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Cultivating Scientist- and Engineer-Educators 2010: The Evolving Professional Development Program

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Abstract. The Professional Development Program (PDP) is at the heart of the education programs of the Institute for Scientist & Engineer Educators. The PDP was originally developed by the Center for Adaptive Optics, and since has been instrumental in developing and advancing a growing community of scientist- and engineer-educators. Participants come to the PDP early in their careers—most as graduate students—and they emerge as leaders who integrate research and education in their professional practice. The PDP engages participants in the innovative teaching and learning strategies of inquiry. Participants put new knowledge into action by designing inquiry activities and teaching their activities in undergraduate science and engineering laboratory settings. In addition to inquiry, members of the PDP community value and intentionally draw from diversity and equity studies and strategies, assessment strategies, education research, knowledge about effective education practices, and interdisciplinary dialogue. This paper describes the PDP, including goals, rationale, format, workshop sessions, outcomes from ten years, and future directions.

1. Introduction

The Professional Development Program (PDP) was developed through the Center for Adaptive Optics (CfAO), and is now at the heart of an education program at the Institute for Scientist & Engineer Educators at the University of California, Santa Cruz (UCSC). Since 2001, the PDP has been instrumental in developing and advancing a growing community of scientist- and engineer-educators. Participants come to the PDP early in their careers—most as graduate students—and they emerge as leaders who integrate research and education in their professional practice.

Successful early-career scientists and engineers have generally been taught in large lectures and step-by-step "cookbook"-style laboratory activities. The disciplinary research skills and scientific reasoning skills that these graduate students need to acquire for the research portion of their careers are rarely formally taught. Instead they pick up these skills from their environment, or they may be fortunate enough to have particularly effective mentors. Meanwhile, they are increasingly called upon to teach the next generations of scientists, engineers, and citizens. Most begin formally teaching their own students as graduate teaching assistants, and many progress as faculty.

In graduate school, scientists and engineers are in a prime position to learn about and reflect on *how research skills are acquired* and *how they might be taught* and to consider *how laboratory units and courses can be tapped to provide students with experiences that impart relevant content knowledge and reasoning skills*. They are in a position to teach research skills explicitly and intentionally, so that their students can develop research abilities through coursework rather than just by good luck. In that position, they can use these developing research skills to strengthen students' scientific/engineering reasoning skills and teach content knowledge with understanding. As they carefully consider research skills, reasoning skills and content understanding, graduate students become better teachers and develop as future mentors. This reflective practice also enhances their own learning, making them better researchers.

The PDP builds, supports, and mobilizes a community of participants by engaging them in the teaching and learning of research skills, reasoning skills and content understanding (in combination, we call this *inquiry*). Participants put new knowledge into action by designing inquiry activities and teaching their activities in undergraduate science and engineering laboratory settings. Subsequent further reflection on the state of the art within the community keeps the PDP active, dynamic, iterative, and responsive. In addition to inquiry, members of the PDP community value and intentionally incorporate diversity and equity considerations, formative and summative assessment strategies, critical use of education research, knowledge about effective education practices, and interdisciplinary dialogue. These shared values, which are further described in Seagroves et al. (this volume) support the community as PDP participants experience and reflect on inquiry, then experiment with and reflect again on inquiry. Participants who thus iterate their way into integrated identities—as both researchers and teachers—emerge as leading scientist-educators and engineer-educators.

This paper draws heavily from our previous descriptive paper on the PDP (Hunter et al. 2008), but also includes new material highlighting new frameworks, workshop sessions, and other infrastructure that have been added to the program in the past two years. Next in §2, we give an overview of the PDP, and then we discuss the PDP's focus areas and frameworks in more detail in §3. In §4, we describe the components of the PDP, including individual workshops, and in §5 we demonstrate some PDP outcomes. Finally, in §6, we discuss the future of the PDP.

2. Overview of the PDP

Originally the PDP was developed through the CfAO, a National Science Foundation-funded Science and Technology Center[1] (STC). STCs are charged to conduct innovative, potentially transformative research and education; develop partnerships between public and private organizations; and demonstrate leadership in the involvement of groups traditionally underrepresented in science and engineering. Centers create environments that support work at the interfaces of research disciplines, and where research and education are integrated. Although each STC has its own unique set of needs, resources, and opportunities, they all share a rare opportunity spending up to ten years to develop, refine, and sustain an educational program within the environment of top tier U.S. research universities. The PDP, and the broader CfAO education program, were specifically designed to take advantage of the opportunities afforded by STC funding: long-term funding, a charge to be innovative, a national presence, and the opportunity to advance future scientist- and engineer-educators (i.e., the Center's graduate students and post-doctoral scholars).

The CfAO education program, including the PDP, was the result of an ongoing strategic planning process that took into consideration the Center's particular strengths and resources, educational needs related to the Center, and the body of knowledge on learning and teaching, to find a niche where the Center could make a unique contribution. From this process, the CfAO developed two integrated strands designed to impact teaching and learning in higher education. Both strands focus on the ways that students experience and engage in the processes, practices, and culture of science and engineering. One strand focuses on the learning experience of current undergraduates, while the other focuses on the teaching practices of early-career scientists and engineers. The two-strand model can be applied to different teaching and learning contexts. However, the CfAO chose to focus these strands on a challenge closely related to its research goals: the fact that a disproportionate number of women, Hispanics, African Americans, Native Americans, and Pacific Islanders who pursue baccalaureate degrees in the physical sciences and engineering (fields that the CfAO relies on for a workforce) leave or choose not to pursue work or an advanced degree in these fields.

[1]More information about Science and Technology Centers may be found within the NSF's Office of Integrative Activities at `http://www.nsf.gov/od/oia/programs/stc/`.

The CfAO's two-strand model, shown in Figure 1, has now been integrated into two major educational initiatives: the Institute for Scientist & Engineer Educators (ISEE)[2] at the University of California Santa Cruz, and the Akamai Workforce Initiative (AWI)[3] at the University of Hawai'i Institute for Astronomy. The model is designed to simultaneously (1) prepare a new generation of scientists and engineers to effectively engage all students when teaching their disciplines (horizontal "strand"), and (2) change the learning experience of students currently pursuing science and engineering careers, in order to retain them (vertical "strand"). The vertical strand includes programs and courses aimed at retaining students of all backgrounds in science and engineering disciplines. These programs and courses have many innovative components that serve as "teaching laboratories" for participants in the horizontal strand.

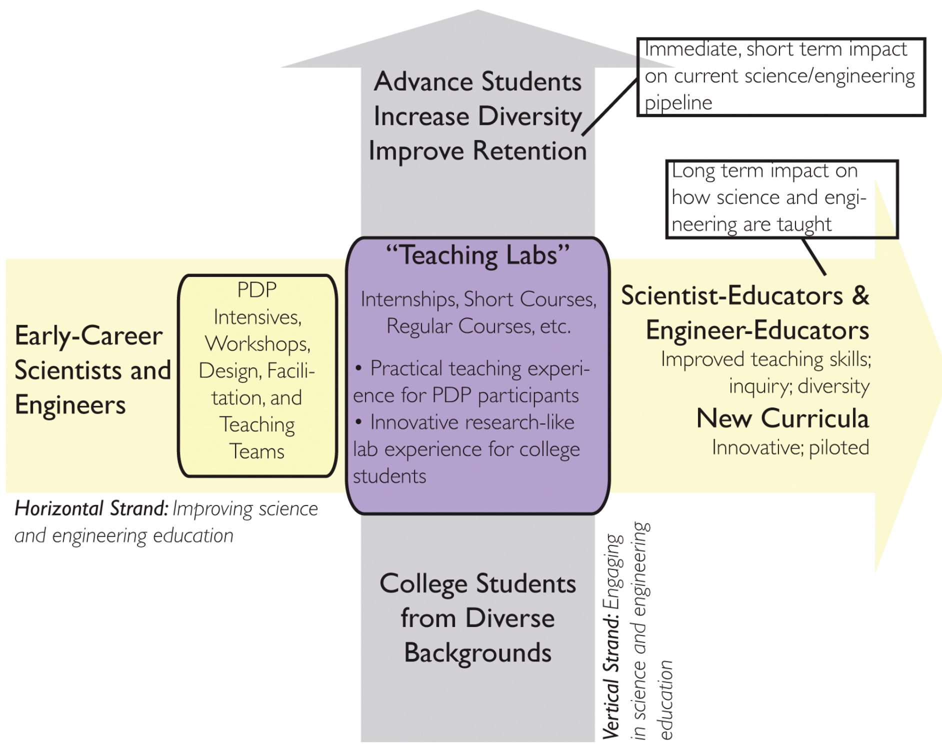

Figure 1. The two-strand education model, in which early-career scientists and engineers are trained to teach more effectively and inclusively (horizontal strand), and college students from diverse backgrounds engage in research-like experiences that increase their knowledge and interest in pursuing further science and engineering opportunities (vertical strand). In this paper, we focus on the horizontal strand of the program, the PDP.

Many of the activities designed within the PDP and used as "teaching laboratories" are described in this volume. The horizontal strand encompasses the PDP, and is aimed

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[2]`http://isee.ucsc.edu`

[3]`http://kopiko.ifa.hawaii.edu/akamai/`

at changing the way the next generation will teach undergraduate science and engineering. Although the two strands are depicted neatly in Figure 1, it is the complexity and interplay between the two strands that has engaged the community for so many years. At the intersection, at least three things are happening simultaneously:

- PDP participants (early-career scientists and engineers) are practicing effective, inclusive teaching
- College students are practicing science and/or engineering in a learning environment created to be more equitable (designed and taught by PDP participants)
- New curriculum is being piloted and demonstrated

The remainder of this paper will focus on the horizontal strand of activities, which we call the PDP.

The broad goals of the PDP are to:

Develop scientist- and engineer-educators: Cultivate scientist- and engineer-educators, who design and teach innovative, authentic inquiry experiences for a diverse population of future scientists, engineers, teachers, and citizens.

Illustrate inquiry: Demonstrate laboratory activities that reflect the practices of scientists and engineers.

Establish infrastructure: Create the tools, methods, professional development curricula, and community that enable emerging scientists and engineers to develop and advance as educators.

Effect broader change: Influence the larger science and engineering community to think innovatively about education—in particular, to reconsider the traditional relationships between teaching and research and between the natural and social sciences, and to reconsider the inclusiveness of their practices.

To achieve these goals, our participants experience a cycle of activities (described in §4) in which they experience a classroom inquiry activity, reflect on this experience, design and teach their own inquiry activity, and reflect on their practices.

The designers, developers, organizers and instructors of the PDP are a group of education professionals and scientists. Several of us were graduate student participants in past cycles of the PDP. Although our current official titles range widely among university (staff, post-docs, faculty) and consulting positions, for lack of a better term, we will refer to those who drive the PDP as "PDP staff."

2.1. PDP Participants

The PDP has focused on mentoring early-career scientists and engineers who are in the process of becoming scientist- and engineer-educators. Through 2010, the PDP has impacted over 250 participants from a broad diversity of disciplines, institutions, and careers. They come from institutions across the continental U.S. and Hawai'i. Their specialties, and the disciplines in which they have applied their teaching, span vision science, astronomy, physics, molecular biology, ecology, chemistry, electrical engineering, optical engineering, and more.

Though participants come from this wide array of disciplines, they all have in common their interdisciplinary endeavor to advance as educators. The fact that everyone is an expert at something else, and none are yet expert educators, becomes common ground and a basis for community. Hierarchies that participants bring with them—such as the fact that they might be junior or more senior members of their research lab—count for little within the PDP community. Instead, contributions to and seniority within the PDP community itself are valued. Some participants have joined the community for as little as a couple of months (from workshops to teaching experience) while many return year after year to grow as leaders and innovators within the community.

Participants have included post-docs, community college and university faculty, administrators, education professionals, and high school teachers, but most have been graduate students. Many science and engineering graduate students are teaching already, and will be in the future, yet they receive little training in education. They are looking for help and are in a prime position to grow. They are at a phase in their careers when they are still actively learning research skills themselves, and can be reflective about the learning and teaching of these skills that are so critical to science and engineering. Not only can the PDP impact their immediate teaching, but there is great potential for long-term impact: Most Ph.D. recipients become college/university faculty, and nearly 75% of faculty positions are at institutions with a strong focus on teaching. In fact, only 3% of U.S. institutions of higher education are "research" universities (Boyer Commission 1998). The PDP is well aligned with calls to reform graduate education to better "prepare students to teach in a variety of settings using a range of pedagogies based on research in teaching and learning" (Nyquist & Wulff 2002, and references therein).

