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### Authors
Perez, Kauahi
Barnes, Austin
Mousavi, Ali
et al.



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# Incorporating PDP Themes the Akamai Way

Kauahi Perez[*1], Austin Barnes[2], Ali Mousavi[3], Richard Kassab[4]

[1] Department of Tropical Plant and Soil Sciences, University of Hawai'i at Mānoa, Honolulu, HI, USA
[2] Scripps Institution of Oceanography, University of California San Diego, La Jolla, CA, USA
[3] Department of Mechanical Engineering, University of Hawai'i at Mānoa, Honolulu, HI, USA
[4] Department of Physics, University of California, Santa Cruz, Santa Cruz, USA
*Corresponding author, kauahip@gmail.com

## Abstract

As part of the Institute for Scientist and Engineer Educators Professional Development Program (PDP), our team designed an activity for the Akamai internship program's Preparation for Research Experiences and Projects (PREP) course. The activity focused on content around different renewable energy and storage technologies, and the widely applicable engineering practice of optimization through iteration and evaluating trade-offs. Here we describe the overall activity, with primary emphasis on how the PDP backward design process and integration of the Equity & Inclusion (E&I) theme led us to design and implement a unique model we call the "expert training model" that has important E&I implications. We found that an educational activity design that focuses on E&I considerations, such as identifying multiple ways to productively participate and developing learners' identity in STEM, simultaneously satisfies criteria for being an engaging and authentic STEM experience. We also reflect on potential pitfalls and ways to improve and adapt this model.

Keywords: activity design, engineering, equity & inclusion, optimization, renewable energy

## 1. Introduction

The Institute for Scientist & Engineer Educators (ISEE) Professional Development Program (PDP) is a program operated through the University of California, Santa Cruz, and provides opportunities for early career scientist- and engineer-educators to engage with the teaching and learning of research skills, reasoning skills and content understanding (Hunter et al., 2010). In addition, PDP participants learn to value and intentionally incorporate diversity and equity considerations, formative and summative assessment strategies, critical use of education research, knowledge about effective education practices, and interdisciplinary dialogue.

Participants are then assembled into teaching teams in which they use ISEE's educational framework to design their own inquiry activities, develop a detailed lesson plan, and teach their activities in undergraduate science and engineering laboratory settings. It is worth noting here that although the PDP assembles participants into teaching teams, they are not "teachers" *per se*. Rather, they are regarded as facilitators of learning. In short, participants come to the PDP early in their careers and emerge as leaders who integrate research and education to facilitate learning in their professional practice.

Inquiry activities that are designed within the PDP are then piloted in a variety of PDP teaching venues that include an array of educational settings and learners (Institute for Scientist & Engineer Educators, 2019). This paper will describe an engineering activity that was designed in the PDP and implemented as a component of the Akamai internship program's Preparation for Research Experiences and Projects (PREP) course.

## 2. PDP themes

The ISEE's PDP curriculum incorporates three central themes: inquiry, equity and inclusion, and assessment. The PDP emphasizes how to consider these themes and related education research to design and teach science and engineering activities. Every PDP activity incorporates all three themes in different ways and to different extents, but this paper will discuss how iterative activity design with a focus on the inquiry and equity and inclusion themes led to the development of our activity's central "expert training" model.

Inquiry can be a powerful means for students to learn substantive content and laboratory skills, and to develop ways of critically thinking about science and engineering (Metevier et al., 2022). However, the term "inquiry" can be interpreted in many ways. ISEE's definition of "inquiry" includes a combination of teaching and learning of research skills, reasoning skills, and an understanding of content (Hunter et al., 2010, see for greater detail). ISEE's definition of "inquiry" extends to engineering activities that mirror design practices of engineers. The PDP's inquiry activities are designed in a manner that integrates six key elements, as outlined in the ISEE curriculum: cognitive science, technology, engineering, and math (STEM) practices, foundational scientific concepts, intertwined concepts and practices, mirroring authentic research and design, ownership of learning, and explaining using evidence (Metevier et al., 2022). The cognitive STEM practices are defined by ISEE as "reasoning processes that scientists and engineers use to understand the natural world and solve problems" (ibid.). The emphasis on teaching and giving learners time, space, and support in practicing and improving at least one fundamental STEM practice is one of the most unique aspects of the PDP.

