Authors
Do, Tuan
Lu, Jessica R
Lanz, Alicia
et al.

https://escholarship.org/uc/item/0sq6r7pd
pp. 333–340 in S. Seagroves, A. Barnes, A.J. Metevier, J. Porter, & L. Hunter (Eds.), *Leaders in effective and inclusive STEM: Twenty years of the Institute for Scientist & Engineer Educators*. UC Santa Cruz: Institute for Scientist & Engineer Educators. https://escholarship.org/uc/isee_pdp20yr

Impact of PDP on Training for Astronomical Instrumentation

Tuan Do*[1], Jessica R. Lu[2], Alicia Lanz[3], and Quinn Konopacky[4]

[1] University of California, Los Angeles, CA, USA
[2] University of California, Berkeley, CA, USA
[2] Carnegie Observatories, CA, USA
[4] University of California, San Diego, La Jolla, CA USA
[*] Corresponding author, tdo@astro.ucla.edu

Abstract

The Institute for Scientist and Engineer Educators (ISEE) Professional Development Program (PDP) has led to the generation of several activities geared toward training in astronomical instrumentation. These include activities developed for the Center for Adaptive Optics summer school and the AstroTech Instrumentation Summer School. The goal of these activities has been to provide the participants with hands-on experience to convey challenging concepts in instrumentation. The inclusion of practices from PDP led to activities that prioritized inquiry-based approaches over the more traditional formulaic lab-based training and activities. Our panel will review the design of these activities and discuss approaches that increase the likelihood of achieving the learning goals. We will also discuss ways in which these activities can help encourage students with little previous experience in instrumentation to consider additional studies in instrumentation. Finally, we will reflect on the importance of facilitators for these activities and the role PDP plays in training facilitators.

Keywords: activity design, engineering, inquiry, instrumentation, STEM practices

1. Introduction

Instrumentation summer schools in astronomy often serve as a bridge between theoretical course work and being an active member of an instrument team. Instrumentation summer schools target advanced undergraduates and/or graduate students and are often 1 to 2 weeks of both lectures and labs. The emphasis is usually on the labs, which offer a structured hands-on introduction to basic concepts in astronomical instrumentation. Often, this is the first opportunity for students to work with hardware and so these experiences can be very impactful for their subsequent education and careers.

The emphasis of instrumentation summer schools on hands-on labs makes them ideal venues for inquiry-based activities. The importance of modeling scientific and engineering practices in inquiry-based activities is well matched to the skills that students will need in building astronomical instruments. For example, developing the requirements for an instrument requires developing scientific questions and translating them to capabilities and requirements on hardware. In addition, inquiry-based activities can often accommodate students from different backgrounds and skill levels. Enabling different entry points and different routes for exploration is essential for accommodating the varied experiences and backgrounds that students come with in the instrumentation summer school.

In this work, we will discuss our experiences in designing and teaching lab activities in two instrumentation summer schools: (1) the Center for Adaptive Optics (CfAO) summer school, and (2) the AstroTech Instrumentation Summer School. We will summarize the learning goals of these summer schools and how inquiry-based activities were used to help students achieve these goals (Section 2 & 3).

In reflecting on the 15 years since the first inquiry-based labs were designed by PDP participants in instrumentation summer schools, two major themes emerge: (1) the principles and training from PDP are particularly well suited for designing and teaching astronomical instrumentation labs; (2) facilitators are central to an impactful experience for students. In Section 4, we will expand on these themes.

2. Learning outcomes of instrumentation summer schools

2.1 CfAO Summer School

The CfAO Summer School aims to introduce students to the basics of adaptive optics (AO) and related topics in the use of AO and instrumentation. The CfAO summer school began in the summer of 2000 and is still taught every summer. Each summer school has about 20 to 30 students, consisting of grad students, postdocs, and professionals in industry. In 2006 labs were included into the summer school. Some of these labs were redesigned to be more inquiry-based by PDP design teams in 2007. A vision science lab was also included at this time. In the next few years, the labs were iterated upon. Since 2009, these labs have been taught at the CfAO summer school, with some changes. Overall, about 8 teams (consisting of 3 to 4 per team) of PDP participants have participated in the design, redesign, and teaching of the labs in the CfAO summer school.