As discussed in §2, one of the goals of the PDP is to develop these participants as leading scientist-educators and engineer-educators. To achieve this, the PDP is designed to help participants make progress in the following areas:

Designing inquiry activities: Participants in the PDP engage in a series of activities in which they experience and reflect on inquiry, then design and teach an inquiry activity, and reflect again on this experience. As they design inquiry activities, participants are expected to draw from education research, known effective teaching practices, assessment strategies, and diversity/equity considerations. Participant progress includes articulating clear learner goals in terms of inquiry, and planning activities that weave the knowing and doing of science and/or engineering together, while taking into account students' prior knowledge and experiences. Participants are also expected to deliberately sequence activity components so that all learners improve at generating and evaluating evidence, and at conveying, using, and interpreting explanations. Participants' designs should improve all students' abilities to productively participate in the practices and discourse of science and/or engineering.

Optimizing learning: Participants advance at creating effective and inclusive learning environments. For the PDP community, improving as an educator includes articulating and communicating learning goals. It also includes honoring students' backgrounds, values, and community, adapting instruction accordingly, and engaging what students already know and think. Effective educators create learning environments that support the further development of students' values, interests, attitudes, and identity, so that students can productively participate in the enterprises of science and engineering.

Facilitating students: Participants not only design inquiry activities, but also teach them, using techniques collectively called "facilitation." Improving as a facilitator requires developing a repertoire of strategies that engage and support all students in building and practicing inquiry skills. The facilitator uses strategies that make learners' thinking visible to both the learner and facilitator (Harlen 2003), and that maintain productive and collaborative group learning environments. In particular, the art of facilitation lies in guiding learners—sometimes even leading them—without taking away their feeling of ownership over their investigations and understandings (King 1993).

Growing more intentional: In the PDP community, "growing intentional" means becoming more informed and thoughtful about choices made when teaching. Participants become more reflective on education and integrate education into their identities as scientists and engineers. Participants reflect on inquiry both in the educational context and in their own research context—and some may find that this reflection improves their research as well as their teaching. Advancing as a reflective, intentional educator includes valuing and using frameworks from education research to develop teaching strategies, valuing diversity and equity as a consideration in education design, and participating in the community of practice that focuses on improving science and engineering education.

3. Focus Areas and Frameworks of the PDP

The PDP is a multi-layered program in which we present advanced concepts about science and engineering education, and we expect our participants to put those ideas into practice as they design and teach their own activities. In order to support participants in this effort, we have recently begun to articulate our emphases in three major focus areas—inquiry, diversity and equity, and assessment—in a more structured way. Articulating the most important concepts we want participants to learn about and put into practice has helped us to more clearly define what we mean by "inquiry," for example, and more clearly tailor our workshops and training activities. Below, we give further background and describe our Inquiry, Diversity & Equity, and Assessment focus areas. Within the Inquiry focus, we have elevated the formality of our emphases to call it a "framework." In all three focus areas, the choice and articulation of emphases is PDP-specific.

3.1. The Evolving PDP Inquiry Focus Area

Engaging undergraduates in research experiences is widely held as a way to recruit and retain students in science and engineering (see, e.g., Russell, Hancock, & McCullough 2006), as well as a way to give K–12 teachers authentic experiences so that they can effectively convey science and engineering content and practices to their students. Yet it is nearly impossible to provide individually mentored research experiences to more than a small fraction of undergraduates. Meanwhile, laboratory units and courses already exist, and they represent a vast untapped potential for providing all students with experiences that impart relevant content knowledge and reasoning skills, mirroring the authentic practices of scientists and engineers. Moving laboratory activities away from cookbook-like performances, toward authentic inquiry, is an emphasis of the PDP. Supporting this emphasis has stimulated ongoing refinement of the PDP, as PDP-designed laboratory activities have expanded into diverse content areas and advanced levels. Designing activities for engineering courses, and for content areas that require synthesizing data from multiple sources with computer models and other abstractions, have been major forces for new PDP workshops, tools, and supports.

3.1.1. PDP Inquiry Framework

Inquiry has always been at the center of the PDP's community of practice. "Inquiry"—along with its close cousin "inquiry-based learning"—is a term that is widely used but less widely defined. Within the PDP, the conception of inquiry has evolved, from an initial literal understanding that it is learning motivated by questions, to a broader yet more nuanced understanding: inquiry is a powerful means of learning substantive content and laboratory skills, and of developing critical ways of thinking about science and engineering. The PDP community has come to use the term inquiry to refer to science activities that mirror the research practices of scientists, and engineering activities that mirror the design practices of engineers. A useful shorthand we have adopted is "learning X the way X is done," with possible values of X including broad terms like "science" or "engineering," or more specific terms like "genetics" or "electro-optics."

In 2010, the PDP introduced a framework that articulated six elements of inquiry, as defined within the PDP community. The framework is intended to help PDP participants design, teach, and reflect on inquiry teaching and learning. It is also meant to help PDP staff more effectively facilitate PDP participants as they push into new areas and new models for inquiry. A major driving force for developing the six elements was the growing need within the PDP community to teach science and engineering at the upper division undergraduate and graduate levels. Science and engineering at these levels often includes using existing databases, computer simulations, mathematical models, and other strategies in which the investigator cannot generate new knowledge just by physically manipulating the objects of investigation. Some have called this kind of inquiry "second-hand inquiry" (e.g., Palinscar & Magnusson 2001) to indicate that the investigation uses data or evidence generated through other sources. The challenges associated with supporting development in these areas of inquiry became evident as PDP participants became interested in teaching topics such as structural elucidation of chemical compounds, fluid dynamics, and adaptive optics system design. The PDP is currently evolving to support the development of these advanced undergraduate and graduate level topics by developing new tools, workshops, and model designs. As part of the process the PDP defined the following six elements of inquiry (shown in Table 1) to help the PDP community innovate in new territories, while staying grounded in inquiry.

3.1.2. Scientific Inquiry and Engineering Design

To learn science and engineering the way science and engineering are done requires engaging the content as well as the processes of these disciplines. Science and engineer-

Table 1. The PDP Inquiry Framework. The PDP's definition of inquiry is articulated through six elements (left column) that are reflected in the design of activities (center column) and in facilitation strategies that instructors employ (right column).

	Inquiry Activity Design	**Inquiry Activity Facilitation**
Element of Inquiry	**Designers articulate goals, activity components, and assessments that include the following . . .**	**Instructors employ strategies and moves that . . .**
1. Cognitive science & engineering processes	At least one important cognitive science/engineering process is operationalized in learning goals, practiced in activity, and assessed.	Assess learners' experience with and engagement in processes and supports practice and improvement.
2. Content: foundational scientific concepts	Foundational scientific concepts (or concepts that can be tied to them) are articulated in learning goals, and assessed. Activity components support learning these concepts.	Make learners' ideas about content visible, and then support learners improving their understandings and making connections to other understandings.
3. Intertwined content and process	Content (#2) is learned through the application of inquiry processes (#1). Application of inquiry processes is motivated by content.	Encourage learners to reflect on how processes were used to learn content, and how processes can be generalized to other contexts.
4. Mirroring authentic research/design processes	Design goals and activity components are driven by, and reflect, authentic research/design processes, practices, and norms.	Convey how the activity mirrors authentic research as part of contexting and synthesis.
5. Ownership of learning	Activity components open and promote multiple pathways to understanding content, and practicing processes, and learners have ownership of paths.	Guide learners in coming to their own understandings via their own pathways.
6. Explaining using evidence	Learners use evidence and reasoning to do at least one of the following in relation to their understanding of content goals: make meaning, articulate, or persuade others.	Help learners focus on using evidence to make sense of their investigation and to talk about their findings by linking them to scientific principles.

ing have much in common, but as the PDP audience has included increasing numbers of engineers, we have adapted to treat the critical differences. For science, processes students must learn and practice include generating and refining research questions, designing investigations, collecting and then interpreting data, constructing explanations, and communicating findings. In engineering, students must learn and practice defining and clarifying a need or problem, identifying requirements and constraints, developing possible solutions, constructing prototypes, testing and evaluating solutions and tradeoffs, and communicating results. In both the science and engineering cases, these processes cannot exist in a vacuum, but are inextricably linked with particular content.

The early PDP focused on scientific inquiry process skills such as those discussed in Chinn & Malhotra (2002) so that participants had deeper understandings of these processes and could support their students in learning them. As the community's population and teaching venues have both expanded to include engineering and technology disciplines, the PDP has had to supplement treatment of scientific inquiry skills with support for engineering skills as well. The PDP's treatment of engineering skills includes ideas such as a step-by-step "engineering design cycle" (see Massachusetts Department of Education 2006, p. 84), and the accreditation criteria for engineering schools (ABET 2008a). But the PDP has also acknowledged that engineering can be much more non-linear and iterative and that students must master skills that are realistic for the engineering workplace (Seagroves & Hunter 2009, and Seagroves & Hunter, this volume). In addition, because PDP participants teach both in engineering design programs and in technology programs, the treatment of skills is broad and includes frameworks such as ITEA (2007) and ABET (2008b). Even with all of this, however, it is important to note that science and engineering have much in common, and indeed, key to any meaningful instructional engineering activity is the inclusion of fundamental scientific concepts.

3.1.3. Inquiry Learning as an Effective and Inclusive Strategy

Inquiry is called for in most national reports on improving science and engineering education (e.g., PKAL 2006; AAAS 1989; NRC 2000, 2005a; NAS, NAE, & IoM 2006). Our conception of inquiry incorporates much of what is known about how students learn (NRC 1999, 2005b), and the PDP emphasizes the importance of becoming an informed consumer of education research and effective practices. We display respect for the fields of the learning sciences,[4] and we demonstrate that one can approach teaching and learning as critically as one would approach science and engineering.

As shown in Table 2, inquiry connects broadly to education research, and also more specifically to strategies that support diversity and equity. Different pedagogical techniques and support for different prior knowledge and experiences are explicitly incorporated in inquiry activities, along with a strong sense of student ownership (one of our six inquiry elements, Table 1) and an emphasis on discourse, communication, and explanations (another of our inquiry elements).

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[4]The "learning sciences" is a term used to describe the interdisciplinary systematic study of learning and of educational interventions. It draws from many fields, such as education, cognitive science, psychology, and others.

Table 2. Connections Between Inquiry and Inclusive Teaching Practices. Inquiry teaching/learning strategies naturally incorporate and connect with features that are known to improve the inclusivity of the learning environment.

Features of Inquiry	Connections to Research
Facilitators (instructors) employ formative assessment	Supports students' use of metacognitive strategies, one of the core principles of learning (NRC 1999, 2005b)
Includes different entry/exit points	Engages and adapts to students' prior knowledge and experience, another core principle of learning (NRC 1999, 2005b)
Includes various pedagogical tools and participant structures (group work, etc)	Supports different ways of learning, a feature of a culturally responsive curriculum (Gay 2000)
Sets high expectations and supports students to meet them	Alleviates stereotype threat (Steele & Aronson 1995) by conveying respect for learners' potential
Allows students to communicate in their own style but also requires them to communicate in a technical manner	Supports an awareness of and proficiency with code- and culture-switching (Aikenhead & Jegede 1999)
Student ownership over knowledge gains: "I figured it out by myself. It was empowering."	Increases confidence, motivation and persistence (Wigfield et al. 2006)

3.2. PDP Diversity and Equity Focus Area

While we know from experience that PDP participants have strongly positive impacts on their students' attitudes and understandings, pinpointing the ways in which they can and do create inclusive learning environments can be challenging. There is a myriad of different resources for learning about diversity and equity in science and engineering, including a great deal of formal research, and there is another myriad of strategies that have been proposed and tested for addressing diversity issues. Table 2 shows that the PDP inquiry model "automatically" provides a good start for improvement, but we and our participants want ways to address diversity and equity more explicitly.

To help our participants navigate this complex space of ideas, we have identified five emphases within the diversity and equity focus area that are particularly relevant to PDP participants' work. These emphases are not meant to be comprehensive, but instead are meant to closely match the PDP's focus on inclusive teaching in the undergraduate laboratory environment. The emphases help PDP participants choose activity components and facilitation strategies, plan for an effective learning environment, and reflect on their teaching.

The emphases not only align with the existing PDP, but they also allow for growth beyond the PDP as the umbrella ISEE and AWI programs grow. For example, PDP workshop sessions may not cover every emphasis in great depth, but a follow-on new workshop could be designed to complement the existing PDP that would be coherent with what is already offered. The emphases will be used to organize tools, strategies, and examples for designing, teaching and assessing activities as well as entire courses and programs. For a full discussion of the emphases within the diversity and equity focus area, as well as the research and practice that inform this focus area, see Hunter et al. (this volume). Here we simply summarize the emphases within this focus area:

Multiple ways to learn, communicate and succeed: Learners should be provided with multiple ways to engage in, approach, and succeed in their work, and multiple ways to communicate their understandings.

