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Authors
Shaw, Jerome
Barnes, Austin
Hunter, Lisa

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Inquiries and Frameworks: Synergistic Support for STEM Student Interns

Jerome Shaw[*1], Austin Barnes[2], Lisa Hunter[3]

[1] Education Department, University of California Santa Cruz, Santa Cruz, CA, USA
[2] Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA
[3] Institute for Scientist & Engineer Educators, University of California Santa Cruz, Santa Cruz, CA, USA
[*] Corresponding author, jmlshaw@ucsc.edu

Abstract

Participants of the Institute for Scientist and Engineer Educators' (ISEE) Professional Development Program (PDP) work in Design Teams to create inquiry activities that foster student learning of relevant STEM content and practices. These teams implement the inquiry activities in one or more teaching venues (i.e., a context in which Design Team members act as instructors or facilitators with actual learners or students). One such venue is the Akamai Internship Program's PREP Course. Concurrent with running the PDP, ISEE supported the development of frameworks to help Akamai interns understand the projects they undertake during their internship. Two frameworks were developed: one focused on scientific explanations and the other on engineering solutions. This paper describes how PDP inquiry activities and the ISEE Frameworks come together in a mutually supportive manner during the Akamai PREP Course. This synergy becomes apparent as we examine the sequential placement of PREP sessions whereby the frameworks both push interns to make sense of their experiences with such activities (e.g., revisiting the explanation framework after a science-oriented inquiry) and prepare interns for effective engagement in upcoming inquiry activities (e.g., using the solution framework before an engineering-oriented inquiry). Recommendations include using a similar pairing of inquiry activities and frameworks in other teaching venues.

Keywords: argumentation & explanation, engineering, inquiry, internships

1. Introduction

This work builds on the Institute for Scientist & Engineer Educators' (ISEE) Professional Development Program (PDP). The cornerstone of the PDP is the idea that science, technology, engineering, and mathematics (STEM) should be taught in a way that students learn the cognitive practices of their field (Metevier et al., 2022). That is, students should learn the nuances of defining requirements, prototyping, optimizing, justifying solutions, and other practices used in engineering innovation. Likewise, students should learn the nuances of generating questions, designing investigations, constructing explanations, and other practices used in scientific inquiry. The PDP refers to these as "cognitive STEM practices" (or just STEM practices), though they are also called "process skills," "reasoning skills," and other similar terms. Throughout the PDP, participants are supported in thinking

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deeply about the core practices used in their field, identifying what is challenging about using those practices, and then designing an authentic learning experience in which learners will improve their proficiency with them.

Over time, the PDP experience evolved to focus a substantial amount of effort on unpacking core STEM practices to make them assessable. Participants created rubrics breaking out a few nuanced dimensions of one specific practice, and then articulating what it looks like when a learner is proficient, and what it looks like when a learner needs more practice. For example, defining requirements is a core engineering practice, and students struggle with dimensions such as stating requirements in a way that is verifiable. A PDP participant might create a rubric for teaching the practice of defining requirements, with a dimension that enables one to assess whether the requirement is stated in a way that is verifiable, or if the learner states something like "user friendly" or "fast," which are unverifiable.

Another foundational aspect of the PDP is applying practical implications from the learning sciences, which provides theoretical support for the PDP approach to teaching STEM practices. For example, participants read, discuss, apply, and reflect on principles outlined in "How Learning Works" (Ambrose et al., 2010). One chapter focuses on how learners develop mastery of complex skills and includes research that supports unpacking or decomposing complex tasks into component skills. Referring back to the earlier example of defining requirements (a complex skill), creating a rubric with dimensions such as stating requirements in a way that is verifiable is a way of unpacking or decomposing the practice. Another chapter in How Learning Works is focused on the importance of goal-directed practice coupled with targeted feedback. Armed with a STEM practice rubric, PDP participants are able to convey to their learners what success looks like and give targeted feedback. Referring again back to the defining requirements example, PDP participants can share their rubric with learners (conveys goals) and use the rubric to give targeted feedback ("requirements are not verifiable" vs. less targeted feedback such as "requirements are not clear").

This paper reports on the development and use of two frameworks and accompanying series of sequenced activities to support college students in understanding and reporting their findings from a summer internship project through the Akamai Internship Program (or "Akamai"). The frameworks are schema that unpack the complex practices of articulating a solution and articulating an explanation into dimensions that provide Akamai instructors a host of ways to give interns goal-directed practice and targeted feedback. The frameworks are the basis of a scaffolded experience for interns, in which they are reporting findings (solutions or explanations) initially with reduced cognitive load, then in increasingly complex ways in inquiry activities, until finally they are tasked with reporting the results of their summer project in an authentic symposium.