In addition to inquiry, ISEE incorporates an Equity & Inclusion (E&I) theme as part of the PDP curriculum (Seagroves et al., 2022). The underlying focus areas of E&I include: 1) multiple ways to productively participate, 2) learners' goals, interests, and values, 3) beliefs and biases about learning, achievement, and teaching, and 4) developing an identity as a person in STEM. PDP participants read research papers on issues of equitable and inclusive teaching practices and intentionally integrate specific E&I focus areas into their activity designs and personal facilitation strategies.

## 3. Teaching venue

The Akamai Internship Program is intentionally designed to support students from underrepresented and under-served groups from Hawaiʻi, and focuses on including students in their early years of college when attrition from STEM is high (Barnes et al., 2018). Moreover, the program serves students who are interested in a broad range of STEM career paths, especially those that require 2-year and 4-year degrees. Interns gain valuable work experience at an observatory, scientific company, or technical facility in Hawaiʻi during a 7-week summer internship. The overarching goal of the program is to connect local students with interests in STEM with local high-tech industry and academic partners to help build Hawaiʻi's scientific and technical workforce.

Immediately preceding their internships, as part of the Akamai Program, all interns complete a 1-week preparatory short course, known as the Preparation for Research Experiences and Projects (PREP), at the University of Hawaiʻi at Hilo on Hawaiʻi Island. The PREP course includes a wide range of activities including 2–3 inquiry activities, supporting sessions in which the interns analyze and reflect on the scientific and engineering STEM practices from the inquiry activities, workshops on writing scientific and engineering abstracts, a career pathway networking discussion, and other technical, professional, and community building sessions. The inquiry activities are a mix of both science and engineering inquiries that focus on content and STEM practices applicable to a wide range of internship projects and intern career paths (e.g., defining engineering requirements, designing and carrying out scientific experiments). By the end of PREP, interns are prepared for working at their internship sites (Barnes et al., 2018).

In June of 2014, our activity was part of the week-long PREP course. We piloted our activity twice over a 2-day period with a total of 30 STEM undergraduates, split up into two groups of 15 students per day. Each iteration of our activity took approximately 5 hours to complete (Table 1). Students ranged from first-year undergraduates through recent graduates, all of whom were either originally from Hawaiʻi or were attending Hawaiʻi-based colleges. Majors varied within the STEM disciplines, but many of the Akamai interns were in computer science and engineering fields, reflecting the workforce needs of the local high-tech partners.

# 4. Engineering a renewable energy activity

## 4.1 Goals for learners

In designing our activity, we focused on a primary content learning outcome and a focal STEM practice that we felt were central to the field of engineering. The primary content learning outcome focused on having students use the concept of intermittency of renewable energy resources to devise a strategy to meet a known power consumption demand. The focal STEM practice goal engaged learners with optimization through iteration and evaluating trade-offs. In an engineering-specific context, we broke down optimization into key dimensions including developing optimality criteria, identifying variables, identifying guiding principles to calculate variables, recognizing the interdependence among variables, evaluating trade-offs, and exploring variable space.

As added complexity to the core concept of renewable energy resource intermittency, we wanted our learners to demonstrate a more nuanced understanding of the limitations of harvesting renewable energy from various sources (i.e., wind, solar, waves) and storing it. Specifically, we wanted them to demonstrate how the intermittency of these sources of harvestable energy might depend on

**Table 1: Overview of Activity Components and Timeline.**

| Activity | Time |
|---|---|
| Introduction | 15 min |
| Starter Activity — Raising Questions | 30 min |
| Group Formation & Discussion | 30 min |
| Expert Training | 15 min |
| Focused Investigation Phase I: Equal Distribution | 60 min |
| Jigsaw Discussion Phase I | 15 min |
| Focused Investigation Phase II: Minimize Excess Production & Costs, Incorporate Automated Spreadsheet | 45 min |
| Jigsaw Discussion Phase II | 15 min |
| Focused Investigation Phase III: Impose Additional Constraint of Team's Choosing | 20 min |
| Poster Preparation | 10 min |
| Poster Presentations | 30 min |
| Synthesis | 15 min |

complex climate, location, and temporal considerations.