Learners' goals, interests, and values: Learners' goals, interests, values, and sources of motivation should be engaged and leveraged through activities that are relevant, meaningful, and challenging.

Beliefs about learning, achievement, and teaching: Learners and teachers should develop beliefs about learning, achievement, and intelligence that support an expectation of success for students from all backgrounds.

Inclusive collaboration and equitable participation: Learners should have equal opportunities to participate and equal access to resources in classroom and collaborative activities. They should have opportunities to contribute diverse ideas, identify problems and solutions, and participate as valued team members.

Social identification within science and engineering culture: Learners should gain a sense of belonging in the science/engineering culture that fits with who they see themselves as, who they want to become, and what they want to become part of.

3.3. PDP Assessment Focus Area

PDP participants learn about assessment throughout their PDP experience, through workshops and sessions, and through direct experience. The field of assessment, goals of assessment, and many types of assessment tools encompass a spectrum of issues that could not possibly be given full coverage within the PDP. However, PDP participants gain significant experience within the particular domain they work within—designing and teaching an inquiry laboratory activity. They articulate their intended learning outcomes, develop a rubric to score their learners' explanations, and practice formative assessment through their facilitation of inquiry activities. PDP staff realized that participants were unaware of the connections between assessment and their thinking within the *How People Learn* (NRC 1999, 2005b) framework (e.g., Scotter & Pinkerton 2007) and the many ways in which they were getting experience with assessment. So in 2010 we made this more explicit with the following outline of assessment-related PDP emphases and activities:

Articulating assessable learning outcomes: PDP participants articulate and communicate learning outcomes that are assessable, through content and process goals that are operationalized. In other words, participants articulate learning goals that refer to the specific knowledge and tasks they expect their learners to be able to understand and accomplish. To support this, we include PDP sessions on types of learning outcomes/goals, with an emphasis on content and process goals, and we give participants practice stating goals. Participants then determine learning outcomes for their own inquiry activities, as well as the evidence they will look for as they teach that indicates learners have reached these outcomes. They articulate these learning outcomes as they design and make them clear to their learners as they facilitate.

Making learners' thinking visible: Facilitation sessions in the PDP emphasize the importance of using strategies to make learners' thinking visible to both the instructor and the learner, as an important part of formative assessment. This way, learners can more clearly pinpoint areas where they may need to improve their understanding, and facilitators can adjust their teaching to better support learners. As they design their inquiry activities, PDP participants develop a facilitation plan that incorporates relevant strategies, and then they practice these strategies as they facilitate their activities.

Monitoring and self-monitoring the application of cognitive processes: The PDP draws from the *How People Learn* (NRC 1999, 2005b) summaries' emphasis on metacognition and also highlights the importance of formative assessment as applied to scientific and engineering process skills. Although this is not covered explicitly in workshop sessions, PDP facilitation training does draw from strategies for monitoring learners' engagement in and application of cognitive reasoning processes in their investigations (such as Black & Wiliam 1998). Self-monitoring by learners is also embedded in PDP inquiry activities, though not explicitly addressed in workshop sessions.

Assessing content understanding through learners' explanations: All PDP participants generate a rubric and use this to assess their learners' content understanding as they watch, listen to or read learners' explanations of their work. This assessment task is designed to help PDP participants assess their learners' understanding of scientific principles at a level deep enough to explain their findings, and if they are able to use evidence to appropriately support a claim. Participants generate their rubric in the context of the inquiry activity they design, identifying the types of scientific arguments their learners might make at different levels of performance. Participants break these arguments down into claims, supported by evidence (e.g., data) and related reasoning that draws from scientific principles, using a base explanation rubric (see Appendix C). The claim-evidence-reasoning structure is based on frameworks common in the education research literature, such as Harris et al. (2006) and McNeill & Krajcik (2009), while the idea of beginning with a base rubric and customizing it for a particular application borrows from Siegel et al. (2006).

4. Structure and Components of the PDP

In the previous sections of this paper, we described the rationale behind the PDP, goals for PDP participants, and the main concepts and emphases we impart through the PDP experience. In this section, we give a practical description of the PDP cycle of activities.

4.1. The PDP Cycle

The full PDP experience includes active participation in a series of workshop-based "intensives," development of an inquiry activity, a teaching experience, and time for reflection. Together, these activities comprise a pathway in which participants experience inquiry from the learner's perspective, reflect on their experience, practice inquiry as educators, and reflect on their practice.

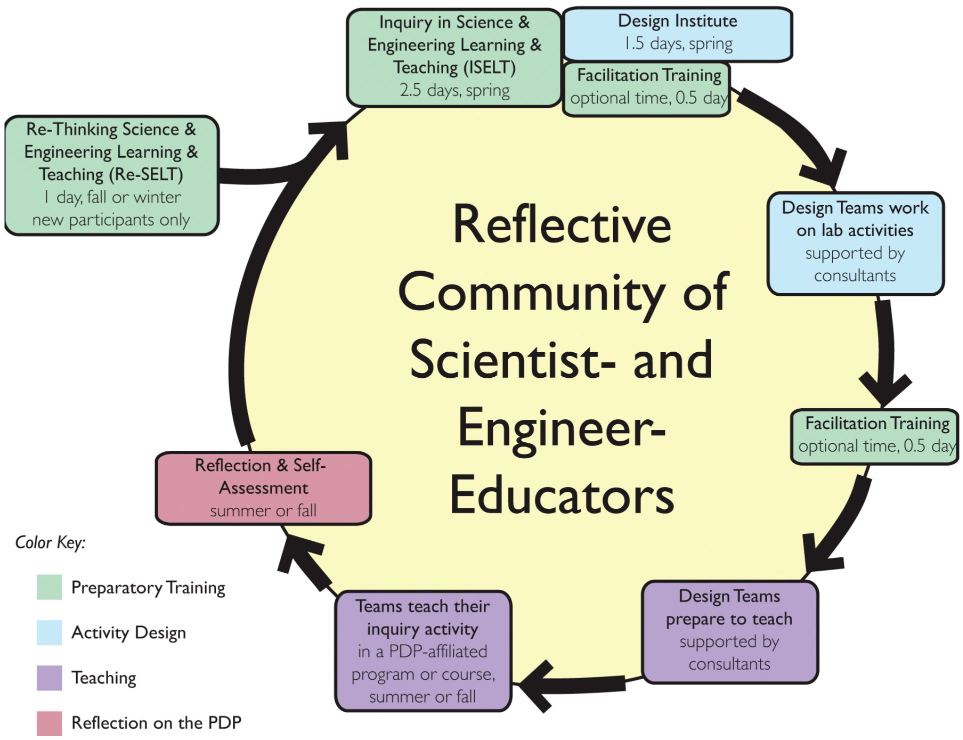


Figure 2. The year-long cycle of PDP activities. Participants engage in inquiry, reflect on their experience, receive training on science/engineering pedagogy, design and teach inquiry activities for their own students, and reflect on their teaching practice. Participants may return for more than one year of the PDP cycle.

In Figure 2, we show the progression of PDP activities. Note that the word "intensive," used as a noun, has a particular meaning in our community. For us, an intensive is a series of workshops in which PDP participants and staff gather together to focus on teaching and learning inquiry. New participants begin with the one-day introductory intensive *Re-Thinking Science & Engineering Learning & Teaching* in the fall, and then join returning participants for the rest of the program. In the spring, 4.5 days of further training begin with the *Inquiry in Science & Engineering Learning & Teaching* intensive. This is a particularly immersive experience in which new and returning participants engage in inquiry activities and consider pedagogical aspects of educating in this way. (Introductory intensives are described in §4.2 and the workshops within these intensives are described in §4.2.1.)

At the end of this intensive, participants begin the *Design Institute*, in which they work in teams on the design of inquiry-focused laboratory activities, primarily for undergraduate students. Each team uses the concept of "backward design" to develop an activity that has clear goals of imparting knowledge about concepts, reasoning processes, and attitudes relevant to a topic in the natural sciences or engineering (see the Design Task, below, the description of backward design workshops in §4.2.1 and the description of backward design of inquiry activities in §4.3). In 2010, the PDP offered the option for teams to thoughtfully plan for the facilitation of an existing PDP activity rather than designing a new activity. The 2010 PDP Design and Facilitation Tasks are shown below:

PDP Design Task: Design Teams will design a PDP inquiry activity where students simultaneously learn scientific knowledge, reasoning processes, and attitudes, by practicing science or engineering. Designs should reflect consideration for contemporary issues in education (such as those summarized in the *How People Learn* series) through careful integration of the ISEE focus areas of inquiry, diversity/equity, and assessment in the activity. Teams will assess learners' gains in understanding through their explanations.

PDP Facilitation Task: Facilitation Teams will prepare to facilitate an existing PDP inquiry activity where students simultaneously learn scientific knowledge, reasoning processes, and attitudes, by practicing science or engineering. Individual designed elements and preparation for "on-the-fly" moves should reflect consideration for contemporary issues in education (such as those summarized in the *How People Learn* series) through careful integration of the ISEE focus areas of inquiry, diversity/equity, and assessment in the activity. Teams will assess learners' gains in understanding through their explanations.

Teams continue to meet regularly throughout the spring/summer to work together on their activity designs and facilitation plans (see §4.3). Each team works with a PDP staff member who consults with them during their planning process. Participants then teach their activity in the summer or fall in a venue supported by or partnered with ISEE or AWI (see §4.4). These venues serve as "teaching laboratories," where participants have the opportunity to test out the activity they designed, as well as the new teaching methods they learned, with the support of their fellow team members and consultation from ISEE/AWI staff.

After teaching, participants reflect on their experience by debriefing and submitting additional reflections on a written form (see §4.5). They consider all they have gained by participating in the PDP: tools, confidence, and community support for teaching science/engineering effectively. They also provide valuable input that helps to shape future PDP cycles, and they consider what they may want to work on as they contemplate returning for another PDP cycle and as they move forward in their education and careers.

4.2. Preparatory Training Intensives

The PDP intensives are the central means by which we provide formal training and support for our participants. Each intensive is an immersive experience made up of a series of workshops on teaching and learning inquiry. The format of the intensives has varied over the years, both in how the workshops are arranged and divided between the intensives, and in the workshops themselves. For example, in 2008 the PDP cycle began with two intensives: a one-day event for new participants, and a four-day retreat for all participants. In 2009 we also offered a separate one-day intensive just for returning participants. For many years we have offered a separate half-day workshop for all participants just before they began their teaching experience, to prepare them for on-the-fly facilitation moves necessary to successfully teach an inquiry activity. In 2010 we continued our one-day intensive for new participants and offered a 4.5-day combined intensive for all participants in which we offered separate training on activity design and facilitation. We also integrated a new "Special Projects" strand for multi-year returning participants who were working on larger scale curriculum development or related innovative work that did not fit into the PDP Design or Facilitation Tasks. Regardless of the variations on the structure of the intensive, there is always a significant multi-day intensive in which first-year and returning participants sometimes work together and sometimes engage in separate activities. Throughout these intensives, participants are mixed in different ways to encourage community and a broad exchange of ideas.

During the intensives, PDP staff model working together as collaborators focused on science and engineering education. Returning participants may take on leadership roles and participate in training new participants.

4.2.1. PDP Workshops

The following workshops are offered within PDP intensives, arranged in various ways depending upon time constraints, funding, and programmatic needs.

Comparing Approaches: Three Kinds of Hands-On Science *(new participants, ~3 hrs)*
In this activity, developed by the Exploratorium's Institute for Inquiry,[5] new participants experience a hands-on science lesson taught in three different ways: via a guided worksheet activity, via a challenge activity with a design goal, and through open exploration with an array of materials. Participants then reflect on the experience, discussing the pedagogical pros and cons of each hands-on technique in small groups. This is the first time many participants consider that "hands-on" does not have one well-specified meaning, that all learners do not learn as they do, and that a reflective teacher can approach pedagogy intentionally. Returning participants may be trained to lead one of the three stations and the reflective discussions.

Science of Learning and Teaching: The How People Learn Framework *(new participants, ~1.5 hrs)*
We build off the previous workshop, demonstrating that one can approach education with the same rigor that is used to study science and engineering, and projecting respect for educators who are informed, critical consumers of research on teaching and learning (Handelsman et al. 2004). Participants work in small groups, discussing a reading from the *How People Learn* series of summaries (NRC 1999, 2005b). Together they elaborate the three principles of effective teaching and learning that are presented

[5]The Exploratorium Institute for Inquiry's professional development activity designs are available at `http://www.exploratorium.edu/ifi/workshops/fundamentals/index.html`.

in this reading: engaging learners' prior knowledge; recognizing the fundamental role of factual knowledge and conceptual frameworks in fostering understanding; and encouraging metacognition, or self-monitoring, during learning.