2. Context: The Akamai PREP Course

The Akamai Internship Program supports undergraduate interns from Hawaiʻi in an effort to retain local students in STEM career paths, particularly at high-tech and academic partners within the state. Akamai interns are drawn from a range of STEM disciplines in both 2- and 4-year degree programs, and the program focuses on including students from underrepresented and under-served groups of the islands, especially just after their first year or two of college when attrition from STEM pathways is particularly high. Each intern is placed with a mentor or set of co-mentors at one of the local observatories, high-tech companies, or University of Hawaiʻi campuses, and the program has a long history of success (Barnes et al., 2018).

The Akamai program runs for eight weeks every summer, beginning with the week-long Akamai Preparation for Research Experiences and Projects (PREP) course. The week-long PREP course has recently taken place at the University of Hawaiʻi at Hilo on Hawaiʻi Island and includes a range of sessions. The for-credit "Communication Course" focused on coaching technical writing and presentation skills begins during PREP with workshops on writing technical abstracts. This Communication Course is woven throughout the internship through weekly meetings, a mid-point technical presentation coaching session, and culminates in final technical project presentations by each intern in public symposia.

The PREP course also includes three science and engineering inquiry activities, designed and taught by a combination of PDP Design Teams and Akamai staff, all of whom have been trained through ISEE's PDP. These inquiry activities are carefully designed to give the interns authentic experiences with scientific and engineering investigations in order to prepare them for their internships. The activities all begin with the interns asking their own questions they will later investigate or design towards, facilitated by the design teams. Each activity focuses on a foundational scientific or engineering concept and cognitive STEM practice that are both relevant to many, if not all, of the interns' summer projects. The inquiries culminate in final presentations, poster sessions, design reviews or other knowledge sharing sessions that allow the learners to engage in real scientific and engineering forums and allow for educational assessments. This paper will describe in greater detail how Akamai staff have carefully designed frameworks, sessions, and the PREP schedule to complement these inquiry activities in order to prepare the students for their summer internships.

2. Frameworks: Explanations & Solutions

The Akamai Internship Program has a long history of engaging participating interns in various forms of "scientific communication" (see "Explaining using evidence" in Metevier et al., 2022). These include the reporting out done as part of inquiry activities within the PREP course as well as formal presentations of their projects to a public audience at the end-of-program symposia.

Over the years, Akamai staff have noted the challenges faced by interns as they grapple with the demands of this type of communication. In response, they developed a support called *Clarifying Your Project* which was designed specifically to help interns articulate the essential features of their projects in preparation for program symposia (Shaw, 2017). Two forms of the *Clarifying Your Project* worksheet were developed - one for projects that focus on seeking answers to a specific question or hypothesis about a phenomenon (the *Clarifying Your SCIENCE Project* version) and the other for projects whose focus is finding a solution for a particular need or problem (the *Clarifying Your ENGINEERING Project* version).

Subsequently, given the recognition that *comprehending* a project is an essential precursor to being able to *clarify* a project, Akamai staff renamed the documents as *Understanding Your Project: EXPLANATION* and *Understanding Your Project: SOLUTION*. With this revision, the title words in all caps indicate the shift in focus from a discipline (i.e., science or engineering) to the type of result from a STEM project, namely explanation or solution. Notwithstanding, the essential components of each worksheet remained the same with minor modifications to format and descriptive text. Described below are the underlying frameworks around which the two worksheets were designed.

2.1 Explanation Articulation Framework

The claim-evidence-reasoning framework is a well-established approach to supporting learners' development and articulation of scientific explanations in educational settings (Berland & McNeill, 2010; McNeill et al., 2006; McNeill & Krajcik, 2008). As translated to the Akamai context and expressed on the *Understanding Your Project: EXPLANATION* worksheet, the C-E-R framework components are described as follows:

Claim: A statement or conclusion that answers the question and has causal structure ("The answer is X because …").

Evidence: Scientific data that support the claim. The data need to be **appropriate** and **sufficient**.

Reasoning: How the evidence is linked to the claim through scientific principles. Why the data count as evidence. May be a chain of reasoning.

2.2 Solution Articulation Framework

An effective expression of a solution to an engineering problem often hinges on the degree to which a proposed solution meets specified requirements. In conjunction with an educational researcher, ISEE staff investigated this aspect of scientific communication and developed a "solution articulation" framework (Arnberg, 2014). This work was informed by research in the field of engineering education such as Robertson and Robertson's (2012) book titled *Mastering the Requirements Process: Getting Requirements Right*. As expressed on the *Understanding Your Project: SOLUTION* worksheet, this framework has the following components:

Need: The specific problem being addressed; recommended to be a single, short statement.

Requirements: What the solution must do or accomplish to address the need/solve the problem.

Constraints: Notable limitations to possible solutions.

Solution: Proposed solution, method, or process.