## 4.2 Activity description

We began our activity with an introduction of ourselves and a preview of the nature of our inquiry activity, particularly since these types of learning methods are not commonly employed in undergraduate curricula. To provide additional activity-specific context, we introduced the concepts and definitions of renewable energy, power and energy management, the necessity of renewable energy broadly and within Hawai‘i, and discussed an overview of the activity in which they would engage.

The starter activity, now known in the PDP as the Raising Questions component, was designed to briefly expose the learners to the different sources of renewable energy (i.e., solar, wind, wave energy) and storage of excess energy production that they would later investigate throughout the activity (Table 1). Students were assembled into groups of four and rotated through each of four stations that represented the four power source domains and respective harvesting technologies (solar power – photovoltaic systems, wind power – wind turbines, wave power – Pelamis Converter, and energy storage including grid stability). At each station, a facilitator gave a brief introduction to the technology, followed by a demonstration using models that hinted at the benefits and limitations (especially intermittency) of each power source and energy harvesting technology. Students were then asked to write down their thoughts, observations, and most importantly any questions that came to mind before they rotated to the next section (Fig. 1).

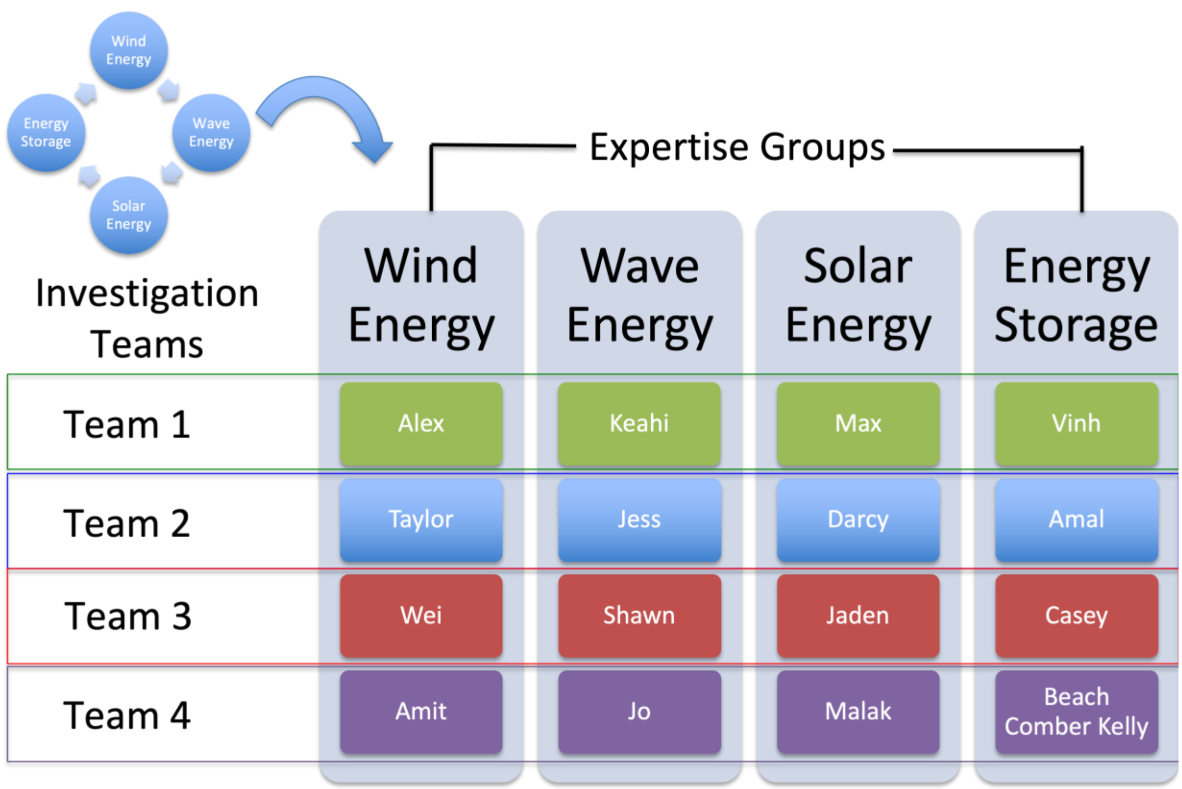


**Figure 1: Structure of Investigation Teams**. An example of how investigation teams were structured to include one member from each of the renewable energy Expertise Groups. Following the starter activity rotations (upper left, in blue) in which learners were briefly exposed to each possible technology and raised their own questions, each learner chose the renewable energy technology of greatest interest to them and received deeper, “expert” training on the respective subject.

