on the most important and effective aspects of the PDP.

This paper was written in two phases. Sections 1–4 were written before the alumni conference, to help position conference participants to contribute to a set of professional development program recommendations. Section 2 summarizes what is already known about effective professional development, and Section 3 provides a high-level overview of the PDP. Then, a major portion of the paper (Section 4) describes essential aspects of the PDP, which are hard to glean from reviewing PDP curricular materials, but which set the stage for sharing a set of recommendations for those interested in professional development of early-career scientists through a program like the PDP. Much has been shared about the PDP and its outcomes (see for example over 75 papers in Hunter & Metevier, 2010 and Seagroves et al., 2022a), and the PDP community has been encouraged to build on what was learned as the program evolved and was refined over twenty years. The intention of Section 4 of the paper is to share aspects of the PDP that may not be visible or could be overlooked, but if changed or omitted would have changed the essence of the program.

The last two sections of the paper were written after the alumni conference in May 2022. Section 5 presents many of the most important legacies of the PDP, in terms of the breadth of the program’s reach, the communities it fostered, and the bodies of work that were produced. Possible future directions for the program (including a possible “PDP 2.0”) are discussed in Section 5, as well. Lastly, recommendations for future professional development programs that were generated from the conference are provided in Section 6.

2. Effective professional development

Preparing tomorrow’s scientists and engineers to be effective educators and practitioners is not a task that can be addressed by simply adding workshops to their training. When students reach graduate school, they have experienced many, many years of lectures (though more recently with some interactive lecture strategies), “weed-out” courses, and cookbook-style labs. These pedagogies do not model effective teaching, nor do they impart strong scientific research or engineering design skills. Even faculty who want to implement better pedagogies are hindered by the fact that their personal experiences tend to have been with poor ones (Apkarian et al., 2021). Learning more effective teaching approaches, and addressing educational disparities and inequities, takes time but can benefit one’s own ability to participate effectively in STEM while positively impacting students and mentees. Research shows that short, one-shot workshops usually do not change teaching practices and have little effect on learning outcomes (Darling-Hammond et al, 2017; Yoon et al., 2007). Participants in brief workshops may come away feeling like they have learned a new skill, but the greatest challenge is in *implementing* the skill (Derting et al., 2016; Ebert-May et al., 2011).

The effectiveness of professional development has been studied a great deal, especially in the K–12 arena. Though there are differences between K–12 and higher education, there are many lessons learned that can be applied to programs like the PDP. For example, Darling-Hammond et al. (2017) reviewed 35 studies that demonstrated links between professional development (PD), teaching practices, and student outcomes.

In their study, Darling-Hammond et al. state:

> "…we identify seven characteristics of effective PD. Specifically, we find that it:
>
> 1. Is **content focused**
> 2. Incorporates **active learning** utilizing adult learning theory
> 3. Supports **collaboration**, typically **job-embedded contexts**
> 4. Uses **models and modeling** of effective practice
> 5. Provides **coaching and expert support**
> 6. Offers opportunities for **feedback and reflection**
> 7. Is of **sustained duration"**
>
> Excerpted from Darling-Hammond et al.'s (2017) study "Effective Teacher Professional Development", p. 4.

The PDP was very much aligned with these characteristics of effective professional development. The program was originally developed using what was known at the time about effective professional development, and was refined based on continual evaluation of which aspects of the program best supported participants' understandings and ability to design and implement effective, inclusive STEM education practices.

3. Overview of the PDP

The PDP trained early-career scientists and engineers (primarily graduate students) to teach effectively and inclusively, through research-based methods, and was aimed at providing authentic STEM learning experiences. Participants spent about 90 hours during the program in a year-long cycle of activities that included (see the Appendix for more detail):

- The Inquiry Institute: a four-day workshop including participants from across the nation.
- The Design Institute: a two-day workshop in which participants from nearby institutions gathered at a regional ISEE "Chapter" site.
- A practical teaching experience in which participant teams-taught the activity that they designed.
- Reflection through a team debrief and individual post-teaching report.

PDP training was complementary to participants' scientific/engineering training, and participants often returned for a second or even third cycle.

In 20 years, the PDP trained over 600 participants, who each worked in a team of 3–4 to design and teach an activity. For many years, these activities were called "inquiry activities" within the PDP community, and they are now referred to as "authentic inclusive STEM learning experiences" (AISLEs; Metevier et al., 2022). The primary audience for PDP-designed and -taught AISLEs was undergraduates.

Throughout the two decades of the PDP, outcomes were established in many ways. Early on, our studies objectively showed that PDP training improves participants' understandings about inclusive teaching (Metevier et al., 2010). Another early PDP study found that undergraduate students were better prepared to take initiative in the STEM work environment after engaging in AISLE activities designed and taught by PDP participants (Ball & Hunter, 2010). In the later years of the PDP, many other outcomes were established, some of which are shown in Table 1.

Table 1: Major outcomes of the PDP: This table summarizes some of the major outcomes achieved by the PDP community. At the center of these outcomes is the PDP's focus on authentic inclusive STEM learning experiences (AISLEs).