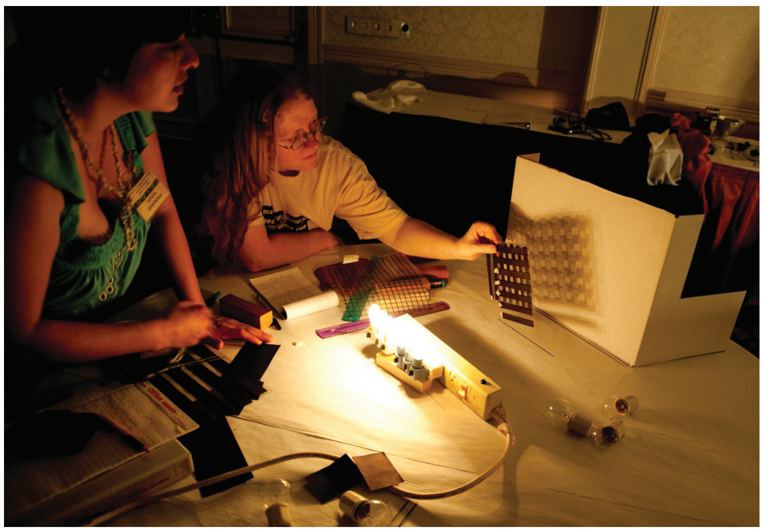
They also consider the four "lenses"—learner-centered, knowledge-centered, assessment-centered, and community-centered—through which educators can "view" classroom activities to successfully implement these principles. Participants are encouraged to share how these ideas have been highlighted in their own formative learning experiences. After discussing their experiences in general, participants are asked to consider how they might apply the principles and lenses in typical graduate student teaching venues (lab courses, small discussion sessions scheduled outside of lecture time, and mentoring undergraduate researchers). By analogy with the participants' experiences in science and engineering, we emphasize the value of having a model or framework for trying out new education ideas and reflecting on the results. *How People Learn* provides a useful and accessible framework, though we note that it is not the only framework supported by education research.

2009 PDP participants discuss the *How People Learn* framework.

Revisiting the How People Learn Framework *(all participants, ~1.75 hrs)*
This workshop opens the four or five day combined intensive, reviewing what was learned from the "Science of Learning and Teaching: The *How People Learn* Framework" and moving participants further with a discussion on a second reading on the learning sciences. Participants also consider how the *How People Learn* framework can be applied to a classroom scenario. Increased familiarity with education research sets the stage for applying the framework to their own inquiry activity design. The PDP's focus areas in inquiry, assessment, and diversity/equity are presented and situated within the otherwise broad *How People Learn* framework.

Light and Shadow Inquiry Activity *(new participants, ~7 hrs over two days)*
This activity is the centerpiece of the new participant experience: all PDP participants experience inquiry as learners and reflect critically on this experience before they design and teach their own activities. The activity has been tailored for the PDP but

is based on a model from the Exploratorium's Institute for Inquiry (see footnote 5). The inquiry begins with three starter demonstrations and brief explorations of engaging phenomena involving light and shadows. While these phenomena appear to be simple, they are rich enough to challenge participants with backgrounds ranging from little to no optics through optical engineers. Participants generate questions about the phenomena, and then form small investigation groups based on common interest in a question. Investigations include cycles of hypothesizing, designing and executing experiments, and devising explanatory models, and are aided by materials and a facilitator. Facilitators do not "teach" in the traditional sense, but guide groups and individuals to come to their own understandings. Participants summarize their investigations and conclusions in semi-formal presentations to their peers. Finally, PDP staff members synthesize the content of the phenomena under investigation.



2009 PDP participants explore light and shadow phenomena.

After completing the inquiry activity, new participants move into the teacher/designer stance with a reflective discussion. They compare the inquiry activity to more traditional labs and in particular consider the diversity of their learning experiences during the inquiry. They also examine how the inquiry activity is structured and facilitated, while retaining learners' ownership over their own knowledge gains.

Some returning participants have special roles in the "Light and Shadow" activity. A few may "shadow" the activity, choosing a focus and closely observing learning and teaching as the activity unfolds. Others may be trained to facilitate the inquiry, an intense experience in which they guide their peers. These participants are coached by PDP staff and debrief the experience afterward.

Parachutes Inquiry Activity *(returning participants, ~2.5 hrs)*

This activity serves as a quick refresher of inquiry from the learner's perspective for returning participants. It differs from the "Light and Shadow Inquiry Activity" in content, structure, pacing, and emphasis. Participants construct a simple parachute as a starter and briefly observe this starter parachute to generate interest and questions.

Questions are then communally voiced and charted for the entire group. Participants with like interests pair up to investigate parachutes further. They then present (often by demonstrating their parachutes) their understandings to the group, and finally a staff person synthesizes content on parachutes.

Comparing Inquiry Elements *(returning participants, ~1 hr)*
Immediately following the "Parachutes Inquiry Activity" there is a reflective discussion. Since returning participants have already experienced the "Light and Shadow" activity and taught an inquiry activity of their own design, they are in a position to compare and contrast the features and components of different activity designs. This helps participants see that the "Light and Shadow" model that is presented in their first year is not the PDP's definition of inquiry; it is simply an (excellent) example of an inquiry activity. In this discussion participants analyze the pros and cons of making different design choices and varying from that model (using the *How People Learn* framework as a structure).

Designing Engineering Activities *(returning participants, ~1.75 hrs)*
Since PDP teaching venues span science and engineering disciplines, participants focus on ideas in engineering education in this workshop. We begin with a lecture on engineering skills, highlighting similarities and key differences between engineering and scientific processes. Participants then work in small groups to apply these ideas. They re-design the "Parachutes Inquiry Activity" with an eye toward fostering one of these engineering skills: identifying constraints, defining requirements for a successful solution, brainstorming a diverse set of solutions, and considering tradeoffs to choose the most appropriate solution to a problem. As participants re-design the activity, they grapple with what it means to engage in an engineering skill, how this differs from doing "pure science," and how they would look for students' improvement at a particular engineering skill.

Preparing to Lead a PDP Design or Facilitation Team *(returning participants, ~1.25 hrs)*
Many returning participants will lead inquiry activity Design or Facilitation Teams, so this workshop is focused on the PDP design process (from which facilitation planning also flows) and our expectations for leaders in our community. Using concrete examples, participants discuss what does and does not fit within the PDP Design Task, and why (see also §4.1 and §4.3). Participants also consider the social dynamics of productively leading their peers, discussing common problem situations and brainstorming strategies for addressing them.

Introduction to Process Skills *(new participants, ~1.25 hrs)*
Participants practice the scientific processes of hypothesizing, predicting, questioning, and so on, in their daily research lives. However, they may not consider these processes as discrete skills, and thus may have trouble identifying where learners are struggling, or how to help them. In this workshop, participants visit several small hands-on stations, each of which asks them to perform a simple scientific task. Participants must then identify a specific process skill that they are practicing at each station. This leads to small-group and later large-group discussions about the process skills. The goal

of this workshop (modified for the PDP from an Exploratorium Institute for Inquiry workshop, see footnote 5) is for participants to view scientific processes with more specificity than a broad construal of "the scientific method" so that they can support learners with more specificity as well.

2009 PDP participants perform simple scientific tasks at a process skills station.

Improving Learners' Process Skills *(returning participants, ~2 hrs)*
In many PDP inquiry designs—even excellent, mature activities—learners may perform science or engineering reasoning tasks but may not learn and improve at science or engineering reasoning skills. In this workshop, small groups of returning participants consider a problematic skill from a real PDP inquiry design that could be improved. They are introduced to two structures that help guide improvement: a move from "simple tasks" toward "authentic inquiry" from Chinn & Malhotra (2002), and the utility of both "generic" and "context-specific" scaffolds from McNeill & Krajcik (2009). They then design small interventions or redesign particular components of the activity to address specific skills. These revisions are then available for the team that ultimately takes on the (re)design and teaching of that activity design. For more on this workshop, see Quan et al. (in the Professional Development section of this volume).

Addressing Diversity and Equity *(all participants, ~2.5 hrs)*
Participants now come together for a series of plenary workshops, beginning with a focus on diversity and equity in science and engineering. This plenary workshop starts with a presentation contrasting demographics of the entire U.S. population with those in U.S. science and engineering fields. The under-representation of women and minorities is demonstrated, and more complicated topics such as the "leaky pipeline" from elementary school through college and beyond are discussed. Participants are motivated to address these problems in the classroom.

As with the *How People Learn* literature, we draw from social science research, assigning readings from the "stereotype threat" and "mindset" literatures (see references at Stroessner & Good 2010, for instance). PDP staff members summarize major findings and lead small-group brainstorms, in which participants suggest strategies for encouraging inclusive classroom environments in their own teaching practice. Finally, we highlight connections between diversity/equity and the inquiry model itself, through a facilitated discussion in which participants consider the ways that the PDP Diversity & Equity Focus Area (§3.2) is highlighted through the various components of the inquiry model.

Sessions within this workshop and relevant outcomes are more fully described in other papers in this volume (Hunter et al., in the Professional Development section, and Metevier et al., in Research and Evaluation, respectively).

Practicing Backward Design *(all participants, ~2 hrs)*
In this workshop, we provide participants with a strategy for beginning the design of their own inquiry activity. We point out that most participants' science and engineering education has focused on content learning, and we encourage participants to reflect on the equal importance of reasoning processes both in the inquiry activity they experienced and in their own research. They read about "backward" curricular design: designing activities not by proceeding forward from materials (e.g., textbooks, lab equipment), but backward from learning goals (Wiggins & McTighe 2005, chapter 1). Different types of learning goals are presented, and the intertwining of content and process goals is emphasized. As a warm-up to their own design work, participants work in small groups to articulate an example learning goal. Given a broad, process-focused learning goal (typical of participants' first attempts at incorporating scientific and/or engineering processes into designs) and a setting (the "Light and Shadow" activity that they are familiar with), participants iterate through the backward design process. They "operationalize" the learning goal, making it more specific and concrete, so that learners' progress can be measured. They then tweak the design of the activity itself to put learners on such a path.

Examining Goals *(all participants, ~0.75 hrs)*
In this session, participants consider different types and levels of learning goals. In discussing goal "types", PDP staff separate out goals in which learners gain an understanding of scientific or engineering content, goals in which students learn new reasoning processes, goals in which students learn new technical skills, and goals that affect learners' attitudes toward science and engineering. Goals are further separated into "levels" that range from overarching course-level or even institutional goals, to goals specific to an activity, to goals that are specific to a particular station or segment of an activity. Participants work together to categorize example goals that were articulated in previously designed activities, and are encouraged to focus on articulating content- and process-related goals at the activity level as they design their own activities. This session is intended to stimulate participants to think deeply about learning goals and how they are articulated. It is more about gaining perspectives through the process of categorization, than about the final placement of goals into each category. For example, a vaguely worded goal is hard to categorize, and through facilitation by PDP staff, participants can see how hard it would be to teach or assess such a goal (or for a learner to understand what they are supposed to gain).

Assessing Learners' Explanations *(all participants, ~1 hr)*
Assessment is an important theme that is woven throughout the PDP, but this workshop is where assessment is most directly highlighted in the PDP intensives. Prior to the intensive, participants read an assessment primer that includes background information on different types of assessment (e.g., formative and summative assessment) and on rubrics, which are an important assessment tool. They also read about scientific explanations, and how they are not only an important and authentic scientific practice, but are important for learning and applying scientific concepts, gaining reasoning skills, and understanding the nature of science. Within this session there is a very quick summary of the readings, leaving time for participants to get practice in applying what they read to their own activity designs.

Developing a rubric for their activity requires PDP participants to debate and clearly articulate how exactly their learners might demonstrate their understandings.

As part of their PDP cycle of activities, participants are charged with developing and using a rubric to assess their students' explanations of their new understandings. To support this work, we give participants a somewhat generic "base" rubric, which breaks an explanation out into three key components (see the rubric at Appendix C and §3.3 for references on these ideas): a scientific or engineering "claim," the evidence or data that support the claim, and the reasoning or principles that connect the claim and evidence. Participants must articulate the kinds of claims they hope to hear from their students, the specific data students might invoke to support their claims, and the reasoning paths students would use to connect the two. Articulating these expectations in advance of their teaching can help PDP participants more effectively facilitate an activity, pinpointing specific areas where students may be excelling or need more support. In this session, participants discuss the various forms of "claims" by considering authentic examples of research projects (drawn from an undergraduate research experience program). Participants also use a strategy developed in Krajcik, McNeill, & Reiser (2008) to define "learning performances" that carefully state how knowledge gained by the learners would be used in an explanation or other scientific practice that would demonstrate the learner's understanding. Participants use their own activity and work from an important concept that they want their learners to understand, and then define how a learner would demonstrate their understanding through an explanation that uses evidence to support a claim, and appropriate reasoning.

