Cultivating Scientist- and Engineer-Educators: The CfAO Professional Development Program

Lisa Hunter, Director
Anne Metevier
Scott Seagroves
Jason Porter
Lynne Raschke
Barry Kluger-Bell
Candice Brown
Patrik Jonsson
Doris Ash
# Table of Contents

1. **Introduction** .................................................................................................................................................. 1  
   The motivation for the Professional Development Program (PDP), including a focus on inquiry skills and early-career scientists and engineers.

2. **Overview of the CfAO PDP** ......................................................................................................................... 1  
   The central role of the PDP in the Center for Adaptive Optics education program, and the program-level PDP goals.

3. **Rationale for Inquiry** .................................................................................................................................. 4  
   The definition of "inquiry" within the PDP community, and the reasoning behind the concentration on teaching and learning inquiry.

4. **PDP participants** ........................................................................................................................................... 5  
   The people who participate in the PDP, and goals for these participants.

5. **The PDP Cycle** ............................................................................................................................................. 7  
   An overview of the PDP cycle of activities, in which PDP participants experience inquiry, reflect on this experience, practice designing and teaching an inquiry activity, and reflect on their practice.

6. **Preparatory Training Intensives** .................................................................................................................... 8  
   Details of two “intensives,” or series of workshops, in which PDP participants are trained for their inquiry activity design and teaching experience.
   
   6.1 **Re-Thinking Science Learning and Teaching** ............................................................................................ 9  
   6.2 **Experiencing and Applying Inquiry in Science Learning and Teaching** .................................................. 10

7. **Inquiry Activity Design** ................................................................................................................................ 14  
   The process by which PDP participants work in teams to design inquiry activities, with an emphasis on program support for their design work.

8. **Teaching Experience** ..................................................................................................................................... 16  
   The teaching component of the PDP, including a description of teaching venues and unique aspects of teaching within the program.

9. **Reflection on the PDP Experience** ................................................................................................................ 18  
   The final activity in the PDP cycle, in which participants reflect on their whole PDP experience, so that they can review successess and challenges, and practice thinking critically about teaching and learning.

10. **Support for Participant Progress** ............................................................................................................... 18  
    A review of goals for PDP participants, highlighting challenges participants face and ways in which the program supports their success.

11. **The Evolution of the PDP** .......................................................................................................................... 21  
    Three examples of changes made to the PDP to refine and better support the program-level goals.
12. The Future of the PDP ................................................................................................................23

Plans for advancing the program beyond the lifetime of the Center for Adaptive Optics.

Acknowledgments .................................................................................................................................24

References and Notes..............................................................................................................................26

Appendix A: Design Template and Lens Overlays................................................................................29

Appendix B: Inquiry Activity Designs.....................................................................................................36
1. Introduction

The Professional Development Program (PDP) is at the heart of an education program developed through the Center for Adaptive Optics (CfAO). 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—mostly 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 advanced through large lectures and step-by-step “cookbook”-style laboratory activities. In graduate school and as independent researchers, they may receive little formal training in the research skills of their discipline; 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. They are in a position to teach these skills explicitly and intentionally, so that their students develop research abilities through coursework rather than by happenstance (see participant quote above). As they carefully consider research skills, 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, or inquiry, skills. 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 draw from diversity and equity studies and strategies, critical use of education research, knowledge about effective education practices, and interdisciplinary dialogue. These shared values 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.

2. Overview of the CfAO PDP

The PDP is an innovative program that has been 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 disciplines, and where research
and education are integrated and create bonds between learning and inquiry. Although each STC has its own unique set of needs, resources, and opportunities, they all share a rare opportunity to spend 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-docs).

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 pursuing bachelor’s degrees in the physical sciences and engineering leave or choose not to pursue work or an advanced degree in these fields.

**Figure 1: The CfAO’s two-strand education model.**
The CfAO’s two-strand model, shown in Figure 1, is designed to simultaneously (1) prepare a new generation of scientists and engineers to effectively engage all students when teaching their disciplines, and (2) change the learning experience of students currently pursuing science and engineering careers, in order to retain them. 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. (In Section 8 we briefly highlight some of these activities, which will be the subject of future publications.) The horizontal strand encompasses the PDP, and is aimed at changing the way the next generation will teach undergraduate science and engineering (see participant quote, right). Although the two strands are depicted neatly in the figure, it is the complexity and interplay between the two strands that has engaged the CfAO community for so many years. At the intersection, 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 publication 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 Section 5) 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 run the gamut of university,
museum, and consulting positions, for lack of a better term, we will refer to those who drive the PDP as “PDP staff.”

3. Rationale for Inquiry

Engaging undergraduates in research experiences is widely held as a way to recruit and retain students in science and engineering, 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.

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 (see participant quote above). 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.”

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 engineering 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. Thus what the PDP calls inquiry engages students in simultaneously learning both process and content.

Inquiry is called for in most national reports on improving science and engineering education. Our conception of inquiry incorporates much of what is known about how students learn, and the PDP emphasizes the importance of becoming an informed consumer of education research and effective practices. We display respect for the fields

“ Inquiry is learning science by doing it.”

2008 participant
of the learning sciences\(^a\), and we demonstrate that one can approach teaching and learning as critically as one would approach science and engineering.

As shown in the table below, 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 and an emphasis on discourse, communication, and explanations.