Evaluation question	**PDP outcome**
Do PDP participants apply what is learned about teaching an AISLE?	A study reviewing participant lesson plans using a set of 29 "indicators" of an AISLE indicated that 79% of teams demonstrated proficiency with our threshold (22 of 29 indicators), with high degree of interrater reliability.[1]
Do teaching strategies employed by PDP participants impact student persistence in STEM?	A longitudinal study found that students in PDP participant-taught AISLEs persisted in STEM at higher rates than comparison groups.[2] In another study, students reporting that they used STEM practices (intentionally incorporated by PDP participants) was correlated to increased intention to stay in STEM.[3]
Do PDP participants gain skills that are transferable to a broad array of career pathways?	PDP participants report gaining professional skills including teaching AISLEs,[4,5] conducting their own research,[4] mentoring,[6] leadership,[7,8] and creating inclusive cultures in programs.[9,10] Skills gained were not just used by those in academia but were used in non-academic careers.[11]
How does the PDP impact participants above and beyond skill development?	Participants report that the culture and community of the PDP was transformational,[12] especially for those participating more than once,[13] was a place they felt they belonged, and supported people from marginalized groups.[14]

1. Metevier, et al., in preparation; 2. ISEE 2022; 3. Starr et al., 2020; 4. West et al., 2022; 5. McConnell et al., 2022; 6. Severson et al., 2022; 7. Strubbe et al., 2022; 8. Tarjan et al., 2022; 9. Shaw et al., 2022; 10. Santiago et al., 2022; 11. Mayfield et al., 2022; 12. Chu et al., 2022; 13. Martinez et al., 2022; 14. Lui et al., 2022.

The PDP community made many contributions to the field of professional development, in particular for early-career scientists and engineers, and an extensive array of frameworks, resources, and curricular materials have been disseminated (see Section 5 and Table 3).

The PDP community has endured, as evidenced by ~80 alumni gathering for the Advancing Inclusive Leaders in STEM conference and the production of this collection of over 30 papers.

4. Essential aspects of the PDP

The PDP was a carefully designed professional development experience for graduate students and postdoctoral researchers. The program included a set of workshops supported by a suite of tools designed over many years of continuous improvement. PDP curriculum and resources have been made available in an open online repository (see Table 3) so that others can use and adapt them for their own contexts. An earlier iteration of the PDP was described in Hunter et al. (2010); at that time what we felt was crucial was discussed in Seagroves et al. (2010). Here we share 13 aspects of the PDP that we now find essential. That is, changing any of these aspects would have substantially changed the experience and/or the outcomes of the PDP.

In designing the PDP, we used research from the social sciences, made many refinements, and developed or adapted strategies for working with

Table 2: Thirteen essential aspects of the PDP. Aspects are not listed in any particular order and are described in Sections 4.1–4.13.

Essential Aspects of the PDP
1. Serving graduate students and postdocs pursuing **broad range of STEM careers**
2. Focus on **teaching STEM practices** within authentic STEM learning experiences
3. Innovating as **consumers of research** from the social sciences
4. Leveraging authentic STEM learning experiences for **equity and inclusion**
5. **Practical experience** in design and teaching
6. Participants design and **teach in teams**
7. Innovative design with structure of a collective **community goal**
8. Design **teams led by a PDP alum** who practices leadership
9. National **off-site intensive**, followed by local implementation
10. **Cycles of practice**, feedback, and reflection
11. **Modeling** what participants are expected to do
12. Opportunities for **growth and leadership roles** are integrated and accessible
13. Community and **inclusive culture**

participants and facilitating their work with each other. We made breakthroughs, mistakes, learned from participants, and at times inadvertently made what seemed like small revisions that ended up triggering far too many other changes. Our curriculum and our curriculum development process could each be the subjects of long papers. We have shared the PDP curriculum in other papers and in our online repository, and we encourage the PDP community to continue to innovate. The spirit of this section is to complement the hundreds of pages of documentation and the resources that we have developed on the PDP. Here, we share aspects of the PDP that we believe could be overlooked or changed in a new implementation of the program, and if so, would likely have a dramatic effect on the experience and outcomes of the PDP. A summary of the 13 aspects is shown in Table 2.

4.1 Serving graduate students and postdocs pursuing broad range of STEM careers

The PDP was intended for STEM graduate students and postdoctoral researchers pursuing a wide range of career paths — not just those pursuing primarily teaching careers. The program was based on the idea that essentially all people with advanced STEM degrees need to be able to teach STEM, even if teaching in the classroom is not a formal part of their job. Scientists and engineers mentor, supervise, and train people throughout their careers, and good teaching skills such as those gained in the PDP are applicable in many ways.

Graduate students and postdocs need other professional skills, such as leadership, collaboration, and teamwork skills, in addition to teaching skills. Over time, it became clear that the PDP could also provide training in these skills, and the curriculum evolved to more intentionally support the development of the broad array of professional skills that scientists and engineers need.