After the starter activity, students were given the opportunity to sign up for training to become an "expert" in one of the technologies that they found most interesting. For each technology, though, only four slots were available for expert training as we simultaneously assembled groups of four comprised of one expert from each technology.

This group of four students consisting of one expert from each renewable energy field would work together as investigation teams for the better part of the activity (Figure 1). The year this activity was piloted in PREP, there were only 15 participating students per day, so we opted to have one of the facilitators assume the role of the fourth member of the cohort that had only three students in it, depending on which technology expertise was missing from the group. At this point, students were also given the option to switch expert roles within groups if they chose. After cohorts had made their final selections of expert roles, they were given their objective to develop a strategy to meet the average daily power demand curve for Hawai‘i Island using a relatively equal amount of power supplied by each technology. Students then brainstormed in their cohorts to generate questions about information that they would need to meet this objective, priming them to enter the training sessions already equipped with questions to ask facilitators about their respective technologies.

We then began the Expert Training module (Table 1). In this module, students were regrouped based on the technology about which they chose to learn more information, so that wind experts were in one group, solar experts were in another, etc. Each facilitator led a training session, providing in-depth information about the technology, including how to harvest energy from a given energy source, and introducing any pertinent field-specific terminology. Students were given information sheets summarizing this information and jargon that they could refer to during their focused investigations. At the end of the training session, students were also able to ask questions to the facilitator that were not already answered in the training. Students then returned to their investigation teams as "experts" of their chosen technologies.

We decided to break up our focused investigations into three distinct phases, imposing more constraints at each phase. In the first phase, using the information they gained in the expert training sessions, cohorts were tasked with developing a solution to meet the average daily power demand for Hawai‘i Island using a relatively equal amount of power supplied by each technology.

Once all groups found a solution, we then transitioned into the first jigsaw discussion phase (Table 1). In this jigsaw phase, experts returned to their expertise groups (i.e., the same groups as in the expert training session) to share their solutions with other groups, thereby exchanging information and gaining insights into how other groups came up with solutions. Students then returned to their investigation teams to discuss solutions from other groups and modify their team's design from Phase I.

In Phase II of the focused investigations (Table 1), cohorts were tasked with the same objective, except with the added constraints of minimizing excess production and costs. In addition, it was at this time that we introduced our "thinking tool" to scaffold their approach to reaching an optimal solution to their objective. We had pre-programmed a spreadsheet that incorporated realistic daily patterns for Hawai‘i Island (e.g. solar hours and intensity, wind speeds, and wave climates) to automatically calculate power generation and storage capacity based on the designed scale of each technology. This tool also tabulated the total cost of the proposed design, and graphically represented daily power output and storage curves against realistic power demand curves (Figure 2). Students used this tool to test different designs as they settled on a solution. They could vary the amounts of solar panels, wind turbines, wave devices, and storage devices to see how each technology affected costs and outputs of