<table>
<thead>
<tr>
<th>Connections Between Inquiry and Inclusive Teaching Practices</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Features of Inquiry</strong></td>
</tr>
<tr>
<td>Facilitators (instructors) employ formative assessment</td>
</tr>
<tr>
<td>Includes different entry/exit points</td>
</tr>
<tr>
<td>Includes various pedagogical tools and participant structures (group work, etc)</td>
</tr>
<tr>
<td>Sets high expectations and supports students to meet them</td>
</tr>
<tr>
<td>Allows students to communicate in their own style but also requires them to communicate in a technical manner</td>
</tr>
<tr>
<td>Student ownership over knowledge gains: “I figured it out by myself. It was empowering.”</td>
</tr>
</tbody>
</table>

4. 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 2008, the PDP has impacted over 200 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.

“Meeting a group of scientists from several disciplines with a common interest in advancing the ways in which science is taught.”

2008 new participant, on what was valuable

\(^a\) 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.
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 faculty, 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 (see participant quotes, right). 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.9 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.”

As discussed in Section 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:

1. **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, 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 knowing, using, and interpreting explanations. Participants’ designs should improve all students’ abilities to productively participate in the practices and discourse of science and/or engineering.

2. **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.

3. **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, 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.

4. **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.

5. **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.

In Figure 2 below, 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 Learning and Teaching* in the fall, then join returning participants for the rest of the program. The four-day spring intensive, *Experiencing and Applying Inquiry in Science Learning and Teaching*, 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 Sections 6.1 and 6.2.)

Toward the end of the four-day intensive, participants begin to 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 Design Task, below, and description
of backward design in Section 6.2). These teams continue to meet regularly throughout the spring/summer to work together on their design, aiming toward teaching their activity in the summer or fall. Each team works with a PDP staff member who facilitates the design process.

Before teaching, PDP participants attend a half-day intensive on facilitation (described in Section 8). Participants then practice their facilitation skills as they teach the activity they designed in a venue supported by the CfAO. These venues serve as “testbeds,” 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 staff facilitator.

After teaching, participants reflect on their experience by debriefing and submitting additional reflections on a written form (see Section 9). They consider all they have accomplished by participating in the PDP: tools, confidence, and community support for teaching science 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.

6. 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 PDP cycle begins with two

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**Figure 2: The PDP cycle.**
intensives: a one-day event in which we inform and recruit new participants, and a four-day retreat for all participants. During the latter retreat, first-year and returning participants sometimes work together and sometimes engage in separate activities. Throughout the intensives, participants are mixed in different ways to encourage community and a broad exchange of ideas.

During both preparatory 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. Participant pathways (Figure 3) and the workshops themselves are described further below.

Figure 3: Participant pathways through preparatory intensives.

6.1 Re-Thinking Science Learning and Teaching

Comparing Approaches: Three Kinds of Hands-On Science (new participants)
In this activity, developed by the Exploratorium’s Institute for Inquiry, 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 the reflective discussions.

**Science of Learning and Teaching: The How People Learn Framework (new participants)**

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. Participants work in small groups, discussing a reading from the *How People Learn* series of summaries. Together they elaborate the three principles of effective teaching and learning that are presented 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. 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 (see participant quote above), though we note that it is not the only framework supported by education research.

**6.2 Experiencing and Applying Inquiry in Science Learning and Teaching**

**Revisiting the How People Learn Framework (all participants)**

Community-building introductions create an informal, social atmosphere, and then the four-day intensive begins with a plenary workshop in which participants discuss 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.

**Light and Shadow Inquiry Activity (new participants)**

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. 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 (see Figure 4). Investigations include cy-
cles 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.

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 (see participant quote, right).

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)*

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. Since returning participants have already experienced the Light and Shadow activity and taught an inquiry activity of their own design, we follow up with a discussion of the different pedagogical aspects of different activity designs, using the *How People Learn* framework to structure the conversation (see participant quotes, right).

**Designing Engineering Activities** *(returning participants)*

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 Team (returning participants)**

Many returning participants will lead inquiry activity Design Teams, so this workshop is focused on the PDP design process 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 Section 7). Participants also consider the social dynamics of productively leading their peers, discussing common problem situations and brainstorming strategies for addressing them.

**Addressing Diversity and Equity (all participants)**

Participants now come together for a series of plenary workshops, beginning with a focus on diversity and equity in science and engineering. This 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 (see participant quote, above right). They then work in small groups, discussing more personal “case studies,” designed by PDP staff and drawn from other sources, which highlight subtleties of equity issues.

As with the *How People Learn* literature, we draw from social science research, assigning readings from the “stereotype threat” and “mindset” literatures. PDP staff members summarize major findings and lead small-group brainstorming sessions, 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, demonstrating that these major components of the PDP are not disjoint but related.

**Practicing Backward Design (all participants)**

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 (see participant quotes above). 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 processes into designs) and a setting (the Light & 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.

**Design Team Working Time (all participants)**

Participants spend much of the last half of the four-day intensive in small Design Teams (Figure 5), working on their inquiry activities for CfAO or partner venues. 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. The PDP design process is further elaborated in Section 7.

Design time at the four-day intensive is interspersed with sessions that provide fresh insight into the activity design process. A few returning participants formally present activity designs they worked on in past PDP cycles, highlighting innovative ideas, successes, and areas for improvement. Halfway through the design period, all Design Teams gather for an informal poster session in which they share their works-in-progress. Toward the end of design time, teams pair up for conferences in which they share their progress and challenges, and provide each other with critical feedback and new ideas. Finally, the PDP staff bring design working time to a close by exposing some of the backward-design elements of the PDP itself.