Though the PDP was designed and aimed at early-career professionals pursuing a broad range of career paths, it was often assumed to be a program for those pursuing teaching-focused careers, and at times there were suggestions that the PDP formally shift to that focus. However, moving away from serving early-career scientists with broad interests would have excluded those who were planning to go into academic research and industry pathways, which would have excluded a large fraction of people who would have benefitted from the training provided by the PDP. Also, it was often difficult to gain advisor "buy-in" for allowing their graduate students to spend time on the PDP, and this would have been even harder if the PDP was perceived as a program only for those pursuing a "teaching pathway." Furthermore, graduate students could be viewed and treated differently if they claimed that they were pursuing careers primarily focused on teaching, quite likely receiving fewer or lesser research opportunities or resources needed to complete their degrees. The perceived lower status of teaching as opposed to research presents a barrier to pedagogical innovation (Brownell & Tanner, 2012).

Further benefits of serving a community with broad career interests included fostering collaborations between people at different institutions, in slightly different fields, and with different balances (or goals) of research, mentoring, and teaching in their careers. The focus on graduate students and postdoctoral researchers (without advisors present) also took pressure off participants and removed the hierarchy and power structures typical of academic research environments.

4.2 Focus on teaching STEM practices within authentic STEM learning experiences

The PDP was focused on preparing participants to teach in such a way that their students would learn to think and work like scientists or engineers. Though essentially all national reports and recommendations point to the importance of teaching STEM subjects in ways that are more authentic to how they are done in practice than, say, lectures, changes in higher education have been slow. A key barrier to making this transformation has been a lack of effective professional development. The PDP tackled this challenge, putting the relevant effective strategies for teaching and learning *authentic* science and engineering under the umbrella of "inquiry."

For 20 years, the PDP community worked on how to design, teach, and assess authentic STEM learning experiences, with a particular focus on STEM practices (e.g., hypothesizing, designing investigations, or defining requirements). PDP developers learned from research and experience how important it was to focus on just one core STEM practice in a single lab unit, so that more challenging and nuanced aspects of the practice could be learned. This evolved to become a significant area of innovation, and many curricular resources and strategies were developed to support PDP participants in designing ways for their students to learn STEM practices. Teaching STEM practices is the cornerstone of the PDP curriculum, threading through nearly every aspect of the curriculum.

Focusing on STEM practices had many benefits and created other opportunities. For example, there are connections between learning STEM practices and persistence in STEM, as well as connections to reducing disparities in who persists in STEM (e.g., Dirks & Cunningham, 2006; Hazari et al., 2010; Starr et al., 2020). For many PDP participants, the focus on STEM practices was very engaging. For instance, before participating in the PDP, many participants had not considered that STEM practices could be taught and assessed.

The focus on STEM practices made the PDP applicable to participants' own work as scientists or engineers, and to mentoring those working with STEM practices in apprentice roles (e.g., student researchers or supervisees). Many participants reported that teaching their learners about STEM practices helped them improve their own research and innovation practices (West et al., 2022). Because nearly all scientists and engineers mentor others, the PDP was applicable and inspiring, providing guidance on how to teach mentees the reasoning practices (STEM practices) of their field (Severson et al., 2022).

4.3 Innovating as consumers of research from the social sciences

Research and theory from the social sciences were used as a platform for innovation in developing the

PDP, and the results were continually evaluated. The PDP development team was made up of education practitioners, not social science researchers, and though we did conduct some research on the PDP, the developers' primary focus was on continual improvement to achieve professional development goals. Mirroring this process, PDP participants were supported in using research and theory to design and teach their own activity, and then to evaluate evidence that they had achieved their goals. In this way, the PDP community, including the PDP developers and the PDP participants, were *consumers* of research findings from the social sciences.

This is very much in line with researchers' findings that educators do not need workshops insisting on faithful reproduction of a particular teaching technique, but rather they need guidance and practice adapting pedagogical principles to their own contexts (Henderson & Dancy, 2008; Chasteen & Chattergoon, 2020; Newton et al., 2020; Strubbe et al., 2020).

An ongoing challenge for the PDP community was finding ways to push back on the persistent pressure from external colleagues to conduct research studies on the teaching methods already shown to be effective, often many times over (e.g., Freeman et al., 2014). There is a rich knowledge base on effective teaching, learning, inclusion, and professional development that is increasingly accessible to an interdisciplinary audience. Though there is still much more to be learned, there is a great deal that can already be implemented. However, the uptake of applying research findings to education in practice continues to be a challenge. This was the challenge that the PDP community embraced.

The PDP community did not necessarily have the expertise nor resources to identify a gap in the knowledge base, frame a good research question around teaching and learning, design an experiment to probe answers to the question, and to contribute generalizable results — that is, to do research in the learning sciences. For both the developers of the PDP and PDP participants, becoming familiar with existing research outside of our disciplines, learning about the nuances of applying it to teaching and learning, and then assessing outcomes already was a lot to accomplish. To encourage our participants to do research would have been asking them to learn an entirely new discipline and conveyed to them a naïve version of the learning sciences. Instead, we challenged them to conduct a meaningful, authentic assessment of their learners' progress, and we challenged ourselves to conduct meaningful, authentic assessment of our participants' outcomes as a means of evaluating the effectiveness of the PDP.