Design Team Working Time *(Design Teams only, ~8 hrs over two days)*
Participants spend the *Design Institute* in small Design Teams, working on their inquiry activities for ISEE, AWI, or partner venues. As noted earlier, their task is to design an activity that simultaneously teaches science and engineering content and processes, while also taking into account diversity/equity and other contemporary education issues. Many returning participants serve as Design Team Leaders, assuming responsibility for driving their teams toward productive design work and teaching. PDP staff work closely with teams to facilitate their progress. Design time at the *Design Institute* is fairly unstructured, but is interspersed with sessions that provide fresh insight into the activity design process. For example, a few returning participants may formally present activity designs they worked on in past PDP cycles, highlighting innovative ideas, successes, and areas for improvement. The PDP design process is further elaborated in §4.3.

A team receives mentoring, feedback, and consultation from a PDP staff member.

Facilitation Planning Time *(Facilitation Teams only, ~4 hrs over two days)*
During the *Design Institute*, Facilitation Teams place an emphasis on planning to

facilitate their activities. As is noted elsewhere in the paper (e.g., previously in §2.1 and later in §4.4.1), facilitation is a means of teaching in which instructors encourage students' ownership over their new understandings. Effective facilitation employs a number of teaching techniques that include careful planning and on-the-fly support for students. Facilitation Teams generally work on an established activity that has already been designed through the PDP. During the *Design Institute*, they reconsider the learning goals of the activity and make decisions about whether or not the activity needs any re-design. They decide what individual facilitators' roles will be during the activity, and how and when they will set the context for each phase of the activity as they work with their students. Facilitation planning also includes considering what knowledge students should be able to demonstrate during each phase of the activity, and how best to support students who may need guidance. This is closely tied to the Facilitation Teams' assessment planning: during inquiry investigations, facilitators engage in informal dialogues with their students and can gauge students' understandings from their explanations of their work. By articulating what they want their students to be able to explain (e.g., through development of their explanation rubrics), facilitators can better plan to support students at different stages in their learning.

Special Projects *(multi-year returners only)*
In 2010, we implemented a new "Special Projects" strand of the PDP. This strand was designed to engage participants who have returned to the PDP for several years and may not greatly benefit from participating in a given set of workshops for, e.g., the fourth time, but still have a great deal to contribute to, and gain from, the PDP community. The Special Projects strand consists of fairly loose working time interspersed with specific readings and discussions, often led by one of the advanced participants themselves. Special Projects participants are required to define and clear their projects with the PDP Director in advance of the 4.5-day combined intensive. Some of the projects participants worked on in the most recent cycle included developing outlines for new scenarios and discussions about diversity and equity issues, adapting PDP-designed activities and teaching models to formal course settings, and curriculum development on scales larger than individual inquiry activities.

Community Sharing of Progress *(all participants, several hours interspersed over several days)*
During the 4.5-day combined intensives, we intersperse several opportunities for participants to share their work on their activity designs, facilitation plans, or special projects. Community sharing within the PDP serves many purposes. Participants are pushed, and held accountable, to make progress; staff can evaluate progress of individual teams as well as the entire cohort; and the entire community gains an awareness of the its processes and products. In the most recent cycle, we included one-minute poster "pops" at the beginning of the intensives in which team leaders and Special Projects participants gave brief descriptions of their activities and projects. These participants updated the community on their progress in later poster pops, and then, toward the end of the intensives, we held a more formal poster session. The latter session was led by other team members, giving them a chance to describe the activity they were working on, while giving team leaders an opportunity to look more closely at other teams' work.

A PDP team reports to the rest of the community on their ideas and progress.

The 4.5-day combined intensive ends with a community celebration. The health and development of our community is enormously important, and is supported by informal meals, different ways of mixing participants during workshops, and the retreat-like setting of the intensives. The final celebration is an occasion for savoring new and renewed friendships and collaborations.

Facilitating Learners Engaged in Inquiry *(~half day)*
Teams with activity designs that are more fleshed-out and closer to being taught begin to focus their attention on the teaching and facilitation of their activities. In a short sequence of workshops, participants role-play common scenarios that they may encounter, such as working with learners who are "stuck," who are convinced of a misconception, who "get it" early, and so on. Participants also discuss the importance of context-setting and giving clear directions, and have dedicated time to plan these critical (but too often overlooked) transitional elements. They discuss a reading on the craft of facilitation (Institute for Inquiry 2005), in particular facilitation's emphasis on formative assessment, on intervening appropriately, on helping learners along their path without depriving them of their ownership, and on attending to learners' social interactions and needs.

4.3. Inquiry Activity Design

The structure of the intensives provides participants with an opportunity to experience inquiry, reflect on that experience, and begin to put what they have learned into practice by beginning the activity design process. PDP participants are supported in this effort through a variety of means, including workshops and sessions within the intensives, the leadership of experienced returning participants, and design tools and guidance from PDP staff.

Prior to the main intensive, PDP staff members begin support for inquiry activity design by placing all participants in Design Teams. We begin this process by reviewing what teaching venues might be available to our participants in the upcoming year, what disciplines these venues cover, what activities might need to be designed or re-designed within these venues, which participants prefer to work on a Design Team versus a Facilitation Team, and finally which returning participants might be the appropriate leaders for Design and Facilitation Teams. Then, we meet with returning participants and select a cohort of team leaders for the upcoming year. To support them in this role, Design and Facilitation Team Leaders are provided with additional leadership training during the workshop "Preparing to Lead a PDP Design or Facilitation Team" (see also §4.2.1). We note that Facilitation Team Leaders are typically also experienced activity designers and need to have a thorough understanding of an activity design in order to lead a team in planning to facilitate it. Once team leaders are selected, we discuss possible team placements with all of our PDP participants, given their interests and content background.

As discussed earlier, participants begin the process of designing their inquiry activities during the combined 4.5-day intensives. In addition to the formal workshops and sessions on design, we give participants a significant amount of semi-structured time in which to begin designing their activities. We emphasize the process of backward, intentional design. Drawing heavily from the method introduced in Wiggins & McTighe (2005, chapter 1), we ask participants to begin designing their activity by setting goals for their students. These goals should incorporate learning about the content, reasoning processes, and attitudes of science or engineering. We then ask participants to consider what would count as evidence that their students are learning and improving according to the goals that have been set. In other words, what do participants expect their students to know and be able to do? Finally, participants begin to map out what their students will do during the activity, thinking carefully about the rationale for each element of the activity. Participants are expected to make intentional choices during the design process, considering results from education research, knowledge of effective practices in teaching, and the PDP focus areas of inquiry, assessment, and diversity/equity (§3). In reality, the design of an inquiry activity often requires several iterations and the overall process can be non-linear, but this "backward" method—beginning with goals and then mapping out the activity itself—provides an excellent way to start.

We also provide participants with tools to assist their design process. The primary tool is a Design Template that is graphically laid out to help participants follow the model of backward design as they work on their activity designs. Accompanying the Design Template is a Template Guide, which has helpful prompts and assists participants in making intentional design choices during each step of the design process. These documents are included in Appendix A.

Finally, we provide each Design Team with guidance and support by assigning a PDP staff member to work with each team. These "consultants" meet with the team throughout the design time to assess the team's progress, give advice, and to help teams stay focused on the task and the process of backward design. Following the intensives, the staff consultant continues to work with the Design Team, helping them make additional progress throughout the weeks and/or months until they teach their activity.

4.4. Teaching Experience

Regardless of whether they participate in a Design or Facilitation Team, all PDP participants teach an activity and spend a significant amount of time planning for that teaching experience. This gives participants an opportunity to put their new ideas about teaching and learning into practice. PDP participants teach in a wide variety of venues. In the most recent cycles, Design Teams worked with a range of learners that included high school students, community college students, university undergraduates, and science and engineering graduate students, post-docs and faculty. Teaching venues included semi-formal courses, residential summer programs, formal college courses, and technical courses for professional scientists and engineers.

Many PDP participants have designed and taught activities for undergraduate students in semi-formal laboratory courses, often called "short courses." These semi-formal courses often have a less structured curriculum and thus provide our participants with the opportunity to be innovative in both the method of instruction and the content covered. As a natural progression, more PDP participants are now designing and teaching activities for standard college and university laboratory courses. Though these formal courses have more constraints than the semi-formal courses, they have the advantages of: (1) providing PDP participants with a venue that may be more similar to those they will encounter in their future careers as faculty, and (2) impacting a greater number of undergraduate students by institutionalizing the new inquiry activities within colleges and universities. The migration of PDP activities into formal courses has posed many challenges to the PDP community, and has been a gradual progression. Introductory courses (e.g., the first year chemistry or physics courses) are often critical to the retention of students in science and engineering, and inclusive inquiry experiences could significantly enhance these courses. However, integrating curricular innovations into introductory courses is complex and involves departments or other institutional stakeholders. The courses are large, with many lab sections offered, and the curriculum is tightly defined. The PDP community has found that upper division and/or elective courses are more amenable to curricular changes. In the longer term, it is hoped that with time and examples of success in the upper division courses, the opportunity for innovation in the introductory courses will grow.

Inquiry activities designed through the PDP are listed in Appendix B.

Regardless of the venue, PDP participants' teaching experiences are unique compared to many other types of teaching experiences in three substantial ways. First, as mentioned earlier in the paper, we emphasize the use of facilitation techniques as a primary teaching method. Next, we provide our participants with support and guidance before, during, and after their teaching experience, in the form of workshops and direct mentoring from PDP staff. Finally, PDP participants team-teach their inquiry activities with the other members of their Design or Facilitation Team.

4.4.1. Facilitation

As discussed in §2.1, a primary theme within the PDP is learning to teach inquiry activities using facilitation techniques, which focus on assisting learners on their own path to understanding. We help our participants think about how to accomplish three primary goals of facilitation (Institute for Inquiry 2005): assessing their learners' current understanding, intervening in a manner that shows respect for their learners' own investigation pathways, and attending to social interactions between learners so that all students are able to fully engage with the inquiry process. PDP participants learn to track their students' progress through careful observations and informal questioning and conversations. They may also model success and give students hints and encouragement without explicitly "giving the answer" (King 1993). Facilitation provides an excellent opportunity for formative assessment of students' progress (Harlen 2003): this in-the-moment dialogue gives instructors continual feedback on students' knowledge gains.

4.4.2. Support from PDP Staff

Teams are also supported in their teaching by a PDP staff member or experienced returning participant acting in the role of a "teaching consultant." Before the activity, the consultant helps the team finish final preparations, alerting the team to any aspects of their planning which may need more attention. During the activity, s/he observes the team's teaching and provides advice and guidance as needed. Finally, after the activity is over, the consultant helps the team reflect and debrief on the entire process of activity design and teaching.

4.4.3. Team Teaching

In many traditional science and engineering teaching experiences, teaching is done solo. However, we prefer to give our participants practice teaching as a team. Team teaching gives them an opportunity to discuss, reflect, and learn from one another throughout the preparation and implementation of their activity. This also allows for participants to individually gain confidence in preparing and teaching without feeling solely responsible. Additionally, because Design and Facilitation Teams usually consist of a mix of first-time and returning participants, team teaching passes on the experience and knowledge of the returning participants to the first-time participants. This sets the stage for the transition of leadership in upcoming PDP cycles. Finally, working collaboratively on teams to design and teach inquiry activities helps to establish the overall community of scientist- and engineer-educators that can consult each other about learning and teaching in the future. PDP staff model this collaborative method of designing and teaching in the way that we plan and instruct the workshops within the intensives.

4.5. Reflection on the PDP Experience

All PDP participants reflect on their experience after teaching their inquiry activity. Just as it is critical to reflect on inquiry before designing an inquiry activity, it is also critical for participants to reflect on the challenges and accomplishments of designing and teaching their activity. Participants also reflect more broadly on their overall PDP experience as a crucial part of becoming scientist- or engineer-educators.

The process of reflection begins immediately after the activity is taught, when teams debrief with their teaching consultant. This debrief includes a discussion of how the activity went and what challenges and successes the team experienced. Teams reflect more deeply on how well they felt they achieved the Design or Facilitation Task, and on how they focused on and supported particular inquiry process skills. Following the debrief, each participant fills out a post-teaching report on the design and teaching of the activity. This form also begins the process of planning for the next year, as participants consider what might be improved on in the activity design or facilitation plan.

Finally, the report also solicits participants' thoughts on their overall experience within the PDP. This provides participants with an opportunity to consider how the PDP has impacted them and what they have gained through their participation. Furthermore, it lays the groundwork for thinking about whether they are interested in continued PDP participation in upcoming years and what new knowledge they may take with them into their future careers.