The four-day PDP 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 this intensive. The final celebration is an occasion for savoring new and renewed friendships and collaborations.
7. Inquiry Activity Design

The structure of the four-day intensive 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. All PDP participants are asked to accomplish the following Design Task: “Teams will design or re-design an 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, including diversity/equity and results from research (such as the How People Learn series of summaries).” 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 four-day 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, and finally which returning participants might be the appropriate leaders for those Design Teams. Then, we meet with returning participants and select a cohort of Design Team Leaders for the upcoming year. To support them in this role, Design Team Leaders are provided with additional leadership training during the workshop “Preparing to Lead a PDP Design Team” (see also Section 6.2). Once Design Team Leaders are selected, we discuss possible Design Team placements with all of our PDP participants, given their interests and content background (see participant quotes, right).

As discussed in the previous section, participants begin the process of designing their inquiry activities during the four-day intensive. 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 the article “What is Backward Design?”14, 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 results from research on diversity and equity in education. 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 (see participant quote above).

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. In addition to the Design Template, we give participants prompts, laid out to mirror the template, to help them consider how different elements of their designs are viewed through the lenses of the How People Learn framework: the learner-centered, knowledge-centered, assessment-centered, and community-centered lenses. These “lens overlays” assist participants in making intentional design choices during each step of the design process (see Design Template and Lens Overlays 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 “design facilitators” meet with the team throughout the design time to assess the team’s progress, give advice, and to help teams stay focused on the Design Task and the process of backward design. Following the four-day intensive, the design facilitator continues to work with the Design Team, helping

**Vignette — Light, Optics, and Telescopes: An Example PDP Inquiry Activity Design**

The products of PDP participants’ design work are inquiry laboratory activities. An example of one of these activities is the “Light, Optics, and Telescopes” inquiry activity. This activity is part of a one-week “short course” for undergraduates who are beginning summer research internships at astronomical observatory facilities.

The activity’s design starts with PDP participants guiding students to interact with lenses, mirrors, and pinholes at three different stations. There the students raise questions about phenomena related to reflection, refraction, image formation, image inversion, and magnification. Next, students form small groups and choose a question for focused investigation. Students explore their question by interacting with additional materials, setting up experiments, recording and analyzing data, making drawings, and testing possible explanations. During this investigation time, one group of students may use a variety of lenses to study the effect of lens shape on image formation, while another group uses a single curved mirror to study how and where concave mirrors form images. Throughout the activity, the groups are assisted by the activity’s designers—PDP participants now act as facilitators. At the end of the investigation, all group members prepare short presentations on their investigation and results. The small groups are then split up, and each group member presents their work in a discussion section of representatives from other investigations. Finally, students apply what they learned to a new situation, a challenge in which they are asked to design either a reflecting or a refracting telescope given a variety of choices of lenses and/or mirrors.

Two intentional design choices PDP participants built into this activity are the mixed-group discussion sections and the telescope design challenge. The designers chose to have students present individually in discussion sections in order to assess the understanding of every member of a given investigation group. Having them present in smaller discussion sections, as opposed to the entire class, also fostered more discussion about the investigations. The second major design choice—the telescope design challenge—was created to gather evidence about whether the students had achieved the goals intended, including the goal that “students can use principles of geometric optics to explain a complex optical system.” The PDP participants wanted to know whether students could transfer the knowledge they gained to a related but entirely new situation.
them make additional progress throughout the weeks and/or months until they teach their activity (see participant quote, right).

8. Teaching Experience

In addition to designing an inquiry activity, we ask PDP participants to teach their activity. This process of designing and teaching provides participants with an opportunity to put their new ideas about teaching and learning into practice.

As the date of their teaching experience approaches, Design Teams transition from primarily focusing on design to focusing on implementing and teaching their activity. PDP participants teach in a wide variety of venues. In the most recent cycle, 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.

As mentioned in the vignette in Section 7, the majority of 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.

Regardless of the venue, PDP participants’ teaching experiences are unique from 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 Team.

Facilitation

As discussed in Section 4, 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: 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.” Facilitation provides an excellent opportunity for formative assessment of students’ progress: this in-the-moment dialogue gives instructors continual feedback on students’ knowledge gains (see participant quote above).

**Support from PDP Staff**

Near the time of their teaching experience, all participants attend a half-day intensive called *Facilitating Learners Engaged in Inquiry* that covers workshops on both facilitating inquiry activities and planning and implementing these activities. In the facilitation workshop, participants discuss a reading from the Exploratorium\(^{15}\) on the overarching goals of facilitation and how one can effectively facilitate learners in an inquiry activity. Then, participants role-play common problem scenarios they might encounter with their learners and develop strategies for dealing with those situations. During the second workshop, we discuss important aspects of planning and implementing a successful inquiry activity. We give participants a checklist of key considerations and logistical details. During the workshop, participants work with their Design Team members to begin addressing the items on the checklist to ensure they have not neglected important aspects in their planning process.

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.

**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. Additionally, because Design 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 (see participant quote above).
quotes above). PDP staff model this collaborative method of designing and teaching in the way that we plan and instruct the workshops within the intensives.

9. Reflection on the PDP Experience

All PDP participants reflect on their experience after designing and 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 Design 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 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.

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.