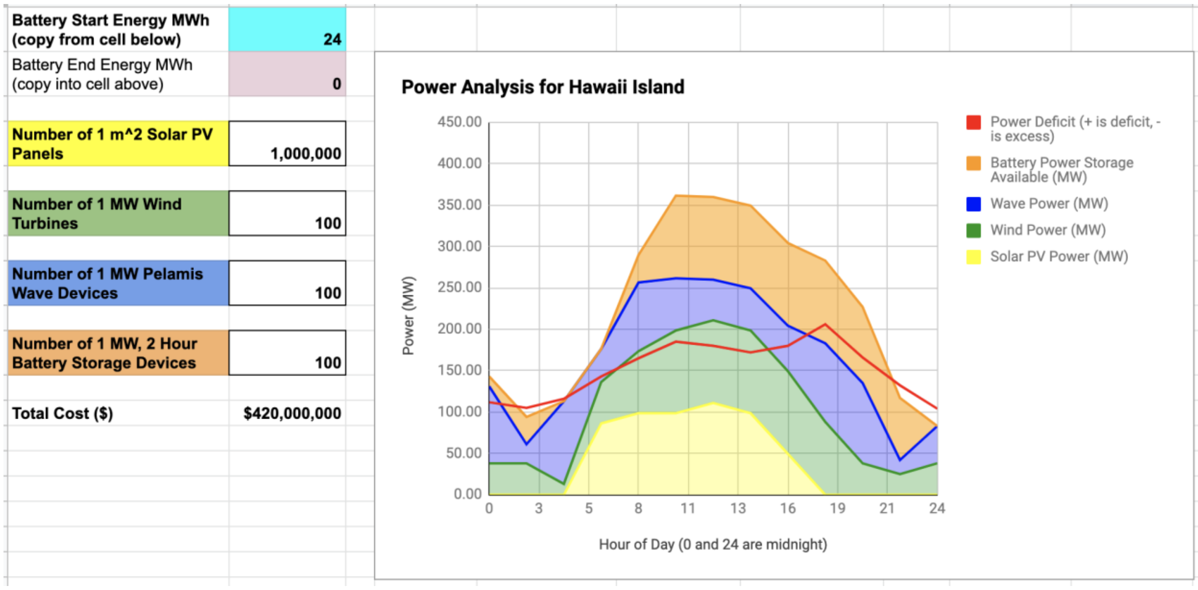


**Figure 2: An Example of Our "Thinking Tool."** This pre-programmed spreadsheet incorporates realistic daily patterns for Hawaiʻi Island to automatically calculate power generation and storage capacity, and graphically represent daily power output and storage curves against realistic power demand curves. We have included an example of a team's design iteration, showing parameters that students could modify (cells outlined in black) to model a combined solution meeting the daily power demand and estimate costs associated with this design.

power, and eventually develop an "optimal" solution. Their design was not considered successfully optimized unless they could meet the power demand for at least five consecutive days.

During the Jigsaw Discussion Phase II (Table 1), student experts again returned to their expertise groups to share what combinations of each of the four technologies they considered an "optimal" solution. Here, we would like to stress that there was no right or wrong answer, and answers varied depending on how each group identified their optimality criteria, outside of the constraints we had imposed.

In the final phase of focused investigations, Phase III (Table 1), students were given the same task and constraints; that is, meeting the average daily power demand curve for Hawaiʻi Island while minimizing costs and excess power production. However, students were to impose an additional constraint of their choosing when coming up with a different design. For example, one group chose to minimize the ecological footprint of their design by using more wave energy harvesters in place of wind turbines to alleviate potential impacts on the native Hawaiian owl population. This phase of the activity built on students' understandings from previous iterations and introduced a new environmental variable or constraint (of the student group's choosing) that they would also strive to minimize or maximize. This additional level of constraint is also a step closer to what engineers in the real world would need to consider when dealing with multiple constraints. Many groups found Phase III particularly challenging to find an optimal solution as they had to track changes and constantly reflect on their solutions considering the optimality criteria and overall objective.

The culminating assessment task for our learners involved a poster presentation. Cohorts were given poster paper and markers, and prompted to explain their objective(s), the variable(s) they were trying to optimize, and indicate their optimality criteria and final optimum solution, including what harvesting technologies they used and how much the entire design would cost. Additionally, each group member of a cohort was responsible for discussing a significant component of their group's poster; this allowed facilitators to assess each student's understanding of a particular aspect of their investigations in addition to the group's solution as a whole.

We concluded with a synthesis of the entire activity, reviewing the learning outcome and focal STEM practice of optimization in which we wanted students to engage, and acknowledging how students each contributed to our collective knowledge. We also expanded our learners' understanding by taking what they just learned in the activity and applying it to a broader context and real-world scenarios as renewable energy and technologies involve concepts that are rooted in multiple fields of STEM (i.e., science, engineering, geography, etc.). Emphasis was placed on how intermittency can take place on different time scales and with other renewable energy technologies. We demonstrated how intermittency is a real problem faced by the current renewable energy sector, so we commended our learners for deeply engaging with this issue in such a short period of time.