A detailed discussion of the CfAO Summer School is given in Ammons et al., (2010), but here, we will summarize the goals of the laboratory activities. The learning outcomes are structured in tiers to accommodate learners with varying background and experience in instrumentation and AO. The learning outcomes related to course content are:

1. *Tier 0: Components of an Adaptive Optics System*. Students are to recognize and understand the purpose of the deformable mirror, wavefront sensor, re-imaging optics, science camera, and control computer.
2. *Tier 1: Manipulation of AO Variables.* Students can explain the interactions between correction rate, gain, bandwidth, and final correction quality.
3. *Tier 1: Basic Optics Alignment*. Learners display basic proficiency in optical alignment of a re-imaging system with lenses.
4. *Tier 2: Interplay of AO System Components*. Students can explain the need for a precise deformable mirror / lenslet array mapping and grasp the consequences of an imperfect mapping. Students can determine the correct order of a set of re-imaging lenses in an AO system to achieve a good mapping. Students understand the need for plane conjugation.
5. *Tier 2: Relationship between Pupil Plane and Focal Plane*. Learners can quickly guess the qualitative shape of a Point Spread Function (PSF) produced by a given pupil shape. Learners can explain the effect of apodized pupils on the PSF.

The learning outcomes related to scientific and engineering processes are:

1. *Tier 0: Confidence with Optics*. Participants display simple confidence in the manipulation of optical components.
2. *Tier 1: Operation of an AO System*. Students can repeatedly operate the controls of a working AO system to achieve basic functionality.

2.2 AstroTech Instrumentation Summer School

AstroTech is a summer school for undergraduate and graduate students with the goal to broaden participation in astronomical instrumentation, particularly to include more women and underrepresented minorities. AstroTech participants spend five full days immersed in the experience of building an astronomical instrument. Throughout the week, participants work in teams, gaining hands-on experience in opto-mechanics, detectors, calibration hardware, electronics, or software. Daily activities build upon one another toward the goal of building and testing an astronomical spectrograph. There are also sessions focused on working effectively and inclusively on a team, sessions on supporting professional skills and a career pathways networking session which includes people from academia, industry, and government who work in instrumentation.

The learning outcomes include:

1. Apply optical principles and an understanding of essential components of spectrographs to design a spectrograph that meets a science goal, and demonstrate an understanding of the role and constraints of a specific subsystem of interest (e.g. electronics, detectors, data pipeline, etc.)
2. Apply the process of instrument development to design, build, integrate, and test an instrument, and present evidence that it meets requirements and accounts for constraints.
3. Use optical hardware and lab space in a safe, active, and productive manner.
4. Advance individual plans for pursuing a career in instrumentation that includes their interest in making the field of instrumentation more inclusive.
5. Practice effective teamwork and collaboration skills that make AstroTech a productive and inclusive environment, and that can be used in academic and industry environments in instrumentation.

These goals are interwoven into multiple activities. For instance, goal 1 is first addressed on day 1 of the summer school in two hands-on basic optics labs. Then the students put into practice what they have learned in a more unstructured manner on day 2 when they develop an optical design for a spectrograph. There are opportunities for feedback from experts and their optical design is refined again on day 3. Finally, they build their spectrograph and test it on days 3–5, which reinforces their learning and shows the added complexity of imperfect optics and unforeseen difficulties in the real world.

3. Activity designs

3.1 CfAO Summer School activities: Fourier optics and wavefront sensing

The Fourier Optics and Wavefront Sensing activity in the CfAO Summer School is a good example of an inquiry-based activity with many of the elements that make them effective for training in astronomical instrumentation. The details of the activity is presented in Do et al., (2010), but here we will summarize the activity and concentrate our discussion on elements that address the overall goals of the summer school.

The overall learning outcomes of the Fourier Optics and Wavefront Sensing activity are (1) to enable students to use the principles of Fourier transforms to interpret the effects of diffraction on optical systems, and (2) gain experience in the design of optical systems. These learning outcomes were broken down into smaller goals with different tiers depending on student backgrounds. The learning outcomes are aligned with content learning outcomes 1, 3, 4, and 5 for process learning outcome 1 in the AO summer school.

The activity consists of 4 main phases:

- **Question generation:** students observe optical phenomena and develop potential questions to guide their investigation.
- **Wave optics investigation:** students investigate various diffraction-related phenomena using a simple optical system and a detector.
- **High-contrast imaging or wavefront sensing:** students have the choice of investigating and designing coronagraphs enabling high contrast imaging of point sources or building a Shack-Hartman wavefront sensor.
- **Student presentations:** each group creates a poster and presents their findings to the class.

These phases in the activity are designed to model some of the fundamental concepts and practices in the building of astronomical instrumentation. For example, this activity enables multiple opportunities for students to develop skills in aligning optics and in different contexts. Students initially align only one lens component as part of their initial investigations. As they reach more sophisticated portions of their investigations, they include more optical components and so need to develop more complex alignment techniques. Facilitators are on hand to help guide students in each stage. During the middle of the activity, facilitators also re-introduce theoretical concepts such as the lens equation to remind students that they can model complex optical systems as a starting point for the locations of the optical elements. Introducing these concepts when students are struggling through a problem can help them to more deeply integrate these concepts compared to only giving students readings on these concepts during the start.