Justification: How you convince others that the solution meets the requirements.

2.3 Summary

In summary, ISEE has supported the development of two worksheets to help interns engage in scientific communication of their projects. Titled *Understanding Your Project: EXPLANATION* and *Understanding Your Project: SOLUTION*, respectively for projects that answer a phenomenon-related question or address a problem or need, these worksheets are based on research-backed frameworks for scientific explanations and engineering solutions. Considered to be "living documents," these worksheets remain open to revision as necessary to better support interns and other users.

As will be described in the next section, Akamai staff and PDP teaching teams alike use the above frameworks and worksheets to design and implement activities that support interns in enhancing their proficiency with the complex process of scientific communication.

3. Synergistic Support: Frameworks & Inquiries

In this section, we describe the layout of the inquiry activities and supporting frameworks in the PREP course schedule. This sequence of events is graphically portrayed in Figure 1. The carefully chosen inquiry activities engage the learners in scientific and engineering practices they will undoubtedly use in their internships, and the frameworks allow for reflection on and practice with these transferable skills in ways that translate to the interns' projects. While we have found that most internships ultimately involve designing solutions to identified problems *even if they are scientific projects*, the ability to make scientific claims and justify them using collected evidence is an inherent part of every collaborative project.

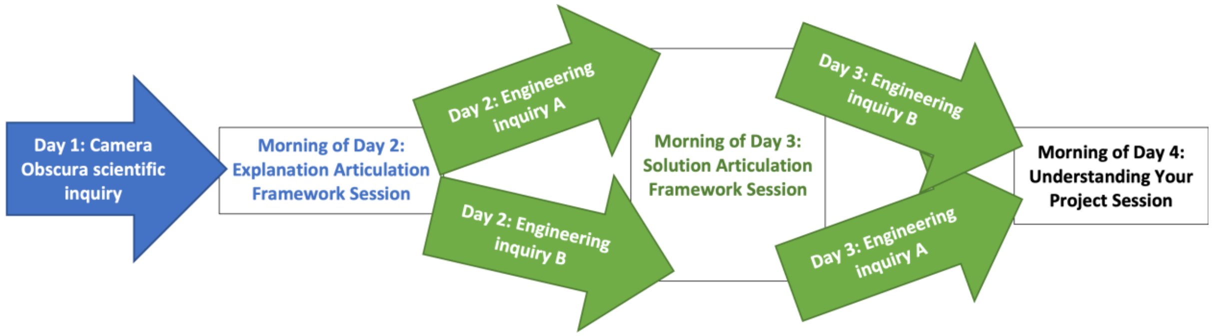

Figure 1: Sequence of inquiries and framework use during Akamai PREP course. All Akamai interns participate in a scientific inquiry together on day 1 and reflect on their engagement with the STEM practice of crafting scientific explanations the morning of day 2 with the **Explanation Articulation Framework**. The interns then split into two groups, participating in two consecutive engineering activities on days 2 and 3, with a session on the STEM practice of defining engineering requirements using the **Solution Articulation Framework** in between. On the final day of the PREP course, the interns take these experiences and apply the frameworks to their own summer projects.

A typical PREP course schedule includes three inquiry activities, all designed and facilitated by past or present PDP participants. The very first day of the course quickly kicks off with an inquiry known as "camera obscura," Latin for "dark chamber," which centers around fundamental characteristics of light propagation. This activity is designed as an authentic scientific inquiry in which the learners observe interesting and perplexing phenomena, write down questions about what they observe, and then form groups around questions they spend most of their time investigating. These groups design their own experiments to answer their questions, collect and analyze data, and ultimately present their results to their peers, all while being guided by PDP facilitators who maintain learner ownership over the process and results. The activity's focal STEM practice goal is to have learners gain experience with and coaching on how to make an evidence-based claim and justify it with scientific reasoning. Investigation teams spend much of their time making claims (their hypotheses) and being pushed by facilitators to explain them with evidence and reasoning linking the two. Their final presentations revolve around a final set of these claims, the evidence they have collected to back it up, and the causal relationships they have inferred.

The morning of the following day, Akamai staff run a session with the **Explanation Articulation Framework** in which the interns reflect on the claim-evidence-reasoning process they all undertook during camera obscura and gain additional practice using hypothetical scenarios. For example, the interns are given a data table containing chemical properties (density, color, mass, and melting point) of four liquids. They are tasked with writing a scientific explanation in response to the question, "Are any of the four liquids the same substance?" The quality of their responses is discussed in terms of the presence or lack of a definitive claim (e.g., naming any similar substances) that is supported by reference to scientific principles relating to the data provided (e.g., liquids A and B are the same because they have the same density, which is one of the properties used to identify similar substances).