### 4.3 The "expert training" model of investigation

Here we will describe in greater detail a key component of our activity that we have called the "expert training" model, summarized in Figure 1. In the next section, we will describe how this component and other complementary considerations were designed in response to the PDP's Equity & Inclusion theme. Recall from section 4 in the activity description that our starter activity rotations had all learners rotate through stations for each of the renewable energy technologies we showcased: wind energy, wave energy, solar energy, and energy storage. These rotations exposed all learners to basic topical concepts and gave time and space for the learners to generate their own questions about the individual technologies. Following the starter rotations, learners independently indicated the technology of greatest interest to them; if we ended up with an imbalance between the technologies we asked for volunteers to shift to their second technology of choice. Learners were given context ahead of this decision that they would receive additional, deeper training on whichever technology they chose, and would represent this technology in a team comprised of one member from each technology. We encouraged learners to choose a technology in which they were interested, but about which they were not necessarily already very familiar, to encourage challenging themselves to learn a new technology and avoid imbalances in familiarity and expertise.

Before additional training, activity facilitators split up the expertise groups into focused investigations teams comprised of one member of each technology. In forming these groups, we considered group diversity from multiple angles including gender, ethnicity, educational level and background, and any additional relevant information we had gained through our interactions with the learners. The groups were told that they were to work together to meet the energy consumption demand of Hawaiʻi Island and would do so by integrating each technology into the solution. They were given time to discuss as a group what kinds of questions they needed to ask in their individual training sessions.

Learners then broke into their chosen technological groups and received additional training from one of the facilitators who prepared a short training module. The training module included relevant technical jargon and an accompanying jargon reference sheet, as well as nuanced considerations about these technologies: underlying physical principles of the energy harvesting and specific geographical, temporal, and climatic availability of this resource on Hawaiʻi Island. Learners had ample time to discuss their technology together as a group and with the facilitator and ask questions they and their investigation teams had come up with. Facilitators stressed to the learners that they would be their chosen technology's "expert" in the subsequent focused investigations, and would be tasked with helping to make sure considerations of their technology were incorporated into their team's solution designs.

After the training, the focused investigation groups reconvened and carried out their solution designs.

We structured in additional time during the activity for the technological expertise groups to reconvene and share their groups' solutions and how their individual technologies were being incorporated into the design. These discussions reinforced the expert group community, sparked additional design considerations teams may not have thought about, and fostered collaboration rather than competition between investigation groups.

## 4.4 Emphasis on equity & inclusion design lens

We incorporated equitable and inclusive pedagogy in multiple components of our activity. As a nod to place-based learning (see, for example, Smith, 2002, and references therein), all teams focused their investigations and energy demand designs on Hawai'i Island, the island on which the Akamai PREP was taking place and roughly half of the learners would carry out their internships. Investigation groups were ultimately tasked with meeting a representative average daily power demand curve for Hawai'i Island through a balanced use of the four renewable energy technologies. The data on renewable energy resource availability, including climate, location and timing criteria, for each of the technologies was also pulled from real, context-specific data to both consider learners' goals, interests, and values (one of the E&I focus areas) and to mirror "authentic research and design" (one of the elements of the Inquiry theme).

In addition to activating learners' individual goals, interests, and values by grounding the activity in a local context, we intentionally designed the starter activities and expert training model to allow learners to pursue their interests and incorporate their values. The starters piqued interest in at least one of the four renewable energy technologies. During these rotations as well as the time with their focused investigation groups before the expert training, learners generated their own questions they would later investigate. We intended to enhance individual ownership of learning by giving each person the choice of technology in which to get trained further and represent in the group's solution. It is worth noting that many interns expressed explicit interest in renewable energy in their applications to the Akamai Internship Program, so the activity was also intentionally focused on this topic to tap into this curiosity.