10. Support for Participant Progress

Now that the elements of the full PDP cycle have been described, we come back to our goals for PDP participants, first elaborated in Section 4. Just as participants are encouraged to start the inquiry activity design process by identifying their goals for students, we design the PDP itself with goals for participants at the forefront. In the tables below, these goals are explicitly linked to the PDP workshops and other formal supports for our participants. Also noted in these tables are the challenges we keep in mind while designing the workshops, sessions and tools, and while training our participants.
### Goal 1. Designing inquiry activities

*Participants design an activity in which their students simultaneously learn concepts, reasoning processes, and attitudes by practicing science or engineering.*

<table>
<thead>
<tr>
<th>Challenges for Participants</th>
<th>Support for Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Being convinced that inquiry teaches content</td>
<td>• Inquiry experience and reflection: <em>Light and Shadow</em> and <em>Parachutes</em> activities and follow-up discussions</td>
</tr>
<tr>
<td>• Seeing the careful orchestration of inquiry in what can at times seem like an open-ended activity</td>
<td>• Placement in an appropriate teaching venue: teaching venues are carefully chosen, Design Team Leaders identified before design time</td>
</tr>
<tr>
<td>• Articulating process goals—scientists and engineers rarely discuss these explicitly</td>
<td>• Experience articulating process goals: Practicing Backward Design and Engineering Skills give structured practice</td>
</tr>
<tr>
<td>• Breaking away from the pre-lab lecture format, where the process, steps, and even the end result are explained first, and the lab is more about verification</td>
<td>• A balance of structure and guidance with room for creativity: <em>Design Task</em> and <em>Design Template</em></td>
</tr>
<tr>
<td>• Articulating learning goals for students without having first decided on the steps students will take during an activity</td>
<td>• Time to work as a team with expert help close by: <em>Design Team Working Time</em></td>
</tr>
<tr>
<td>• Opening up to the idea that an activity can be designed so that students come to their own understandings</td>
<td>• Time to work as a team independently, with occasional consultation</td>
</tr>
<tr>
<td>• As a designer, staying focused on teaching processes; the pull toward teaching primarily content is deeply entrenched</td>
<td>• Design is enacted in an authentic setting</td>
</tr>
<tr>
<td></td>
<td>• Reflection on design successes and challenges: Debrief and post-teaching report</td>
</tr>
</tbody>
</table>

### Goal 2. Optimizing learning

*Participants progress at creating effective and inclusive learning environments.*

<table>
<thead>
<tr>
<th>Challenges for Participants</th>
<th>Support for Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Considering retention in higher education, not just recruitment, as a way to increase diversity</td>
<td>• A focus on education research and a research-motivated framework that support effective teaching: workshops on the <em>How People Learn</em> framework</td>
</tr>
<tr>
<td>• Understanding that science and engineering are not cultureless endeavors, but are practiced by a community of people who value certain norms and practices</td>
<td>• Reflection on the pedagogical pros and cons of designing an inquiry activity in different ways: <em>Comparing Inquiry Design Elements</em> discussion after the <em>Parachutes Inquiry Activity</em> discussion (returning participants only)</td>
</tr>
<tr>
<td>• Accepting the fact that, in subtle ways, the culture of science and engineering in the U.S. is not inclusive of all U.S. citizens</td>
<td>• Explicit consideration of the nuances that affect learners of different backgrounds and strategies for supporting all learners: <em>Addressing Diversity &amp;</em></td>
</tr>
<tr>
<td>• Thinking beyond issues related to academic preparation when considering barriers to student success</td>
<td></td>
</tr>
</tbody>
</table>

19
**Goal 3. Facilitating students**

*Participants teach using a repertoire of strategies that engage and support all students in building and practicing inquiry skills.*

<table>
<thead>
<tr>
<th>Challenges for Participants</th>
<th>Support for Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening up to the idea that an activity can be taught without giving students answers, but instead by supporting students as they come to their own understandings</td>
<td>Experience working with facilitators, from the learner’s perspective: <em>Light and Shadow</em> and <em>Parachutes</em> activities and follow-up discussions</td>
</tr>
<tr>
<td>Understanding that students’ learning can be assessed formatively and often (e.g. via informal dialogues), as well as summatively (e.g. via quizzes and tests)</td>
<td>Experience facilitating peers during <em>Light and Shadow</em> inquiry activity (some returning participants)</td>
</tr>
<tr>
<td>While teaching, bringing out each student’s understandings, not just those of the students who are most extroverted or most comfortable with the subject matter</td>
<td>Time to focus on facilitation strategies: <em>Facilitating Learners Engaged in Inquiry</em></td>
</tr>
<tr>
<td>While teaching, adapting on the fly to best support students’ knowledge gains</td>
<td>Experience facilitating an inquiry of their own design, as members of a teaching team, with support from a teaching consultant</td>
</tr>
<tr>
<td>While teaching, addressing social interactions between students that are barriers to learning</td>
<td>Reflection on facilitation experience during debrief and self-reflection</td>
</tr>
</tbody>
</table>

**Goal 4. Growing more intentional**

*Participants become more reflective on education, and they integrate education into their identity as scientists and engineers.*

<table>
<thead>
<tr>
<th>Challenges for Participants</th>
<th>Support for Participants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Approaching teaching and learning as critically as they would approach science or engineering</td>
<td>Experience of and reflection on a hands-on science activity taught in three different ways: <em>Three Kinds of Hands-On Science</em></td>
</tr>
<tr>
<td>Shifting perspective from what is being taught to what is being learned.</td>
<td>Reflection on how the inquiry model</td>
</tr>
</tbody>
</table>
11. The Evolution of the PDP

The PDP is a rich program that has evolved over the past eight years to better support our goals and to meet the needs of changing cohorts of participants. To sustain this evolution, PDP staff members have become increasingly agile, drawing from fields within the natural sciences, engineering, and education sciences, and staying abreast of new developments within our community and in national research. We remain open to change, perhaps adjusting the wording of a program or participant goal, adding a new discussion to a workshop, or even emphasizing or developing a new theme throughout the entire program. To round out this description of the PDP, we highlight some of the changes we have made to better reach our goals and those of the PDP participants.