We use our participants' reflections to guide our planning for the next PDP cycle. We adapt and modify the PDP each year, drawing in part from the feedback the community provides us during this reflective time. We use this time to talk with participants about their interest in continued participation and leadership roles in the upcoming PDP cycle.

Within the PDP, reflections and debriefs are not just about finding flaws or celebrating successes. Rather, participants are learning and practicing the process of self-assessment: stopping to consider what has or has not worked and why. PDP workshops emphasize the notion that an educator should approach teaching and learning critically—teaching should be approached systematically and intentionally. Reflections and debriefs serve to make sure participants consider what happened at least as systematically as they had considered their plans.

5. Outcomes from the PDP

Outcomes from the PDP fall into the four broad goals outlined in §2:

- Development of scientist- and engineer-educators
- Illustrating inquiry
- Establishing infrastructure
- Effecting broader change

Below, we describe some of the most notable outcomes relating to each of these goals.

We emphasize that the entire *Learning from Inquiry in Practice* volume that this paper appears in is a major outcome of the PDP, containing proceedings that reflect the work and leadership of many PDP participants. While this paper provides a stand-alone description of the PDP for the broad community of science and engineering educators, researchers, and policy-makers, it also provides an introduction to the PDP within the volume. Therefore, within our formal description of PDP outcomes, we also include references to each of the papers that follow in these proceedings.

5.1. Development of Scientist- and Engineer-Educators

Since its inception in 2001, the PDP has served 255 participants, who have in turn designed and taught $\gtrsim$60 inquiry activities through their involvement with the program (these activities are listed in Appendix B below). Through participation in the intensives, experience designing and teaching an inquiry activity, and then reflection, participants make progress in the following areas described in §2.1: 1) designing inquiry activities; 2) optimizing learning; 3) facilitating learners; and 4) growing more intentional. All participants in the PDP actively design an inquiry activity, and then teach the activity in a venue where they have the opportunity to facilitate learners as they engage in inquiry. Throughout the PDP, staff members formatively assess PDP participants' progress—first in their design work, and then later when they teach. Participants complete design templates, report on their designs at multiple points, discuss their designs with staff consultants, and often maintain an electronic record of their progress. This open and transparent design process allows multiple points for staff to assess and intervene if necessary, and ultimately ensures that all participants clearly articulate learning goals and form a general plan that aligns with inquiry learning. At a more detailed level, participants' designs vary in how closely they align with the PDP inquiry framework. Almost all participants design an activity that engages their learners in inquiry processes, and provides for learners to have ownership over their process. The more accomplished designs give learners practice with a specific inquiry process that reflects authentic research, while simultaneously gaining an understanding of important scientific concepts. Less accomplished designs may try to incorporate too many general inquiry processes, or may fall somewhat short on content, or in some cases end up more guided than had been intended. However, participants reflect on their designs, and their facilitation, and so come away from each PDP cycle with a better understanding of how to design, facilitate, and assess inquiry.

In addition to observations by staff and participants' documentation of their activity designs, an education researcher led a study documenting the inquiry learning that occurred in a PDP teaching venue (Ball & Hunter paper on inquiry and implications for the research setting, this volume). In this study, the lead researcher recorded multiple inquiry activities while PDP participants facilitated them. The study included an examination of how and when learners engaged in explaining, or the early stages of generating scientific explanations (an important inquiry process). Opportunities for learners to take initiative as they were participating in the inquiry activity were also recorded. Instances of explaining and initiating were quantified and compared to how learners engaged in these two practices while completing a formal, mentored research project. Findings indicated that the rates of both explaining and initiating were higher in the PDP inquiry activities than in the research experience. The extensive documentation of learners engaged in explaining, and the PDP participants' facilitation, is compelling evidence that PDP participants are successfully designing and implementing inquiry activities.

PDP participants are all expected to include consideration for diversity and equity in their activity designs and teaching practice; this falls under the broad PDP participant goal of "optimizing learning." There are specific sessions to inform them of relevant issues, expose them to inclusive teaching strategies, and to facilitate the integration of inclusive teaching practices in their own design and teaching. An assessment was designed to gauge participants' increase in understanding about how they could engage diverse learners through their teaching and research, using an open-ended prompt that was given before and after the PDP workshops. The prompt asked participants to briefly describe how they would engage a diverse undergraduate student population through their teaching and research. A total of 98 pairs of pre- and post-workshop responses from two different PDP years were analyzed, scored, and compared (Metevier et al., in the Research and Evaluation section of this volume). The analysis and scoring used a rubric based on the PDP Diversity & Equity Focus Area (in fact, it was a main stimulus for developing the Diversity & Equity Focus Area and was the first version of the five "emphases," which later evolved into the current form reported in §3.2). Two authors scored the responses, blind to pre/post and new/returning participation status, and established a satisfactory inter-rater reliability. Results from this analysis showed a significant improvement in participants after participation in the PDP, indicating that the PDP training does improve participants' understandings about how to teach inclusively.

In order to assess the effect of the PDP on participants after their participation, we sent out a survey to gather information on the long-range impact of the PDP, and we summarize some of those results here. Of the 255 people who have participated in the PDP over the past 10 years, we regard 118 of those as "primary" participants who have completed at least one full cycle of PDP training, activity design, and teaching activities during the years 2001–2009; and who participated in the PDP while they were either a graduate student or postdoctoral researcher. (We note that particularly in the earlier years of the PDP, some participants received partial training through the program but did not necessarily design and teach an inquiry activity). Of the primary participants, 60 responded to our long-range survey, giving us a ∼50% response rate.

As part of the survey, participants were asked to rate the value of various aspects of the PDP on a four-point scale, with 0 = not valuable, 2 = somewhat valuable, and 4 = extremely valuable. Some of the highest rated aspects of the PDP are:

- Being part of a scientist-educator community (mean response: 3.6)
- Learning how to teach inquiry (mean response: 3.6)
- Having an opportunity to design and teach something of your own (mean response: 3.6)

These responses indicate that participants strongly value the PDP community and the opportunity to spend time on teaching as part of their career training. One of the lower-rated aspects of the PDP was "Learning how to advise and/or mentor students doing research projects," which received a mean response of 2.6. While participants still found this aspect of the PDP valuable, it is possible that we could do a better job of explicitly linking inquiry activity facilitation to advising students in a formal research setting. This might generally make the connection between the education and research sides of our participants' career training clearer, as well. Participants' rating of the overall value of the PDP experience was very high, with a mean rating of 3.7.

Since their participation in the PDP, many of our participants have received prestigious postdoctoral positions, and 15 participants (10 of these are "primary" participants) have now moved on to tenured or tenure-track faculty positions. Clearly, there is much potential for the PDP to benefit not only our participants, but also their current and future students. On our long-range survey, we asked participants to rate the impact of the PDP on various aspects of their careers, now using a four-point scale with 0 = negative impact, 2 = neutral, and 4 = positive impact. Participants' responses indicate that the PDP has had a notably positive impact on:

- Enhancing your job qualifications (mean response: 3.5)

- Valuing education as a part of your career (mean response: 3.6)
- Overall impact of PDP on career (mean response: 3.3)

We do not have the space to share the full results of our survey here, but we intend to do so in a future publication.

5.2. Illustrating Inquiry

As stated earlier, members of the PDP community have designed and taught $\gtrsim$60 inquiry activities (see Appendix B). These activities span a wide range of disciplines and are designed for educational levels from high school to the graduate level, with many aimed at the undergraduate level. Inquiry activities have been taught in informal and formal settings, in some cases using an informal setting to pilot an activity for later use in a formal classroom.

The collection of papers in this volume demonstrates the diversity of designs created by the PDP community. The range of content taught through PDP activities is very broad, including topics such as stellar populations (Rafelski et al., this volume), telescope design (Sonnett et al., this volume), molecular biology (Quan et al. paper on "Central Dog-ma" activity, this volume), fluid dynamics (Traxler et al., this volume), and vision science (Putnam et al., this volume). The community has grappled with the unique challenges posed in designing inquiry activities across disciplines such as biology (Petrella et al., this volume) and engineering technology (e.g., Morzinski et al. paper on circuit design activity, this volume). PDP teams have demonstrated models for inquiry to overcome other curricular challenges that are present across a range of disciplines, such as inquiry learning with hardware systems (e.g., Harrington et al. and Ammons et al., this volume), and with content that could not be investigated directly with physical objects (e.g., Montgomery et al. paper on galaxy activity, this volume). Activities have been designed for high school students (e.g., Yuh et al. and Dorighi et al. papers on bacteria activities, both in this volume), community college students (e.g., Mostafanezhad et al. paper on CCD activity and Morzinski et al. paper on digital image activity, both in this volume), four-year university undergraduates (e.g., Dorighi et al. paper on PCR activity, this volume), and graduate/professional level audiences (e.g., Do et al., this volume). At the college level, activities have been designed for science majors (e.g., Rogow et al., this volume), as well as non-majors (e.g., Putnam et al. paper on lens activity, this volume). The format of activities has followed traditional three-hour lab periods (e.g., McConnell et al., this volume), 6–8 hour activities spread over two days (e.g., Kim et al., this volume), and multi-week student projects (Bresler et al., this volume).

Within the PDP community, staff, participants, and researchers (studying the PDP) have identified challenges to implementing inquiry activities, and have either developed or observed strategies to make inquiry successful. As noted earlier, observations of PDP participants during their teaching experience yielded interesting findings about both the PDP participants, and their learners (Ball & Hunter, this volume). The learners often were not immediately ready to engage in inquiry learning. They arrived with expectations and classroom habits that made it difficult for them to engage in the kind of self-directed learning that PDP inquiry activities require. However, it was also observed that through careful design of the curriculum, PDP participant-instructors overcame the barriers, using specific strategies such as setting the context for inquiry, sequencing activities, and carefully timing facilitation moves. Over the years, participants have created their own innovative solutions to overcoming barriers to inquiry learning, such as very brief facilitated brainstorming sessions with learners that served to establish expectations and classroom norms (Sonnett & Montgomery, this volume). Full activities have also been developed to help students transition from more traditional modes of teaching and learning to the experience and expectations of an inquiry learning environment (e.g., Seagroves, this volume).

Inquiry activities have been used to accomplish goals that go beyond learning scientific content and processes. A number of activities have been designed to engage students transferring from community college into a university (e.g., Kretke et al., this volume). Programs aimed at motivating high school students to pursue science/engineering majors have been designed by PDP participants (e.g., Cooksey et al., this volume), and have integrated a number of PDP activities (e.g., Raschke et al. paper on optics activity and Quan et al. paper on astrobiology activity, both in this volume). Activities have been incorporated into special courses designed to prepare college students for research (e.g., Montgomery et al. paper on the Akamai Maui Short Course, Rice et al. paper on the Akamai Observatory Short Course, and Metevier et al. paper on the Hartnell Astronomy Short Course, all in this volume), as well as short programs to recruit prospective graduate students (e.g., Jacox & Powers, this volume). Through the design and implementation of this diverse range of activities, the PDP community has demonstrated that inquiry learning is broadly applicable, and can accomplish many valued educational goals.

5.3. Establishing Infrastructure

Through ten years of an evolving program, the PDP has produced tools, methods, professional development curricula, and a community, all that enable and empower participants. This infrastructure can be used in the broader community. Tools include frameworks, templates, reading materials, models, handouts, and other concrete items that the community uses. Methods include the ways that we accomplish the goals of the PDP, ranging from our philosophy to the lessons learned about how to carry out the particular professional development in our arena. Our curriculum includes the large to minute details that make up each of our intensives, workshops, and sessions. Finally, we consider the PDP community part of the infrastructure and an essential part of the success of the PDP.

From ten years of an evolving design, the PDP staff and participants have developed many tools that are integrated into our curriculum at all levels. A PDP design template and guide (see Appendix A) provides structure for inquiry design while still encouraging creativity. Our articulation of primary focus areas and emphases within the PDP (see §3) provides reference points for work on inquiry, assessment, and diversity/equity. As PDP participants have expanded into teaching in new areas, we have created new tools to support their work. For example, the expansion into engineering education led us to collaborate with the Akamai Workforce Initiative to develop a new framework for engineering technology skills (Seagroves & Hunter, this volume). We have developed many handouts that are either used in workshops or read before participation, and include carefully written scenarios that participants can analyze and templates for encouraging reflection.