An additional challenge was balancing participants' experience in such a way that they gained an appreciation for the breadth of the knowledge base in the social sciences *and* grappled with the challenges involved in implementing the practical implications. Many of our participants had very limited, if any, exposure to the vast literature published on teaching, learning, equity & inclusion, and professional development. However, we found that exposure to summaries and synopses of research, without digging in deeper to some specific research, led to over-simplified, superficial implementations. Ultimately, we landed on broad exposure to research, and then careful implementation of the practical implications from one or two studies from each of the applications listed above (teaching, learning, equity & inclusion, etc.). We conveyed to participants that we were modeling how to implement findings from research, and that we hoped it opened avenues for them to expand their knowledge to use other studies, but it was very easy for participants to infer that we had a narrow focus that excluded all other research.

4.4 Leveraging authentic STEM learning experiences for equity and inclusion

The PDP community has held equity and inclusion (E&I) as a central theme (Seagroves et al., 2022b) since nearly the beginning of the program. PDP developers experimented with different ways of incorporating E&I into the curriculum during a 20-year period when there was a notable change in the experience and perspectives of the cohorts entering the PDP. In the early years, a large fraction of participants was best served by sessions that focused on the issues, such as disparities in the demographics of STEM as compared to the demographics of the overall U.S. population (such as what one might find in NSB NSF, 2022). As years went by, a larger fraction of each annual cohort came into the PDP with a general understanding of these issues; they were more interested in learning about what they could do to address them. We adapted to this by creating a background document about E&I-related issues for participants to read before starting the program. That allowed us to create sessions that focused on what an individual instructor could do, and in particular what could be done in a short (4–6 hour) authentic STEM learning experience. In their E&I-related work, as with nearly everything in the PDP, participants were supported in applying research and theory to what they were designing and teaching, so that they engaged in cycles of learning, practicing and reflecting.

The vast knowledge base on E&I is far more than can be incorporated into a professional development experience such as the PDP, which required the PDP developers to continually make tradeoffs. Issues related to race, ethnicity and gender were prioritized rather than attempting to broadly cover all groups that have been marginalized and experience biases and discrimination. Higher education and STEM workplaces (such as academic lab environments) were prioritized over K–12 settings, because the career paths of most PDP participants are aimed at academic, industry and government positions. These priorities led us to the create four “focus areas,” which further directed the scope of the PDP’s E&I theme to focus on practical implications from research that could be applied to PDP participants’ activity design and teaching efforts. Finally, in alignment with the PDP’s commitment to using assessment-driven design, the E&I theme pushed participants toward implementation of inclusive strategies that were assessable by the PDP developers, so that we could evaluate the effectiveness of the PDP.

Much like in Section 4.3, we resisted pressure to “prove it again” when pedagogies such as ours are known to be disproportionately effective for marginalized students (e.g. Theobald et al., 2020).

The PDP goal of applying research and theory to participants’ PDP design work and teaching experience, and having some way to evaluate their level of success, was challenging to reach. Again, this came with tradeoffs. Getting participants to go beyond listing off teaching strategies or E&I concepts, to articulating why a strategy might have a differential effect on marginalized groups, required the PDP developers to continually refine curriculum and facilitation strategies used during workshop sessions. The focus on the nuances of applying research to teaching led to many rich and productive discussions; however, this limited space for participants to talk about their personal experiences. This was a point of tension for the PDP developers, and was considered an unresolved issue. Personal experiences are relevant and impactful, but having supported conversations about them requires creating a safe space and instructors who are trained and prepared to productively lead those conversations.

4.5 Practical experience in design and teaching

The PDP included a practical design and teaching experience, which is rare in professional development. Nearly the entire PDP curriculum was focused on participants putting what they learned into practice by designing and then teaching a lab unit, typically of 5–6 hours in length, and most often for undergraduate learners. Arranging and matching participants to teaching venues was a complex and time-consuming process, but was always viewed as essential, so this component of the PDP curriculum never changed. It was a defining feature of the PDP.

There was often external pressure to push the PDP toward supporting lecture-format teaching venues, rather than having participants design a lab unit. However, there are many arguments against this, which kept the PDP developers from changing the scope of teaching formats, including: 1) teaching a lab unit is an extended opportunity to practice many teaching strategies and ways of interacting with learners (e.g., Cooper et al., 2022); 2) lab courses are an under-utilized opportunity to provide authentic STEM experiences involving the learning of STEM practices (e.g., Buck et al., 2008, Cooper et al., 2022, Hester et al., 2018, Kozminski et al., 2014); 3) lab units often do not capitalize on the rich opportunities for learners to gain a deeper understanding of STEM content, and this was something PDP participants could positively affect (e.g. Kozminski et al., 2014); and 4) much of what PDP participants learned by teaching a lab unit could be applied to many different teaching and mentoring contexts (as evidenced by many articles in this collection).

4.6 Participants design and teach in teams

PDP participants designed and taught a lab unit together in teams of three to four; each team was called a PDP "design team". Having participants design and teach as a team built in the social construction of knowledge and ongoing reflection. Because teams were always talking and co-creating a lesson plan, PDP instructors had many opportunities for formative assessment. Talking through design choices, and being able to reflect and adapt throughout the design and teaching experience, was a transformative part of the PDP. Though creating teams was time-consuming and constrained participation, the advantages were considered too important to change this aspect of the PDP.