Teaching and Learning in Context

To support the intentionality of their inquiry activity designs and teaching efforts, we ask all PDP participants to consider the larger context (geographical, cultural, etc.) in which they teach. Maui is the unique home of the main four-day intensive, and the Hawaiian Islands are the setting for many of the participants’ teaching venues. To encourage participants’ awareness of the Hawaiian context of their work, and to inform the Hawaiian community of PDP products and practices, we developed the Maui Science and Technology Education Exchange (MSTEE).

MSTEE provides the Hawaiian and PDP communities with the opportunity to discuss the current state of research, technology, and education on Maui and Hawai‘i. For instance, while the Hawaiian Islands are home to world-class astronomical observatories and high-tech industries, Native Hawaiians and Pacific Islanders are greatly underrepresented in the high-tech workforce. The Hawaiian community has therefore identified a critical need to develop a technical local workforce to support and diversify its economic potential.
During the MSTEE workshop, the PDP community joins a group of leaders from the Hawaiian technical community in an exchange designed to connect PDP activities to workforce needs. The exchange focuses on college-level research internships (or apprenticeships) offered through the CfAO. These internships place local college students in summer positions at Hawaiian observatories and high-tech companies, with the ultimate goal of retaining the interns for future jobs. Projects completed by interns typically reflect the types of tasks and projects taken on by new workers, making these projects an ideal mechanism for an exchange between the education and technical communities.

The Hawaiian technical community shares their particular needs by discussing internship projects and highlighting the skills and knowledge needed to be successful in entry-level technical jobs. PDP participants, in turn, present the science and engineering activities and curricula they are developing to engage students in inquiry. Several of these activities are taught in preparatory “short courses” for local Hawaiian interns. Through MSTEE, we have identified the close alignment between our PDP inquiry activities and the needs for developing a technical workforce. Inquiry gives students practice in defining and designing solutions for problems, working on collaborative teams, communicating, and using the range of processes and practices used every day by scientists and engineers.

**Setting Learning Goals in Inquiry Activities**

As detailed in Section 7, participants are expected to begin their activity designs by focusing on articulating learning goals for their students. In years past, we encouraged participants to write out separate content- and process-focused goals, an idea that reflected an established practice in science education. Design Teams were typically able to state rich content goals, but their process goals were fairly vague (see example goals, right). We wanted to support equally well-stated content and process goals, but surmised that most participants did not have a good model for this from their own learning experiences. Our strategy was not filling in this apparent gap.

At roughly the same time, a new, research-based framework for thinking about how scientists practice inquiry was published in the summary *Taking Science to School*:

Research has often treated aspects of scientific proficiency as discrete. However, current research indicates that proficiency in one aspect of science is closely related to proficiency in others (e.g., analytic reasoning skills are greater when one is reasoning about familiar domains). Like strands of a rope, the strands of scientific proficiency are intertwined.

The authors of this summary went on to describe “Four Strands of Scientific Proficiency” that, in brief, describe ways in which scientists simultaneously engage process and content knowledge as they practice their craft.

We began to draw from the “Four Strands” to support our participants as they set learner goals. This was new and untested territory for the PDP community. Some returning participants, who were used to the content/process separation, resisted the change. However, the use of these strands has helped us to achieve the program goal of
illustrating inquiry. Drawing from this new resource has helped participants better describe what they expect their students to know and be able to do (see example learner goal, right).

**Addressing Diversity and Equity**

Recruiting underrepresented students into science and engineering fields has always been an important goal of the CfAO education program. Our intention of reaching **all** learners through inquiry is built into program-level and participant goals. When we first developed the PDP, we chose to focus on inquiry, in part because it was a model that seemed inherently inclusive. By recruiting underrepresented students into CfAO-sponsored venues (in which PDP participants teach their inquiry activities), and using an inclusive teaching model, we hoped PDP participants would gain experience and insights related to our goals for diversity.

However, over the years, it became clear that it would be valuable to our community to start an explicit conversation about diversity and equity. While this is undoubtedly a sensitive topic, as staff members we grew concerned that we were potentially modeling complacency by not addressing the subject outright. We therefore designed an entirely new workshop, *Addressing Diversity and Equity*, to raise awareness of the issues and train participants to incorporate inclusive strategies in their inquiry activities (see also Section 6.2). We continue to build inclusive practice into our expectations for participants’ design work, and we encourage participants to be intentional about this aspect of their work. The intentional nature of our expectations can be seen, for example, in the way the Design Task is worded (see also Section 7). A new focus of the PDP staff is to make the connections between inquiry and inclusive teaching practices more explicit.

**12. The Future of the PDP**

The PDP has been running for eight 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 positive impacts of the PDP, which will be the subject of future publications, are as complex as the structure of the program itself. The PDP has provided hundreds of graduate students with a time, place, and the training to think about what it means to do science/engineering, and then to practice engaging learners from all backgrounds in the processes and practices of their fields. The focus of the PDP on laboratory courses fills a
gap in the professional development of graduate students that complements their research training and the preparation they get for lecture-based teaching. Much of what PDP participants learn can be applied to teaching and mentoring in other contexts, as well, such as in the research setting. Many PDP participants find that their experience teaching inquiry has improved their own research skills as well as their enthusiasm for research. Finally, the bonds formed by PDP teaching teams and the sense of belonging to a community are major impacts that may ultimately affect graduate student satisfaction and retention. One of the most important lessons learned from the PDP has been that graduate students need more and want more than what traditional programs are providing.

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 Hawaii. The work of the PDP will continue through the newly established Institute for Scientist and Engineer Educators (ISEE) based on the University of California, Santa Cruz campus. The PDP, with its established yet evolving implementation and its dedicated community, lies at the core of this new enterprise. ISEE will continue to advance this program and will complement it with new graduate-level courses, a certificate in higher education science and engineering teaching, and new research on teaching, learning and professional development.17 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 electro-optics program, bringing in PDP participants as designers and visiting instructors for new laboratory courses at Maui Community College. If funded beyond the pilot phase, AWI will become a model program within ISEE.