A significant aspect of the PDP infrastructure is our method—how we go about doing what we do, and how we overcome the challenges that inevitably arise in teaching, learning, and professional development. This paper and our earlier paper (Hunter et al. 2008) give high-level perspectives on our methods. We have also articulated our values and the unique attributes of the PDP (Seagroves et al., in the Perspectives section of this volume), and the priorities that significantly shape our methods. In addition, our 2008 paper includes a section that outlines some of the specific challenges for participants (pages 19–21), and how we support participants so that they can reach the intended learning outcomes. These methods include knowing participants' common prior understandings about and experiences with teaching and learning, and having strategies for dealing with them when they become constraints. For example, participants may arrive at the PDP with some exposure to inquiry and even view it as a method for teaching scientific processes, but they may not recognize its value in teaching scientific content. One of our most important methods for changing this view is to give participants a personal experience in inquiry, and an opportunity to reflect on the experience. Telling participants about inquiry, in our experience, is not enough—they must experience it as a learner before they can design an inquiry activity. The importance of experience and reflection was also one of the findings in the Ball & Hunter research described above. Their study suggests that it was PDP participants' experience of producing and applying their own understanding of inquiry that was key to the transformational experience.

The PDP's curriculum—the intensives, workshops, and workshop sessions—are exhaustively documented: hundreds of pages (bound into "Staff Guides" for each intensive) describe the design and delivery of every professional development workshop we offer, while hundreds more pages (bound into companion booklets) encompass handouts, readings, and other supplemental material. PDP Staff Guides are internal documents, used by the staff team to implement PDP intensives. In addition, the PDP staff team writes up workshops, or thematic clusters of workshops, to disseminate more broadly. While not at the detailed level available in Staff Guides, published papers describe the goals, structures, and other important details of these workshops, such as common pitfalls. For example, the "Improving Process Skills" workshop (Quan et al., Professional Development section of this volume) describes successful strategies for helping PDP participants first articulate an inquiry process learning goal, and then design an activity in which learners improve their skills with that process. Lessons learned include the importance of engaging participants in an authentic design experience rather than just telling them about it, or engaging them in a fabricated scenario. The PDP's workshops on diversity and equity, including how they evolved over time, are described along with the PDP Diversity & Equity Focus Area (Hunter et al., also in the Professional Development section of this volume). A somewhat different example is a paper describing an important element of inquiry activities, the inquiry "starter" (Kluger-Bell, this volume), which piques learners' curiousity, generates questions for further investigation, and defines the content area of the activity. Kluger-Bell's paper describes the goals, elements, and important attributes of starters, along with several concrete examples.

One of the most valued aspects of the PDP is the community. PDP participants indicate in many ways how much they value being part of this particular community and the experience it provides. As described above, alumni of the PDP reported that being part of a scientist-/engineer-educator community was one of the most valued aspects of the PDP (average value rating 3.6 out of 4), and could be differentiated from merely "being part of any community"; in fact, in our long-range survey, a lower value rating was given to "being part of any community" (average value rating 3.1 out of 4). Comments on post-PDP surveys also reveal that being part of the community is extremely important to participants. They feel like valued contributors and have a sense of ownership and agency within the community.

Community is an essential part of the PDP infrastructure, but is hard to identify, describe, and demonstrate. Broadly speaking, community can be considered a strategy for accomplishing a desired outcome, or community can be the outcome—within the PDP it is both. Community is one of the ten major aspects or attributes that distinguish the PDP and is further described in Seagroves et al. (Perspectives section of this volume). Like other communities, the PDP community exists within, is shaped by, and overlaps with, other communities and organizations. The PDP was originally embedded within a prestigious science center (the CfAO) that exerted pressures to conform to long-standing expectations and norms, yet was part of an education program that was charged by the funding agency to be innovative and to challenge existing norms. Over time the PDP community grew to exert its own pressure outward, influencing others and challenging norms and practices. Authors of an organizational study (Ball & Hunter, another paper in this volume) reviewed institutional records and documented the changes that occurred within the CfAO as the education program became increasingly successful. The study found that the PDP community played a significant role in this success, negotiating and capitalizing on the tensions that existed at the boundaries of the various communities. In addition, the authors posit that inquiry was a fulcrum for change, and acted as a "boundary object" that is used in different ways by different communities, having a common identity but interpreted differently depending upon the community (Star & Griesemer 1989). In this case, the PDP generates its own community of participants that draws from a community of early-career scientists and engineers, who in turn interact with the larger community of established science and engineering researchers.

5.4. Effecting Broader Change

The last major goal of the PDP is to influence the larger science and engineering community to think innovatively about education—in particular, to reconsider the traditional relationships between teaching and research and between the natural and social sciences, and to reconsider the inclusiveness of their practices. PDP outcomes related to this goal include the impact of PDP participants interacting within their other communities to effect change, and the rippling effect that occurs as they advance in their careers and initiate their own education work. In addition, the PDP is a rich environment that has opened new collaborations that span disciplines and sectors. As described above, the difference between community as a strategy, and community as an outcome, is blurry; thus there is overlap between this section and the discussion of how the PDP community is part of an infrastructure in the prior section.

Although the primary focus of PDP participants is on designing and teaching an activity (or unit) that gets integrated into a course or program, the PDP community has expanded upon this to develop courses, and even full programs. The Akamai Workforce Initiative is built upon the PDP, and is now funded to run a Hawai'i-based PDP focused on the development of a new Engineering Technology Bachelor's of Applied Science (BAS) degree program. The BAS program will include courses that incorporate inquiry lab activities, and integrate PDP teams as visiting instructors. In the first phase of this work, interviews with high-tech companies (future employers of the graduates of the new BAS program) yielded strong support for inquiry, with an emphasis more toward problem-solving. From these interviews a new framework for engineering technology process skills (Seagroves & Hunter, this volume) was developed which is used by AWI to develop courses, and is now integrated back into the PDP. A second new program utilizing inquiry learning, this time at the graduate level, is also in the planning phases by a member of the PDP community (Sheinis et al., this volume).

PDP participants also learn about, and pursue, the practice of professional development. The PDP curriculum and methods open opportunities for participants to hone their own skills as professional developers, both within and beyond the PDP. PDP participants who return for a second cycle (or more) have the option to apprentice with the PDP staff team in some of the workshops. For example, many participants receive training and then lead a discussion in the "Comparing Approaches: Three Kinds of Hands-on Learning" workshop, either within the PDP, or at other venues arranged through the PDP community. PDP participants have led this workshop on their own in outreach activities, and in science teaching methods courses for pre-service teachers. The experience gives PDP participants many new perspectives and a rich experience (e.g., Rice, this volume). Participants have also developed their own professional development activities, utilizing PDP methods and curriculum. For example, a PDP participant designed a two-day workshop for Mexican teachers using the "Parachutes" workshop, along with other reflective components (Racelis & Brovold, this volume).

The PDP offers a rich environment for education researchers to conduct studies on learning, teaching and professional development, and has been the basis for several studies. A dissertation research project (Ball 2009) centered on the study of the PDP and led to two of the papers in this volume (both papers by Ball & Hunter). The cross-disciplinary nature of the PDP has led to many new collaborations and spin-off projects, as well. PDP teaching teams are formed based on factors that naturally cross the boundaries of disciplines, often bringing together individuals from diverse backgrounds. In a recent example, a team that included graduate students from astronomy, ocean science, and environmental studies designed and taught an activity on fluids and layering. There is an immediate benefit to the team members, as they must learn to communicate and appreciate the different ways that disciplines view a topic, and there are also examples of new opportunities arising from interdisciplinary teams, such as visits and research collaborations. The PDP has also integrated the natural sciences, education, and social science into its activities. An interesting array of projects has emerged from ongoing interactions between CfAO education (primarily through the PDP) and the UCSC Educational Partnership Center (Goza et al., this volume). These projects include and cross boundaries between evaluation, educational assessment, and social science research—often stimulating new questions and methods.

An emerging spin-off area of the PDP is the application of PDP curriculum and methods to mentoring student research. Over the years a number of PDP community members have made connections between the "facilitation" that PDP participants are trained to do while teaching their inquiry activities, and on-the-fly interactions that mentors employ as they work with students engaged in authentic research. Many PDP strategies can be translated to facilitate students' productive engagement in formal research (Severson, this volume) and to design productive research projects.

6. The Future of the PDP

The PDP has been running for ten years, changing and evolving, and growing in demand from graduate students. The program sprung from what seemed like a radical idea, in 2001, to add teaching (in addition to research) preparation to a graduate student's professional development. Many questioned whether science and engineering graduate students would even be interested in such a program. The PDP has shown that they are not simply interested, they are eager for it. Today's graduate students know that there are serious deficiencies and challenges in all levels of education. They are preparing for careers in which they will impact thousands of undergraduates through their own teaching and mentoring, and they want the skills and knowledge to teach well when they become the next generation of college and university faculty members.

The success of the PDP has led to the continuation of the program in the two regional areas it has served for many years—California and Hawai'i. In California, the PDP continues through the UCSC Institute for Scientist & Engineer Educators, where it is now being integrated into graduate training. In Hawai'i, the PDP is a core activity in the Akamai Workforce Initiative, which includes a PDP focusing on engineering technology, astronomy, and the fields related to the growing astronomical facilities in the state of Hawai'i.

6.1. Institute for Scientist & Engineer Educators (ISEE)

ISEE was launched in 2008 to institutionalize the PDP as a program to be offered broadly to the science and engineering community at UCSC. The PDP is a major program within ISEE, and is at the heart of almost all other programs and activities, as it was with the educational arm of the CfAO. ISEE is developing several certificates, the first formalized one being a Certificate in Teaching Innovative Laboratory Experiences. Participation in the PDP is a major requirement for earning this certificate. ISEE is developing new workshops and courses, and building a research strand so that we can continue to learn more about the teaching and learning related to the PDP, and the broader applications of this teaching and learning.

In the transition from a grant-funded program to an institutional program, the PDP is evolving to include more teaching venues within formal undergraduate courses, and even graduate courses, but continues to find teaching venues in programs and other semi-formal settings an extremely productive "teaching lab" for PDP participants. The format of the PDP within ISEE is also evolving. Financial constraints may require that the PDP move away from residential multi-day intensives toward a series of workshops offered on-campus. The value of a multi-day intensive at a remote site—where staff and participants drop everything else, eat meals together, and find ample opportunity for informal discussions—cannot be overlooked. An outstanding question is how important the retreat format of the past PDP cycles is for inspiring the PDP community and community members' accomplishments.

The ISEE community that is emerging is as vibrant as the PDP community has been, with new leaders emerging and initiating new activities. Graduate students and postdoctoral researchers who work on ISEE-related projects, "ISEE Fellows," meet weekly to share their progress and get input from other Fellows. One ISEE Fellow created a journal club, which meets monthly to discuss education research journal articles.

The enthusiasm, commitment, and innovation demonstrated by ISEE participants and staff creates a momentum that will likely keep ISEE funded and growing.

6.2. Akamai Workforce Initiative (AWI)

The PDP model is also a key component of the Akamai Workforce Initiative (AWI) in Hawai‘i, which will focus on the development of a new engineering program, bringing in PDP participants as designers and visiting instructors for new laboratory courses at the University of Hawai‘i – Maui College. The PDP element of AWI is run by ISEE, and to date has remained integrated into the ISEE PDP, continuing the long tradition of collaboration between the University of Hawai‘i Institute for Astronomy/Maui and UCSC. Funding from the National Science Foundation and the Air Force Office of Scientific Research will continue the Hawai‘i-based PDP through 2014.

The particular needs and opportunities of Hawai‘i are also creating changes within the PDP, and spinning out new projects. The AWI focus on engineering technology has brought increased attention to the similarities and differences between engineering and science, which has required changes in PDP workshops. AWI is closely tied to industry, and the PDP teaching venues are often aimed at preparing students for work in the high-tech industry and astronomical observatories. The AWI interest in industry needs has been a new and expanding area of work, starting with inventories of desired skills (Hunter, Hoffman, Armstrong, Reader, Seagroves, & Raschke 2009; Seagroves, Hunter, & Armstrong 2009), and leading us to create an engineering technology skills framework (Seagroves & Hunter 2009, and Seagroves & Hunter, this volume), which feeds back into the PDP participants’ work to help them focus on designing activities aimed at teaching industry-related skills. A further evolution in this vein is a pilot project, Promoting Engineering Problem Solving Through Argumentation and Reasoning (PEPSTAR), which is aimed at improving engineers’ ability to generate well-conceived solutions to technological challenges. PEPSTAR overlaps significantly with the PDP, using its infrastructure, integrating with the PDP community, and feeding new tools back into the PDP.

7. Summary

Out of ten years of funding through the CfAO, the PDP has grown into a dynamic, evolving, highly successful program that develops early-career scientists and engineers into innovative scientist-educators and engineer-educators. The PDP illustrates inquiry as a teaching/learning strategy in higher education science/engineering laboratories and builds tools, infrastructure, and community to support innovation in university science/ engineering teaching. The PDP has effected broader change in the institutions it is associated with; as PDP alumni move forward in their careers, they effect even broader changes at new institutions. The PDP continues to develop, adapt, and expand through major new programs such as the Institute for Scientist & Engineer Educators and the Akamai Workforce Initiative.