Teaching in teams provided other benefits. It created an experience in teamwork and leadership, which are important skills that PDP participants also needed and wanted training in. Over time, we increasingly developed support for those skills within the PDP curriculum. The PDP task of designing, teaching, and assessing a lab unit (see Section 4.7) was a difficult task, which challenged participants' teamwork skills.

4.7 Innovative design with the structure of a collective community goal

To support participants in their activity design and teaching experience, we developed parameters (described as the "PDP task") that all participants could work within, creating a common goal for all PDP teams. However, this goal had plenty of room for innovation and was applicable to a breadth of STEM disciplines. The PDP task was:

> All participants will develop their own teaching plan for an inquiry activity that embodies the three PDP themes: Inquiry, Equity & Inclusion, and Assessment; and integrates research-based understandings of teaching and learning.
>
> Participants work on a team to design, teach, and assess learners in their activity. PDP teams pilot, evaluate, and reflect on their work.

The PDP task created opportunities for collaboration across design teams, as well as peer-peer learning. It also enabled the PDP to efficiently use resources, as all curricular tools and instruction had a common focus. Finally, having a clear goal that could be achieved in many ways made it possible for participants to come back for a second cycle of participation (or more) and lead a team.

Although it was not explicitly stated in the PDP task, the large majority of PDP teams designed and taught lab units for undergraduate learners. Opening the PDP experience to teaching different kinds of activities (e.g., active learning lectures, outreach activities, K–12 classroom units, mentoring) on the surface sounded appealing to many, but to do this, the PDP curriculum would have needed significant revision. It would have reduced the PDP's efficiency, reduced opportunities for collaboration, and it would have reduced the learning that the entire community was part of by having a common goal.

Finally, having a collective goal made it possible to evaluate outcomes of the PDP. Each year the PDP core development team was able to review outcomes from the prior year to make curricular revisions from the coming year using a set of metrics that could be applied to the work of all the teams (Metevier et al., in preparation).

4.8 Design teams led by a PDP alum who practices leadership

All PDP teams were led by an individual that had successfully completed the PDP at least once. This helped teams stay on track in many ways, and significantly increased the efficiency of teams. The PDP task was challenging, and without returning participants taking on the role of team leaders, it would have been much harder for participants to be productive and efficient.

In later years, team leaders became very important for moving teams forward efficiently, including by making pre-workshop decisions. For example, it became clear that teams were taking far too long coming to consensus on the learning goals for their activities, so we shifted to having team leaders decide on learning goals before designing the activity with their teammates. As the PDP evolved, support for team leaders increased substantially, growing to include a half-day workshop prior to the Inquiry Institute. Returning participants were an important part of the PDP community, even creating a pool of people who could advance into instructional roles in the PDP itself (Martinez et al., 2022).

Having a team leader also created an opportunity for leadership development, which grew to become an area of innovation for the PDP developers, who realized the unique opportunity for a practical leadership experience that was embedded in the PDP. In moving a small team forward in accomplishing the PDP task, PDP team leaders were required to make decisions, support collaboration, be inclusive, and resolve differences of opinion — all within a time constraint. It was a perfect opportunity for a short, authentic, and challenging leadership experience.

Requiring that teams had a leader was a significant constraint which dictated the size of the PDP cohort each year, limited teaching venue options, and ultimately created a situation in which some applicants could not be accepted simply because there was not a returning participant available to lead their team. However, in most cases, we were able to create teams and provide support for team leaders.

4.9 National off-site intensive, followed by local implementation

A multi-day residential intensive (the Inquiry Institute) was always part of the PDP, though there was some variation in the length and content of the intensive over the 20 years that the PDP ran. During the institutes, participants set aside their regular work/tasks and just focused on the PDP. Participants often reported that the concentrated time was the only way that they could have stepped away from their demanding research schedules, and/or gained approval from their advisors. Over what became established as a four-day intensive, community was built and the culture of the PDP was established. Discussions started a little lighter and moved to more challenging topics. There was social/informal time for participants to get to know peers and instructors or continue talking about sessions. The final celebration after four days of hard work played an important role in a number of ways, including opportunities for individuals to share more about their backgrounds in small one-on-one interactions and/or more publicly.

The four-day intensive added expense due to travel and hotel costs, but it enabled national participation, which was important in many ways. Participants appreciated meeting people from across the country, from different fields and institutions. We believe it also contributed to the sense of feeling valued, which many PDP participants reported. Providing travel awards and putting participants in a nice hotel conveyed that the PDP valued participants. We did not set out to learn about this, but graduate students often reported how under-valued they felt in the academic environment, and even reported that PDP was the first time they had felt valued since being in graduate school.

The PDP started as, and always was, a national program. It started that way because it was designed to serve a national science and technology center, and continued because of the well-established national community. However, it is important to note the tension this introduced in our efforts to sustain the program. To gain institutional support at a university, a program must focus on benefitting the students at that university. However, many funding agencies prioritize national efforts. The PDP landed by doing both: The Inquiry Institute was a national intensive, and further training took place at Design Institutes, held at local ISEE Chapter institutions. This solution worked, but required a great deal of effort to obtain both institutional-level and national-level support.