Making a change within existing and deeply entrenched educational systems is an enormous challenge that takes innovation, leadership, and significant resources. The original NSF STC funding enabled us to try something new and risky, to revise and refine, and to lay the groundwork needed to establish a sustainable program. It is unusual to have the luxury of ten years for an education project, and it cannot be understated how much the success of the PDP relied upon the funding, resources, opportunities, people, partners, and national profile afforded and encouraged by STC funding.

**Acknowledgments**

This work has been supported by the National Science Foundation Science and Technology Center for Adaptive Optics, managed by the University of California at Santa Cruz under cooperative agreement No. AST - 9876783.

The PDP has been a collaborative endeavor, involving many individuals and organizations over the years. To acknowledge each contributor individually would require far too much space, but we would like to express our appreciation for all of those who have been a part of this work. We would like to give a special acknowledgment to those who have made a significant contribution:

**PDP staff members**, in addition to the authors, who have taken on key roles and have contributed intellectually to PDP workshops and sessions: Sally Duensing, Scott Severson, and Jerome Shaw.
**PDP event managers**, whose work behind the scenes make the PDP run smoothly and effectively. It would have been impossible to coordinate such an elaborate event without the skills and expertise of these individuals: Hilary O’Bryan, Malika Bell, and Lani LeBron.

**Morris Aizenman**, CfAO’s NSF STC Program Coordinator, who has participated in many workshops, and who has believed in and advocated for the PDP from the very first event in 2001.

**Nathaniel Pitts**, NSF Office of Integrative Activities, whose leadership at the NSF enabled us to create and sustain the PDP, and who took the time to truly learn about the PDP and get to know our participants.

**Claire Max**, CfAO Director, who has an inspirational commitment to education, and whose leadership changed the position of “education” within the CfAO to be an equally valued theme, commanding the same level of respect and intellectual energy as the science and technology themes.

**Our Maui partners**, who have opened their doors and contributed in many ways to the PDP: Maui Community College, Maui Economic Development Board, University of Hawaiʻi Institute for Astronomy, Air Force Maui Optical and Supercomputing Site, Maui high tech industry.

**Sarah Anderson**, for her beautiful photographs that visually capture the work of the PDP. Co-author Scott Seagroves also contributed photographs.

**PDP participants from 2001-2008.**
References and Notes

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/

2 For instance, this stance is presented in the NSF’s Research Experiences for Undergraduates (REU) program solicitation at http://www.nsf.gov/pubs/2007/nsf07569/nsf07569.htm and is supported by:

3 A high-level review of some recent reports may be found within:

Other prominent references that support this point include:

4 An accessible primer into the learning sciences is the How People Learn series, which we draw upon heavily in the PDP:

b “ERIC #” refers to the record in the Education Resources Information Center at http://eric.ed.gov and is provided when we could locate it.


11 Elements of the PDP build on ideas from the Exploratorium’s Institute for Inquiry (IFI). Their professional development activity designs are available at http://www.exploratorium.edu/ifi/workshops/fundamentals/index.html

12 In particular, we used and adapted resources from the Center for the Integration of Research, Teaching, and Learning (http://www.cirtl.net):


13 An excellent annotated bibliography of the stereotype threat literature (including articles that discuss “mindset” or “malleability of intelligence” strategies for combating stereotype threat) is: Stroessner, S., and Good, C., http://ReducingStereotypeThreat.org


16 There is an active literature and scholarship engaged in science and engineering education for the K-12 audience. Though the PDP’s focus is on higher education, we have found that the K-12
literature is rich with insights that should not be dismissed. Just as we were revising our approach to learning goals, these two companion works came out with well-articulated thinking just along the lines that we needed:


17 New courses and programs will draw in part from the CfAO education program (http://cfao.ucolick.org/EO/) and from the work of the Center for Informal Learning and Schools (http://cils.exploratorium.edu/).
Appendix A: Design Template and Lens Overlays

The Design Template is a major 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, 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 participants 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 inquiry activity model they experienced during the four-day intensive, bringing in explicit considerations from the How People Learn framework and inclusive strategies to support all their learners. We also prompt participants to articulate their facilitation strategy.

On the following pages, we present:

- The PDP Activity Design Template
- A Guide for Productively Using the Design Template: includes prompts to help participants design their activity using the template
- Four Lens Overlays: each overlay includes prompts specific to a “lens” through which educators are encouraged to “view” their activity designs in order to incorporate effective teaching practices (based on ideas from the How People Learn literature)
  - Knowledge-Centered Lens Overlay
  - Learner-Centered Lens Overlay
  - Assessment-Centered Lens Overlay
  - Community-Centered Lens Overlay

![Figure A1: Participants from the 2008 PDP cycle discuss their activity design, using the Design Template.](image)
PRODUCTIVELY USING THE ACTIVITY DESIGN TEMPLATE

Teams will design or re-design an 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, including diversity/equity and results from research (such as the How People Learn series of summaries).

BACKGROUND AREA
What do you know about your learners coming into the activity? What prior knowledge, skills, and experiences do they bring? What else do you know about their backgrounds?