3.3 AstroTech activities

AstroTech is structured around a “Build Your Own Spectrograph” activity that takes 3 full days (Figure below). To prepare participants for this activity, they first engage in introductory optics and spectrograph labs and an instrument design activity. They also reflect on inclusive teamwork. All of these early activities provide an essential foundation on which to assemble their own team and design and build their own spectrograph to meet their desired science goals.

One novel design schema that is deployed in the Build Your Own Spectrograph activity is a matrix structure. Participants are first divided into spectrograph teams (~6 people per team). The team works together to define and design their spectrograph on day 2. Then within each team, each person takes on a specific role within the spectrograph project. The 6 roles are (1) science and calibration lead, (2) control electronics and software lead, (3) detectors lead, (4) opto-mechanical lead, (5) software pipeline lead, and (6) systems engineering lead. The teams split apart on day 3 and the expert groups come together for activities aimed around the specific subject area. For example, in the detector leads group, participants explore detector properties such as gain and dark current, learn to read out the detector, and evaluate the quality of the images they receive. Periodically, the spectrograph teams are reassembled for check-ins and to further their design; but the expert groups continue activities throughout day 3. Finally, on days 4–5, the spectrograph teams re-assemble and build, integrate, and test their full spectrographs.

This approach gives each member of the team ownership over a component of the spectrograph. Furthermore, they get to demonstrate their newly acquired expertise to their peer groups and pass on knowledge via informal peer learning. Lastly, this

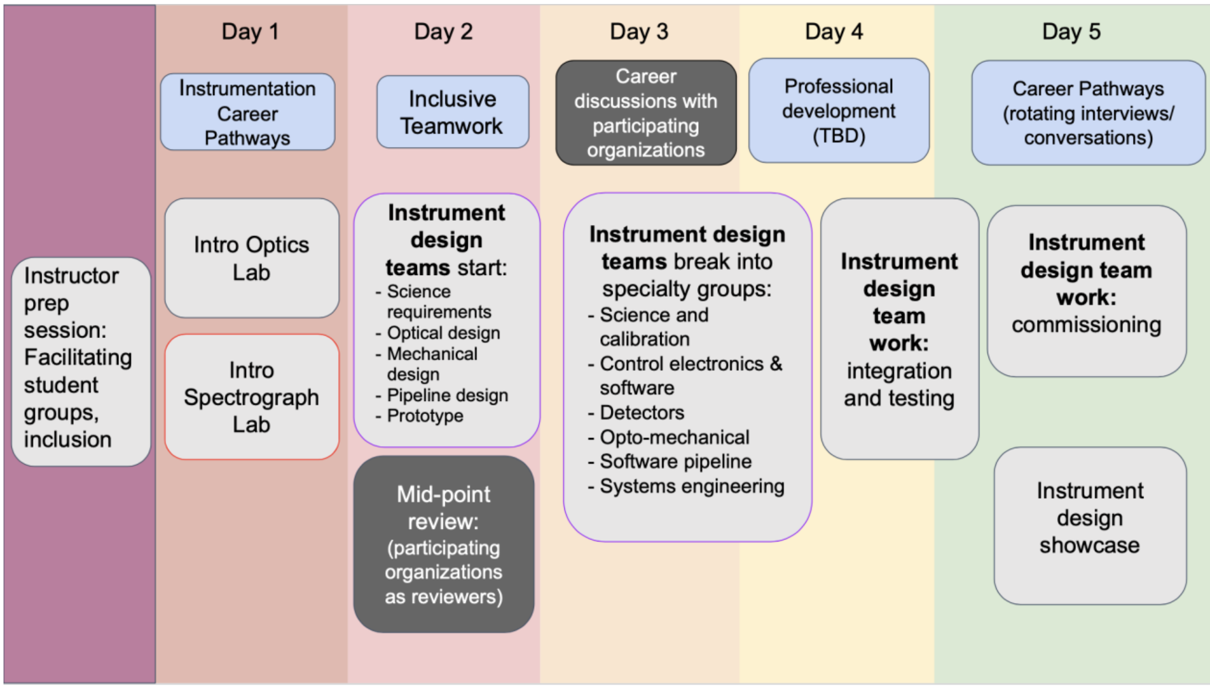

Figure 1: AstroTech interweaves activities aimed at building astronomical instrumentation skills with professional development and inclusive teamwork skills.

shows the importance of inclusive teamwork and accurately reflects scenarios participants will experience during real-world instrumentation development projects.