4.10 Cycles of practice, feedback, and reflection

Practice and feedback were woven into the entire PDP experience. For example, learning outcomes and assessment prompts for inquiry activities were drafted by participant teams, and PDP instructors gave feedback multiple times so that participants had an opportunity to revise them (Hunter et al., 2022). Participants brainstormed design ideas during discussions, got feedback from instructors and peers, and then drafted their activity design work within their teams, again getting feedback and revising their work. The PDP created an online "Design Notebook" and "Teaching Plan" in which PDP teams documented their activity design work, and which enabled ongoing feedback from instructors. Discussions in the PDP created ways for participants to reflect and to make their ideas assessable to instructors and peers, who could then give feedback. Instructors met around the edges of workshops to discuss participants' progress, and to share ideas for how to best give productive feedback. Describing all the ways that the PDP created cycles of practice, reflection, and feedback is beyond the scope of this paper, but collectively these opportunities were extremely important, and required expertise and time from instructors. Over time, PDP instructors steadily increased feedback to participants, which we believe led to more participants achieving the intended outcomes, but also required more instructor time.

Feedback after PDP teams taught was an area that the developers and instructors viewed as an underdeveloped opportunity. Debriefing with teams was conducted as much as possible, but little if any feedback was given on the final designed activity, and the post-teaching report submitted by participants did not receive feedback. However, those that returned to the PDP were essentially in a continued cycle of feedback and practice. PDP instructors reviewed returning participants' prior work, gave feedback, and made suggestions for improvements as they began their new cycle.

4.11 Modeling what participants are expected to do

The hallmark PDP experience for many participants was their experience as a learner in an inquiry activity; during this experience, PDP instructors modeled how to teach an authentic and inclusive STEM learning experience. However, PDP developers and instructors were modeling expectations in many more ways. The program developers continually held themselves accountable to "walk the talk." That is, if participants were asked to do something, the developers took stock of whether it was modeled during PDP workshops, and if it was not, then the workshops were revised. Even the design process of the PDP developers mirrored what participants did as they designed inquiry activities, and in fact observing participant teams working at times would influence how the developers worked.

Though the PDP task was for participants to design an inclusive STEM learning experience (or an "inquiry" lab activity), participants could observe a wide range of teaching formats and strategies in action during the PDP. Instructors modeled a range of different ways to have discussions, facilitate small groups, devise ways for peers to share ideas (e.g., “pair-shares” and “jigsaws”), formatively assess, and provide context for an activity. A similar listing of a variety of strategies may be found in Tanner (2013). The PDP developers also incorporated authentic assessments throughout the PDP, many of which were formative assessment tasks, but also a post-teaching report which was a summative assessment. Participants were prompted to write about what they designed and taught in a way that could be later used in a teaching statement when they applied for jobs. The post-teaching report provided participants an opportunity to synthesize what they learned into a product that was authentic and useful for them, and simultaneously a way for the PDP developers to assess what participants learned, and ultimately evaluate the impact of the PDP.

Multi-year participation in the PDP offered significantly more benefits to participants in many ways. For instance, the modeling of teaching approaches and strategies was particularly hard for first-year participants to take in when they were also learning about social science research on effective education practices, participating in activities and discussions, and actively designing and preparing to teach an activity with their design team. The PDP experience was demanding, so to step back and think about what the PDP instructors were doing and why was a cognitive overload. Participants who returned for a second experience often commented on how they had more bandwidth to observe and reflect on this aspect of the PDP. Those participants that returned for a third experience had an opportunity to shadow instructors during one of the inquiry activities, giving these participants an extensive opportunity to observe and reflect on what PDP instructors were doing, and even a chance to talk with them about their rationale.

4.12 Opportunities for growth and leadership roles are integrated and accessible

The PDP had a range of roles for participants who chose to come back for a second or more times (Martinez et al., 2022). As noted above in Section 4.8, participant teams were led by returning participants. In addition to leadership training, second time participants also had a somewhat different experience than first year participants, by participating in concurrent sessions during some parts of the Inquiry Institute. Two-year participation was fairly common, with about a third of all participants completing two cycles of the PDP. A smaller set of participants would come back for a third cycle, and had yet another experience. A very small fraction of participants became interested in building their own skills in designing and leading professional development and could come back in an apprentice PDP instructor role.

Returning roles in the PDP were accessible to all participants, and new participants could observe their peers trying out roles and reflect on whether they would like to return and in what role. In many ways, coming back as a design team leader opened the door to other roles. Leaders spent more time, in smaller groups, with instructors, which opened opportunities for establishing relationships and gaining additional recognition for their work.

The opportunities for growth and leadership roles within the PDP afforded many benefits. Participants could continue gaining skills and knowledge, new participants could learn from more experienced peers, and it became a “grow your own" strategy for building a pool of instructors. After 20 years, there is a pool of about 20 potential instructors, and all but three of them were originally participants in the PDP. This national team of instructors had disciplinary breadth and a wide range of experiences and career positions and gave the collective team a great deal of credibility.

The returning roles established in the PDP were a big part of creating and maintaining an enduring community. Some multi-year participants reported that they were aware that they might not gain as much after the first few years of participating in the program, but they wanted to come back for the community. More generally, returning participants helped to establish the credibility and culture of the PDP, through testimonials of how valuable their prior experience had been and through their overall "buy-in." For the entire community — participants and instructors — the PDP was rejuvenating, and though it was rigorous and demanding, we all always looked forward being surrounded by scientists and engineers committed to becoming effective and inclusive professionals.