GOALS AREA
What kinds of goals do you have for your learners in this activity?
The classic way to categorize types of goals in science education is to divide them into understandings of:
- science content
- science process
- attitudes about science
- nature/role of science
This way of thinking about goals helps you to remember that science content is not all there is—it is important to build students’ science skills and science attitudes as well. However, we have noticed that drawing a distinction between content and process often forces us to think of things separately when the richest science-learning experiences (and the practice of science itself) feature them inextricably intertwined.
Consider how meaningless it is to "raise questions" or "test hypotheses" or "explain" in the abstract—these practices require something to question, hypothesize about, and explain; there must be some content for the processes of science to work on. We are not alone in this view—the new works Taking Science to School and Reason, Sci., Sci. also emphasize moving beyond the classic content-process dichotomy. These works emphasize not the knowledge itself, but the use, application, and deployment of knowledge. The four bullet points above emphasize nouns, while the four bullet points below emphasize verbs.
To help you inter-weave the features of science that are all necessary for real, deep, rich scientific learning, consider the "strands of scientific proficiency" from Taking Science to School:
- knowing, using, and interpreting scientific explanations
- generating and evaluating scientific evidence and explanations
- understanding the nature and development of scientific knowledge
- participating productively in scientific practices and discourse
Whatever framework you choose (and perhaps you will mix the two), the challenge is making these kinds of goals specific to the context you are planning to work in.

EVIDENCE AREA
What would achieving each of your goals look like in practice?
How would you look for?
How will you know that your students are making progress?
How will your students know that they are making progress toward the goals?
Is the evidence you would need collectible somehow?
Feedback between the goals and the evidence will require you to iterate back-and-forth—the goals may need to be refined, the evidence may be difficult to collect, etc. For instance, wanting students to gain "critical thinking skills" is a worthy goal but is very difficult to assess. Refining this goal to something much more specific (details here would depend on your context) might suggest what evidence should be gathered; or, to put it another way, thinking about what evidence you would look for might suggest a more refined vision of the goal.

ACTIVITY DESCRIPTION AREA
What will students actually do in the activity?
Try to break down every component of the activity. For instance, each discrete period of student work and each planned "teacher intervention" (like a mini-lecture or a demo) is a separate component.
You don’t have to plan in time-ordered, but you might want to write things down here in this area with the beginning of the activity on the left and subsequent components of the activity progressing to the right.
In addition to planning activity elements that move toward content-type goals, are your students engaged in learning processes and improving their process skills as well?
Components of the activity should move you and your students toward the goals listed above.

SYNTHESIS AREA
How do you plan to wrap up or synthesize the activity?
Consider synthesizing student work and student progress toward all your goals—don’t necessarily just synthesize the science content of the activity.
What will you plan to do here near the end of the day if some or all of your goals are not being achieved?

RATIONALE AREA
For each component of the activity, what considerations have driven your particular design choices?
Why do you believe that each activity component will help you meet a particular goal or set of goals?
How do your design choices connect with education research considerations, such as the How People Learn principles and lenses?
What diversity/equity considerations are important in each design choice? Have you examined your design through an “equity lens”?
Are there tradeoffs associated with your design choices—for instance, are you sacrificing one kind of consideration in favor of another, or due to time constraints, or some other tradeoff?

FACILITATION AREA
What is the role of the “teachers” in each component of the activity?
What is the facilitation plan?
Are there some components where facilitation should be "light"—leaving learners to work more independently? And other components where facilitation should be "heavy"—where facilitators actively guide or assist learners?
Should facilitators be "shadowing" learners to collect evidence and assessment data? If so, what will you be looking for (see the "evidence" area above)?
Are there things you are planning not to do (like, make sure not to mention X until a student notices it).

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The KNOWLEDGE-CENTERED LENS

Teams will design or re-design an 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, including diversity/equity and results from research (such as the How People Learn series of summaries).

<table>
<thead>
<tr>
<th>GOALS</th>
<th>EVIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Do the goals accurately reflect what is important for learners to gain and understand?</td>
<td>Can you gather evidence to measure real understanding and not just rote memorization?</td>
</tr>
<tr>
<td>Are the goals focused on connected knowledge, organized around fundamental ideas, concepts, and skills?</td>
<td>Can you gather evidence on the use and application of knowledge, or perhaps the transfer knowledge and understanding to another context or application?</td>
</tr>
<tr>
<td>Are the learners have prior conceptions related to this activity? Are the learners likely to have prior misconceptions? (e.g., seasons are caused by distance from the Sun)</td>
<td>Are you able to gather evidence that shows your students are learning and applying new skills? (in addition to learning and applying new ideas)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ACTIVITY DESCRIPTION</th>
<th>RATIONALE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Does the activity allow sufficient time for learners to reflect and gain deep understanding?</td>
<td>Does the synthesis tie together different learners' investigative paths to show common concepts and knowledge?</td>
</tr>
<tr>
<td>Are there opportunities for learners to learn metacognitive strategies related to the content?</td>
<td>Does the synthesis stress the knowledge goals that are truly important? What &quot;enduring understanding&quot; should be synthesized?</td>
</tr>
<tr>
<td>Does the activity emphasize empirical evidence and reasoning from such evidence?</td>
<td></td>
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<table>
<thead>
<tr>
<th>FACILITATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are there areas of the activity that facilitators can keep in their &quot;back pockets&quot; to challenge learners who need an extra push?</td>
</tr>
</tbody>
</table>

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The LEARNER-CENTERED LENS

Teams will design or re-design an 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, including diversity/equity and results from research (such as the How People Learn series of summaries).

**GOALS**

- What past experiences do your learners bring to the activity?
- Are the goals matched appropriately to the learners' levels of knowledge, skills, and attitudes?
- Are the learners motivated to achieve these goals?
- Are you planning to use several different teaching styles and techniques for a diversity of learners?
- Are you also planning to use differing participant structures (for instance group work, pair work, individual work, etc) for a diversity of learners?
- Will the activity emphasize that the skills, knowledge, and attitudes are learned rather than fixed or innate?
- Are there multiple ways for learners to get to the goals of the activity?