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Appendix A. Design Template

The Design Template is a significant tool developed to support PDP participants as they work on their inquiry activity designs. We have constructed the template to help participants use the "backward design" strategy (Wiggins & McTighe 2005, chapter 1), considering their students' backgrounds and starting their design by articulating learning goals that incorporate the content and process knowledge they want their students to gain. Through the template, we encourage partici- pants to consider the evidence they will look for, as they teach, that will indicate their students are achieving these learning goals. We encourage participants to build off of the "Light and Shadow" inquiry activity model they experienced during PDP workshops, bringing in considerations from the PDP Focus Areas of inquiry, assessment, and diversity/equity (§3). We also prompt participants to articulate their facilitation strategy and plans.

On the following pages, we present:

- The PDP Activity Design Template
- Page 1 of a Guide to the template, with prompts to help PDP participants develop their designs
- Page 2 of a Guide to the template, with prompts to help PDP participants connect their design plans to considerations from education research and best practices. Specifically, participants are prompted to consider input from the *How People Learn* framework and the three PDP focus areas of inquiry, assessment, and diversity/equity (§3).

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PDP ACTIVITY DESIGN TEMPLATE

Design Name: ____ Date: ________________

Audience: _________________________________ Designers: _________________________________

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PDP ACTIVITY DESIGN TEMPLATE: GUIDE

Below are some prompts to help you use the Design Template productively as you decide on learner goals and plan what you and your students will do during your activity.

TEACHING AND LEARNING CONTEXT

GOALS AREA

What do you expect your students to know and be able to do?

Be descriptive as you state the following types of goals:

- **Content:** science/engineering concepts
- **Process (cognitive):** science/engineering critical reasoning skills

Your learner goals should reflect the fact that in an inquiry activity, both content and process skills are equally essential.

Also, be sure that your goals mirror the type of learning that happens in a research setting.

Other types of goals that you may want to include:

- Attitudes: may relate to students' sense of belonging in the science/engineering community, or their self-confidence or self-efficacy
- Nature of science: understandings about how science/engineering are practiced, e.g., understanding the difference between observations and inference.
- Technical process skills: e.g., soldering, titrating

EVIDENCE AREA

How will you and your students know if they are reaching your goals?

What will you look for as evidence that they are making progress?

What would you like your students to include in an explanation of their new understandings?

Are their multiple ways in which students could demonstrate their understandings?

GOALS

EVIDENCE

Rationale

ACTIVITY DESCRIPTION

Setting the context

Consider how you will convey:
- that this activity mirrors authentic research
- high expectations for your students' ability to succeed

Inquiry starters

Do the starters motivate students and lead them toward the content and processes of the main activity?

Are there multiple ways for students to engage?

Will you tie your starters to learners' backgrounds and interests?

Focused investigation

How will your students move toward new understandings?

How will they work together?

What processes will they engage in as they learn new concepts?

What lines of reasoning will they pursue as they move toward new conclusions?

Are multiples investigation paths possible?

Sharing understanding

How will students demonstrate their new understandings to you and to each other?

Are there multiple ways for students to communicate what they have learned?

Synthesis

How will you summarize the content (and processes) your students learned?

Can you reference each investigation group's accomplishments?

Can you provide opportunities for students to reflect on what they have learned?

FACILITATION PLAN

Setting the context

Consider how you will convey:
- that this activity mirrors authentic research
- high expectations for your students' ability to succeed

Inquiry starters

What do learners need to notice in starters, and how will you get them to notice?

What kind of info can you elicit about students' prior knowledge, for formative assessment?

How will you facilitate the transition from starters to investigations?

Focused investigation

What content should be learned at each station?

What will indicate to you that each learner has gained their own understanding?

How can you help your students learn from each other?

Are there common misconceptions or unproductive investigation paths?

What strategies will you use to make your students' thinking visible?

Sharing understanding

What are your expectations for sharing, and how will you convey them?

How will you support your students in using evidence in their claims as they prepare to share?

Synthesis

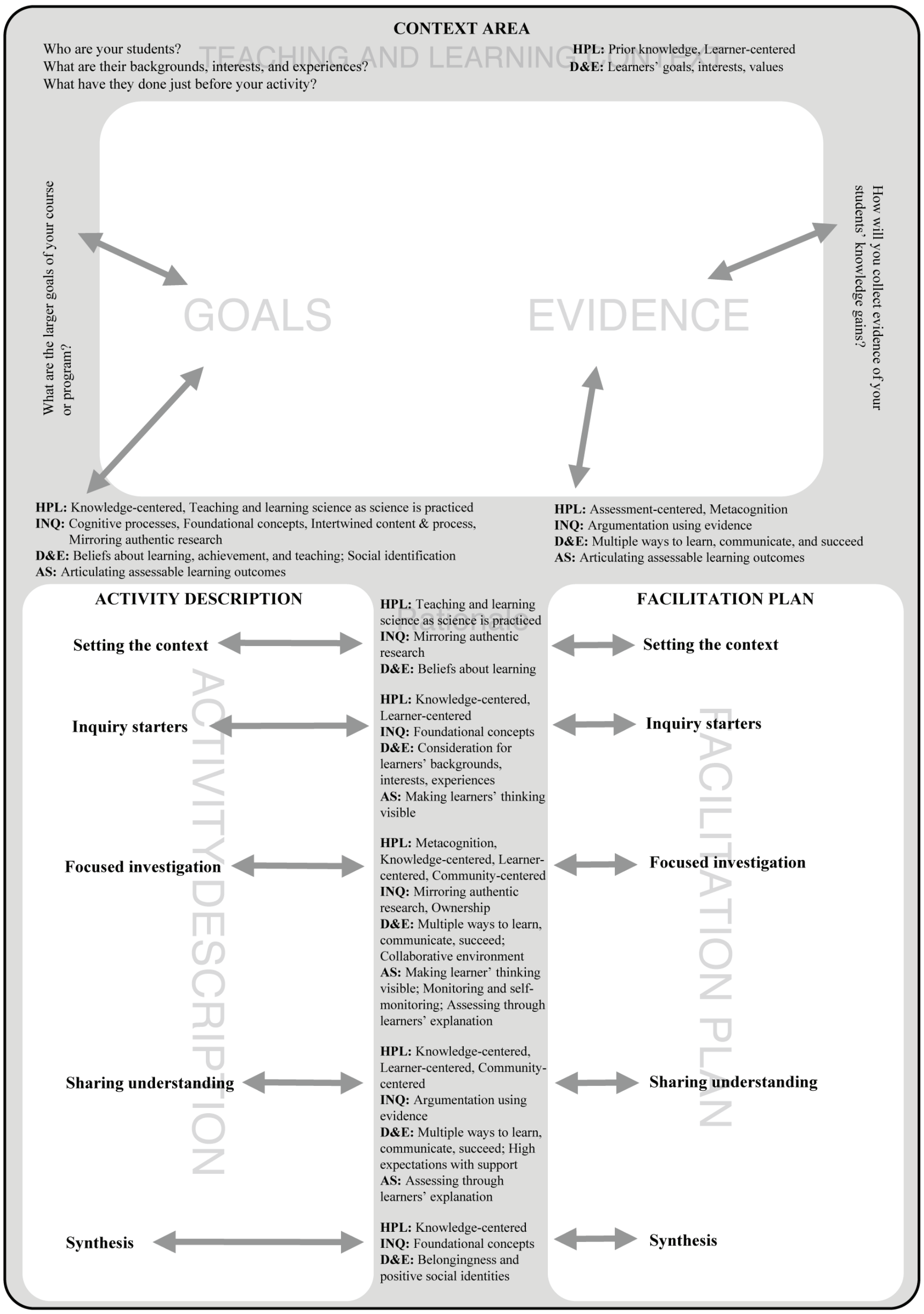
How will you reinforce individual and collective understandings?

How will you correct any misunderstandings?

How will you foster reflection on processes used to learn content?

PDP ACTIVITY DESIGN TEMPLATE: Considerations from theory and practice

Below are some links to the How People Learn **(HPL)** framework and ISEE focus areas on inquiry **(INQ)**, diversity & equity **(D&E)** and assessment **(AS)** to help you think about *why* you are making your design and facilitation choices.



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Appendix B. Inquiry Activity Designs

These are the inquiry activities that teams of PDP participants have designed, taught, and in some cases redesigned. They span a wide variety of science and engineering disciplines and are designed for a range of audiences. See §5.2 for more discussion of this diversity in activities.

For Undergraduate Learners

- Stellar Populations
- Galaxy Morphologies in the Hubble Ultra Deep Field
- Mystery Galaxies
- Galaxy Clusters: Mass vs. Visible Light
- Galaxy Components
- Recipe for a Galaxy
- Spectroscopy Astronomy Lab
- Transiting Planets
- Photometric Calibration and Transiting Planets
- Color, Light, and Spectra
- Light, Color Addition, and Color Subtraction
- Lenses and Refraction
- Camera Obscura and Pinholes
- Light, Optics, and Telescopes
- Compound Pendulums
- Resonant Pendula
- Fluid Dynamics
- Water Lab
- Wavefront Correction
- Understanding Adaptive Optics
- Electronic Detectors
- Digital Image Files
- CCD Models
- Circuit Design
- Spectrograph Design
- Telescope Design Challenge
- Solar Intensity Monitoring System
- Retinal Anatomy
- Physiology and Optics of the Human Eye
- Color Perception
- Central DOG-ma Disease Detectives
- Biological Imaging: Understanding Image Files
- UCSC CSI: Understanding DNA
- DNA in a Box
- Linking PCR to Research
- Growing Bacteria

- A Walk in the Woods
- At the Tipping Point (Thresholds)
- Ocean Science Lab
- Efficacy of Porous Materials
- Interpreting Spectroscopy Data
- Math Methods for Chemistry

For Graduate and Professional Learners

- Fourier Optics
- Adaptive Optics System Demonstrator
- Adaptive Optics System Design Project
- Human Vision and Aberrations
- Adaptive Optics for Vision Science

For High School Learners

- Variable Stars
- Open and Globular Star Clusters
- Planetary Nebulae
- Classifying Galaxies: Color and Morphologies
- Stars and Color
- Tabletop Optics: Lenses and Mirrors
- Spectroscopy Physical Science Lab
- Lenses and Human Vision
- Visual Perception
- Astrobiology: Extremophiles!
- Bacteria and Viruses
- Ecology in the Intertidal Zone
- Sea Turtle By-Catch

Appendix C. Base Explanation Rubric

This is the "base" rubric that all PDP participants use to develop a more fully-articulated rubric for assessing learners' explanations during an inquiry activity. For more details and references, see §3.3. This document is copyrighted and is reproduced here with the kind permission of ISEE and CfAO.

Rubric structure for assessing explanations in inquiry activities ISEE/AWI PDP 2010

This rubric is meant to guide your thinking about some general features of explanations. But each definition in the rubric has a companion empty area (labeled "e.g.") where you should specify *examples of the kinds of things learners might say in* ***your activity*** *that exemplify that part of the rubric.* In practice, you may need to jot these down on a separate paper for space.

	Off-track (not at all what you wanted) **0**	**Emerging** (partial success, progress) **1**	**Accomplishing** (meeting your basic goals) **2**	**Mastering** (all you hope for in the activity) **3**
The *claim* or *finding* or *new understanding* or *solution* – what did learners "figure out"?	The findings are not stated or are stated inconsistently. *e.g.:*	Simple findings that summarize observations are stated. *e.g.:*	Findings that generalize from observations are stated. *e.g.:*	Findings are stated that generalize from observations and go on to further connect to other understandings. *e.g.:*
The *evidence* or *support* – what information, data, and other evidence supports what learners figured out?	Evidence is not provided or only evidence not related to the claim is provided. *e.g.:*	Insufficient evidence related to the claim is provided. *e.g.:*	Sufficient, relevant evidence is provided. *e.g.:*	Sufficient, relevant evidence plus further relevant evidence is brought in to bolster, enhance, or further test the claim. *e.g.:*
The *reasoning* or *logic* or *argument* or *justification* – links the evidence to the claim; uses appropriate scientific principles for your content	Reasoning is not provided, or it does not link the evidence to the claim. *e.g.:*	Repeats evidence and links to claim, or insufficiently uses scientific principles. *e.g.:*	The reasoning that justifies making the claim from the evidence is provided, and uses sufficient and appropriate scientific principles. *e.g.:*	Multiple sufficient arguments are provided that link the evidence to the claim, including appropriate use of scientific principles. *e.g.:*