4.13 Community and inclusive culture

Community and culture were simultaneously strategies and outcomes of the PDP. From the earliest versions of the PDP, participants were aware of the community that grew, in particular for those that returned one or more times. The PDP developers intentionally nurtured the formation of a community, or a "community of practice" (Lave & Wenger, 1991; Wenger, 1999), in many small ways during workshops, and in a major way by integrating returning participants and their ideas. Many of the other twelve essential aspects of the program contributed to creating the PDP community. For example, designing and teaching on a team (4.6), having a collective goal (4.7), having a returning participant lead a team (4.8), and having opportunities for growth and leadership roles integrated and accessible (4.12). Most in the PDP community would argue that the offsite four-day intensive (4.9) that brought together a national team of instructors is an aspect that could never be replaced by a course or a workshop in which participants stayed home. Creating a safe space where participants can try out new ideas, voice different opinions, and feel comfortable in being themselves takes time and separation from everyday life.

Over time it became clear that "community" might not fully capture what people felt and why they came back to the PDP, and that perhaps "culture" is a better descriptor. Participants reported that the PDP was a place where they felt valued, respected, and trusted. It was a place where most felt that they could take risks, and that it was a place where they had a sense of belonging. It is impossible to identify all of the elements of the PDP that created this culture, but some of the essential aspects above are likely contributors — for example, integrating equity & inclusion in a way that directly applies to everyday experiences of participants (4.4) and modeling inclusive strategies within the workshops (4.11). Expecting — and trusting — participants to lead a team in their second year (4.8), and providing opportunities for participants to continue to grow and take on new roles (4.12), not only provided additional professional development, but also created an infusion of new ideas and a way for anyone to rise in PDP leadership if they were willing to continue to learn and return to the program.

Being surrounded by peers who wanted something more than what was being provided through traditional graduate and postdoctoral training was invaluable for many in the PDP community. Year after year, they were willing to carve out time from their busy lives, at times putting themselves at odds with their advisors, to return, gain more, and give back to the community. It was a place where they could see **"this is the type of scientist/engineer I want to be."**

5. Legacies and future directions for the PDP community

When it originated, the PDP's innovations were also risks: it was a risky program in that it focused on developing early-career researchers and did not include established professionals (their advisors). It involved new and unfamiliar approaches to teaching, learning, leadership, and collaboration. However, these risks demonstrated trust, and empowered a rising community of science and engineering professionals over 20 years. This has led to a significant legacy and continuing innovation toward the future:

- **More than 600 early-career scientists and engineers participated in the PDP**, who are now at various stages in their careers, who continue to have an impact on their students, colleagues, and communities.
- **Advancing Inclusive Leaders in STEM project:** National chapters were developed that offered further opportunities and professional development for PDP alumni who wanted to open the PDP experience to their graduate students and postdocs. In addition, the project supported a remote workshop, "**Leading by Design**," in which participants could design ways to use PDP curriculum in their own context. Furthermore, a **Leadership Institute** was offered in May 2022, which brought together 18 instructors, chapter leads, and other veteran participants to plan a PDP 2.0. Finally, this project supported the **20-year reunion conference** that brought together eighty alumni to share ways that the PDP influenced their work and career.
- **Two volumes of more than 75 papers** describing the work and impact of the PDP community:
    - Learning from Inquiry in Practice (Hunter & Metevier, 2010)
    - Leaders in Effective and Inclusive STEM: Twenty Years of the Institute for Scientist & Engineer Educators (Seagroves et al., 2022a)
- **PDP curricular resources have been disseminated** through an open access online repository, eScholarship (see Table 3).

Table 3: PDP curricular resources. All these resources are available on ISEE's eScholarship site; most are at the subsite https://escholarship.org/uc/isee_pdpresources, except the two marked * are at the subsite https://escholarship.org/uc/isee_pdp20yr.

Topics	Resources published on eScholarship
Themes framing professional development	• Assessment-Driven Design: Supporting Design, Teaching, and Learning • ISEE's Framework of Six Elements to Guide the Design, Teaching, and Assessment of Authentic and Inclusive STEM Learning Experiences* • ISEE's Equity & Inclusion Theme
Assessing STEM practices and concepts	• Tips for Constructing STEM Practice Rubrics • Examples of STEM Practice Rubrics
Vignettes for discussion interactions during teaching and learning	• Light and Shadow Vignette • Analog-to-Digital Vignette • Choosing and Investigable Question Vignette (and Instructor Guide)
Moment-to-moment teaching moves of "facilitation"	• Using Active Facilitation Strategies to Transfer Ownership in Teaching and Mentoring • Facilitation Aims and Moves Handout • Personal Facilitation Plan • ISEE Inquiry Activity Shadowing Guide • Facilitating Learning in the Professional Development Program*
Leadership and teamwork development	• Introduction to Leadership Development in the PDP • Guide to Effective Meetings • Leadership Scenarios

- **A vibrant and enduring community,** which has created the momentum for the emergence of a new group of leaders now working on the next iteration of PDP-related efforts.