**EVIDENCE**

- Is there something in your learners' backgrounds that connects with the activity?
- Are you looking for a variety of kinds of evidence, to gather information about a diversity of learners?
- Is there a way to connect the synthesis of the activity with the learners' everyday lives?
- Will the synthesis respect the work of the learners? Can the synthesis make specific reference to their contributions?

**RATIONALE**

- Do the facilitation plans emphasize the importance of respecting the learners and their work?
- Can the activity be learner-driven rather than facilitator-intervention-driven?

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The ASSESSMENT-CENTERED LENS
Teams will design or re-design an 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, including diversity/equity and results from research (such as the How People Learn series of summaries).

<table>
<thead>
<tr>
<th>GOALS</th>
<th>EVIDENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Is there any data you can gather or would like to gather about your learners beforehand, that would help you during the activity?</td>
<td>What kinds of assessment and self-assessment are your learners likely to be familiar with and expecting?</td>
</tr>
<tr>
<td>Should you include goals of self-monitoring, self-assessment, and metacognitive strategies?</td>
<td>What is the evidence you will look for that shows your students meeting goals or progressing toward them?</td>
</tr>
<tr>
<td></td>
<td>Is the evidence really measuring your goals?</td>
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<tr>
<td></td>
<td>Have you considered a variety of assessment methods in order to gather evidence about your students' progress in all of your goals?</td>
</tr>
<tr>
<td></td>
<td>Are the assessments driving the learning, and if so, is that what you want? (ex: are you &quot;teaching the test&quot;?)</td>
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<table>
<thead>
<tr>
<th>ACTIVITY DESCRIPTION</th>
<th>TIME</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are there components in the activity that allow learners to assess their progress for themselves?</td>
<td>At the end of the activity, do the learners have a good idea of their strengths and weaknesses?</td>
</tr>
<tr>
<td>Does the activity provide learners with opportunities to revise and improve their thinking?</td>
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<tr>
<th>RATIONALE</th>
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<tbody>
<tr>
<td>Are there ways to incorporate &quot;formative assessment&quot; -- that is, are there opportunities for facilitators to judge if learners are making progress?</td>
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<tr>
<th>FACILITATION</th>
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<tbody>
<tr>
<td>Are the facilitators equipped to adjust the activity or their facilitation based on formative assessment?</td>
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</table>

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The COMMUNITY-CENTERED LENS

Teams will design or re-design an 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, including diversity/equity and results from research (such as the How People Learn series of summaries).

What do you know about the values and norms of the learners’ larger communities?

What sort of learning-community has been established (if any) for your learners before they enter your activity?

Are there ways to connect your goals to learners’ outside communities?

Can the community of learners within this activity monitor their own progress, assess themselves, or contribute to the evidence of their own understanding?

Are you including goals that build a supportive community of learning in the venue your activity is situated within?

Do your goals include bringing learners into the community and culture of scientific practice, with its norms and values? (e.g., respect for evidence, critical questioning, risk-taking)

Does the activity encourage the sorts of community values you want to emphasize? For instance, does the activity reward learners for taking risks and exploring their own ideas, rather than punishing them or discouraging them for designing a “failed” experiment?

Will the synthesis tie together learners’ individual or small-group work into the collective work of the classroom community?

Will the activity highlight positively the community’s diversity of pathways through investigations and toward the goals?

Can the synthesis continue to bring learners into the community of science practice, by for instance encouraging respectful argument and skepticism?

If there are these multiple paths to the goals, are there some paths that particularly resonate with learners’ other communities?

Are there particular facilitation moves that can help develop the community of learning you want to grow?

Can facilitators help make it clear when it’s appropriate to step in and out and among these various communities?

Are there particular facilitation moves that can help bring learners into the community of science?
# Appendix B: Inquiry Activity Designs

Created by PDP participants 2001-2008

## Undergrad Audiences

1. Stellar Populations
2. Galaxy Morphologies in the Hubble Ultra Deep Field
3. Mystery Galaxies
4. Galaxy Clusters: Mass vs. Visible Light
5. Galaxy Components
6. Recipe for a Galaxy
7. Spectroscopy Astronomy Lab
8. Color, Light, and Spectra
9. Light, Color Addition, and Color Subtraction
10. Lenses and Refraction
11. Camera Obscura and Pinholes
12. Light, Optics, and Telescopes
13. Compound Pendulums
14. Wavefront Correction
15. Understanding Adaptive Optics
16. Electronic Detectors
17. Digital Image Files
18. CCD Models
19. Spectrograph Design
20. Retinal Anatomy
21. Physiology and Optics of the Human Eye
22. Color Perception
23. Central DOGma Disease Detectives
24. Biological Imaging: Understanding Image Files
25. UCSC CSI: Understanding DNA
26. DNA in a Box

## Graduate Student and Professional Audiences

27. Fourier Optics
28. Adaptive Optics System Demonstrator
29. Human Vision and Aberrations

## High School Audiences

30. Variable Stars
31. Open and Globular Star Clusters
32. Planetary Nebulae
33. Classifying Galaxies: Color and Morphologies
34. Stars and Color
35. Tabletop Optics: Lenses and Mirrors
36. Spectroscopy Physical Science Lab
37. Lenses and Human Vision
38. Visual Perception
39. Astrobiology: Extremophiles!
40. Bacteria and Viruses
41. Ecology in the Intertidal Zone
42. Sea Turtle By-Catch

## Content Areas:

- Astronomy
- Physics
- Engineering/Instrumentation
- Vision Science
- Biology
- Ecology