In addition to the instrumentation goals and matched activities, AstroTech also seeks to provide professional development that supports participants in their plans to pursue instrumentation career paths. These activities are interspersed throughout the AstroTech summer school and provide additional critical skills, networking opportunities, and cohort building.

4. Impact of instrumentation summer schools & PDP

Instrumentation summer schools offer unique opportunities for both students and instructors. For students, they gain hand-on experience in the basics of the design and construction of astronomical instrumentation. For instructors, these summer schools offer a way to learn and implement pedagogy in a self-contained activity. Instructors can carry forward what they have learned as they advance in their careers. Here, we will reflect on these common themes that run through these instrumentation summer schools.

4.1 The principles and training from PDP are particularly well suited for designing and teaching astronomical instrumentation labs

Inquiry-based activities enable students to model practices that are used in designing and building instruments. A core element of PDP is on designing and teaching an inquiry-based activity. In particular, Metevier et al., (2022):

"PDP participants will design and teach an activity in which learners:

- Raise questions that are related to concepts they later explore or apply.
- Engage in STEM practices (focal practice and others) to come to their own understanding of content.
- Explaining findings or solution using content understanding."

Designing activities that have these qualities create an authentic experience for students learning instrumentation. Concepts advocated by PDP like backward design and assessment driven design help to support designs that are focused on the learning outcomes. In addition, values such equity and inclusion, active student decision making, and learning from failure are incorporated into the design.

The flexibility of investigations allows inquiry-based activities in these summer schools to serve a diversity of student educational backgrounds. Instrumentation is an interdisciplinary field with a combination of domain specific science, engineering, optics, software, electronics, etc. Students can therefore have a large range of background and hardware experience. One of the advantages of student-led investigations is that, through effective facilitation, students can engage with concepts that are challenging but are at the right level.

Students are generally enthusiastic and engaged in the activities of the summer school. Many students experience inquiry-based activities for the first time through the activities designed by PDP participants. Student reactions and their learning outcomes are generally positive. For example, in the Fourier Optics and Wavefront Sensing Activity, students report greater satisfaction and interest in the lab in 2007 when the lab was redesigned to be inquiry-based compared to 2006 when the lab was a worksheet (Ammons et al. 2010). Some students however do comment that they prefer more traditional lab activities.

4.2 Facilitators are central to an impactful experience for students

PDP provides the facilitation training that is crucial to help students achieve learning outcomes. The instrumentation summer school offers a chance for graduate students and postdocs with previous experience in instrumentation to also gain experience in designing curriculum and teaching students. Many of the instructors have not taught using inquiry before and have not designed lab activities before attending PDP. Through PDP, facilitators gain knowledge and experience in

- designing, teaching, and revising a STEM inquiry-based activity
- developing ways to engage with learners and promote collaborative student interactions
- engaging with diversity, equity, and inclusion issues and gain confidence in supporting students in future teaching and mentoring roles.

The emphasis of PDP on increasing diversity, equity and inclusion results also in facilitator cohorts that are more diverse than students typically encounter in their STEM courses.

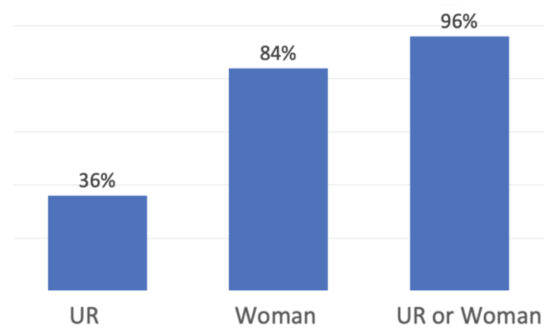

Figure 2: The 2021 AstroTech cohort consisted of 25 undergrads and grad students from 20 institutions in 11 states. Within the cohort 96% of participants were from underrepresented backgrounds.

Acknowledgements

We thank Lisa Hunter, PDP team, and PDP community for providing the support necessary to design and teach these activities.

This work was funded in part by the National Science Foundation (NSF), AST#1743117. The PDP was a national program led by the UC Santa Cruz Institute for Scientist & Engineer Educators. The PDP was originally developed by the Center for Adaptive Optics with funding from the NSF (PI: J. Nelson: AST#9876783), and was further developed with funding from the NSF (PI: L. Hunter: AST#0836053, DUE#0816754, DUE#1226140, AST#1347767, AST#1643390, AST#1743117) and University of California, Santa Cruz through funding to ISEE.

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