6. Recommendations for professional development of early-career scientists and engineers

The 13 essential aspects outlined in Section 4 are what we believe made the PDP work and have the success that it has had. Within the rationale for the 13 aspects there are many lessons that we learned which we hope are helpful to others interested in the professional development of early-career scientists and engineers. In May 2022, eighty members of the PDP community gathered for a reunion conference in Hilo, Hawai‘i to share the ways that the PDP influenced their work and career trajectories. During the conference, participants responded to a draft of the essential aspects above, which helped us to refine them. Perspectives of our alumni community also informed a set of recommendations, which have emerged from our two decades of work. In addition to agreeing with research and reports on effective professional development (see Section 2), our experience can be translated into a set of recommendations for those interested in providing impactful professional development to STEM graduate students and postdoctoral scholars:

Table 4: Recommendations for the professional development of early-career scientists and engineers.

1. Invest in establishing program culture
2. Prepare participants pursuing all STEM career paths to teach inclusively
3. Focus on authentic STEM practices of participants’ fields
4. Provide authentic and challenging practice for learning professional skills
5. Model all aspects of what participants are expected to do
6. Provide opportunities for growth and becoming a collaborator within the community

- **Invest in establishing program culture**: Early-career scientists and engineers need opportunities to develop as professionals in a community with an inclusive culture in which they feel they belong, are valued, have agency, and can be themselves — which is often lacking in academic environments. Building this culture takes time, a safe space, and intentionality.
- **Prepare participants pursuing all STEM career paths to teach inclusively:** All scientists and engineers teach, mentor, and/or supervise people, whether they pursue careers inside or outside of academia, and will benefit from learning how to design and teach authentic inclusive STEM learning experiences. Furthermore, professional development focused on teaching that includes a team “project” to design and teach a unit (such as a lab activity) is an ideal way for participants to learn about teaching while also gaining leadership, collaboration, project management and other professional skills.
- **Focus on authentic STEM practices of participants’ fields:** Focusing on how to teach authentic STEM practices is valued as an educational outcome for learners, but also is a rich opportunity for integrating inclusion into participants teaching, as well as being applicable to their work environments. In addition, it can improve participants’ own research and engineering design skills.
- **Provide authentic and challenging contexts for learning and practicing professional skills:** Early-career scientists and engineers need professional skills such as leadership,

collaboration, and project management, and need an authentic, challenging opportunity to learn and practice these skills, through training that uses what is known about effective professional development.

- **Model all aspects of what participants are expected to do:** Modeling not just skills that participants are expected to implement in their own practice, but how to create a community and nurture a culture of inclusion, is extremely important. It takes a lot of work, but is an essential part of effective professional development.
- **Provide opportunities for growth and becoming a collaborator within the community:** Establishing an enduring community that supports professional development requires that participants have opportunities for growth, and as they grow to have ways to contribute to the work of the community in meaningful ways.

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Appendix

ISEE's Professional Development Program (PDP)

Graduate students and postdocs pursuing academic, industry and other careers

The following experience (~90 hours) supported up to 25 teams of 3–4 in designing an authentic inclusive STEM learning experience (AISLE), which is simultaneously a project that provided a practical experience with many professional skills. Each team was led by a returning participant.

Throughout program:

- Cycle of ongoing practice, with facilitation and feedback from instructors
- Many intentionally designed ways of creating an inclusive culture in which participants report: "I could be myself" and "I felt valued, trusted, and like I belonged"
- Opportunities for growth and advanced roles in the PDP
- Putting social sciences research and theory into practice
- Leverage team design format for professional skill development

Returning participants

Propose & get feedback on STEM concept that will drive design

3-hour remote workshop for team leaders, which included:

- Set personal and team goals, project management (30 min)
- Identify own strategies for inclusive leadership (60 min)
- Establishing a credible leadership image (75 min)

New participants

4-day residential, off-site workshop for all participants, which included:

- Experience and compare different approaches to hands-on learning (3 hrs)
- Discuss research on how people learn, and apply to a classroom vignette (1.5 hrs)
- Experience and reflect on an AISLE, as a learner (6.5 hrs)
- Designing equity & inclusion into teaching (2 hrs)
- Applying teamwork and leadership strategies to authentic scenarios (1 hr)
- Using assessment-driven design, culminating assessment task and rubric (2.5 hrs)
- Identifying challenging and assessable aspects of STEM practices (1 hr)
- Team design time, using online tools embedded with a "design notebook" (3 hrs)

2-day on-site workshop for all participants, which included:

- Teams work on design project, using online "teaching plan" (13 hours)
- Using strategies for teamwork and collaboration (0.5 hr)
- Discussing and applying research on equity & inclusion (2 hr)
- Using leadership strategies (leader only, 2 hours)

Independently work on design project, which included:

- Teams work on design project, using online "teaching plan" (~20 hours)
- Instructors facilitate, including a 2-hr meeting to plan for in-the-moment teaching, maintaining learner ownership, and inclusion

Teach activity as a team in an ISEE affiliated venue (~6 hrs)

Reflect, document accomplishments for CV and ISEE (~2 hrs)

About 1/3 return as team leaders