Following this session, all interns participate in a second inquiry activity. The cohort is split into two groups and experiences the two remaining inquiries in either order over the next two days. Because making scientific claims is so fundamental to all of science and engineering, the interns gain additional practice with and feedback on this practice in both subsequent inquiry activities.

The morning of the third day of the PREP course, between the two final inquiry activities, Akamai staff run a session with the **Solution Articulation Framework**. Similar to the Explanation Articulation Framework session, the interns reflect on how to turn an engineering goal into defined requirements and a solution that is justified by meeting those requirements. They apply the framework to hypothetical engineering scenarios and get feedback from each other and Akamai staff on their process. One scenario that interns grapple with is a telescope redesign based on a real Akamai internship project, in which interns are given a detailed description of the redesign that includes the project needs, requirements and constraints without being told which are which. The interns use the frameworks to demarcate and discuss these distinctions and get feedback from Akamai staff. Following this session, the interns participate in their third and final inquiry activity, whichever they did not do the previous day.

The content and STEM practice foci of these two activities vary from year to year because the inquiries are designed by PDP teaching teams who formulate their own goals, but PDP staff work closely with the PDP design teams so that the activities involve a practice closely related to defining engineering requirements. Frequently, PDP design teams will use the frameworks, particularly the Solution Articulation Framework, to help define their STEM practice goals and rubrics. As Akamai interns participate in the two engineering activities, the Solution Articulation Framework session pushes interns to reflect on and improve at working with engineering requirements.

On the morning of the final PREP course day, Akamai staff run an "Understanding Your Project" session drawing together each of the frameworks and the interns' practice with these skills as they apply them to their internship projects that they are about to begin. Interns break down their mentor-provided project descriptions and any additional information they have received and begin to define their project in terms of the need, requirements, constraints, possible solutions, and how they will justify that they have met the need. As mentioned earlier, Akamai staff have found that most projects involve designing a solution, even when they are initially framed as a scientific investigation.

The combination of three scientific and engineering inquiry activities, supported by the Articulation Frameworks and corresponding sessions, and the ultimate application to the interns' own projects effectively prepares the Akamai interns for engaging with the invaluable and universal practices of justifying scientific claims using evidence and defining engineering requirements in order to design a solution meeting a need. These frameworks are revisited throughout the internship during the Communication Course by Akamai staff and are used to iteratively refine the interns' understandings of their projects, aid the interns in progressing towards their projects' goals, and finally to effectively communicate their project outcomes to technical audiences at the final symposia.

4. Closing Comments

In this paper we share our approach to supporting STEM undergraduates (e.g., Akamai interns) in learning the nuances of critical STEM cognitive practices associated with authentic experiences in science and engineering. In applying precepts from the learning sciences along with existing schema in teaching practice, we developed frameworks for understanding, unpacking, and developing science explanations and engineering solutions. We present these frameworks to interns in the form of concise documents that provide a basis from which, over time, Akamai staff iteratively work from to enhance intern understanding of and capability with science explanations and engineering solutions. As part of the Akamai Internship Program, interns have the opportunity to demonstrate these skills in an authentic forum, namely the end-of-program symposia during which they present key aspects of their internship project.

We have found the pairing of the frameworks with activities that provide the opportunity for their application to actual experiences (e.g., inquiry activities led by PDP teaching teams during the Akamai PREP course) to be powerful learning supports for STEM undergraduates. Akamai Communication Course instructors have noted interns' improved understanding and articulation of their projects as they revisit the frameworks while writing abstracts and preparing symposium presentations.

We have designed this pairing of the frameworks and inquiry activities to offer an additional benefit: the bolstering of each intern's identity as a person in STEM. In the introduction, we described one of ISEE's cornerstones, cognitive STEM practices. Another major ISEE theme is known as "Equity & Inclusion" (E&I), which encourages ISEE program participants to use research on equitable and inclusive pedagogy and leadership to support learners (Seagroves et al., 2022). One of the focus areas of the E&I theme is "Developing an identity as a person in STEM," acknowledging that STEM environments have their own cultural norms and values. The inquiry activities and use of the frameworks give multiple opportunities for Akamai staff to explicitly draw attention to some of these common STEM norms and values (e.g., specific ways of constructing explanations and developing engineering solutions, as well as the language used in practice). Akamai interns reflect on their integration into STEM norms and values, their agency as authentic scientists and engineers in the PREP course activities where they receive practice and feedback in a deliberately low-stakes environment before entering their internship site as apprentice scientists and engineers.

Especially important is the carefully sequenced introduction and use of the frameworks over time coupled with targeted feedback from staff. We encourage others who work with learners in similar contexts to consider the use of our, or the development of their own, frameworks so that STEM undergraduates can more deeply understand as well as perform the complex cognitive skills practices of developing scientific explanations and determining viable solutions to engineering problems.

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