The expert training model, sessions, and context given to the learners were all deliberately designed with the learners' diverse backgrounds, self-efficacy, and STEM identity in mind. Our design team's experiences and personal connections to Hawai'i gave us valuable insights into some of the local educational norms. Even if some learners came in with cultural backgrounds in which challenging others' ideas or speaking up independently was not typically practiced or socially acceptable, the fact that every person had to represent their technology in their group's solution encouraged more equitable participation. Indeed, prior to the expert training module, multiple learners expressed feeling uncertain or inferior relative to others' content knowledge and experience. We wanted this model to encourage growth in individual learner's self-efficacy, which can be defined as one's belief in his or her ability to complete tasks and reach particular goals, and their identification as a "person in STEM" (e.g., a scientist or engineer in this context) which have both been positively linked to academic performance and retention (Trujillo and Tanner, 2014). By treating the groups learning individual technologies as "expertise groups" with additional, exclusive training and jargon, we hoped to increase each learner's sense of being a valuable contributor to their group's final design solutions and as a true, practicing engineer. In addition, we designed our activity such that learners would collaborate multiple times in both their expertise groups as well as their focused investigation teams because Trujillo and Tanner (2014) also found that collaborative learning contexts were often linked to positive self-efficacy and self-identification as a person in STEM.

We provided every learner with technical jargon handouts specific to each technological expertise to address different cultural backgrounds, comfort with language, foster a greater sense of belonging, and address inherent beliefs about learning and achievement. Participants in the Akamai Internship Program come from such a diverse array of educational backgrounds and majors that we knew very few would have had significant exposure to these topics. In addition, many of the students speak the local “pidgin” or are multilingual and would have varying levels of comfort with the scientific and engineering jargon. We wanted to arm everyone with definitions and notes that would be relevant for learning the concepts and then communicating them with their teams to level the playing field for these varying levels of comfort, strengthen every individual’s sense of belonging in the scientific and engineering field in which we were operating, and positively reinforce their beliefs that they could learn and achieve in this STEM context.

Many other aspects of any PDP activity design contribute to considerations of equity and inclusion, so we will not touch on them here. However, by intentionally designing and employing our expert training model, we attempted to bolster multiple focus areas of the PDP’s Equity and Inclusion theme by providing multiple ways for learners to productively participate, supporting learners’ goals, interests, and values, and providing opportunities for learners to develop an identity as a STEM person.

## 5. Assessment description

As our content learning outcome was for students to demonstrate an understanding of the intermittency of renewable energy sources by devising a strategy to meet a known power consumption demand, we assessed our learners based on three basic criteria as evidence of understanding (Appendix A). First, we assessed students on how well they could calculate power output for each source of renewable energy (wind, wave, solar power) throughout an average day. Second, we assessed them on their ability to use multiple sources to meet the average demand curve at each time interval. Finally, we assessed them on their ability to use energy storage technology to provide power during times of lower energy output from renewable energy sources.

## 6. Future considerations

Overall, the engineering activity we designed was a success, both in terms of meeting the activity goals and the PDP goals (such as equity and inclusion, etc.). Our learners gained practice and feedback on the focal STEM practice of optimization by iterating their strategy, attempting to meet their goal while finding the lowest cost, and finally evaluating trade-offs with other identified variables. However, there were a number of modifications that we considered for future iterations of this activity. The following are just a few of the salient considerations.

Regarding the central scientific and engineering content goals of our activity, we noticed that some students were using the terms "power" and "energy" interchangeably, despite the fact that these terms represent different physical quantities. Those students that were using the terms interchangeably were confusing the other students in their groups (who understood the distinction between the two terms) because similar units, for example megawatts (MW) and megawatt-hours (MWh) describe power and energy, respectively. Therefore, we have agreed that in the introduction and throughout the activity we should emphasize the concepts of power and energy, and elaborate on the distinction between the two.

While our learners engaged in our STEM practice goal of optimization, we suggest improvements to emphasize practice and feedback on the dimensions of this fundamental practice. We should have stressed how important developing optimality criteria that would allow for solution evaluation is for an iterative process like this. We also found that many students were tempted to guess-and-check without reflecting on their optimality criteria (e.g., meeting demand, lowering cost, limiting excess power production, etc.) within the solution space rather than reason their way to ever-increasingly optimal solutions. One factor was the spreadsheet we employed as a way for students to design and test solutions. We suggest that facilitators should control the input and testing of a group's solution, asking for justification before allowing the groups to iterate on their solution. This crucial step would slow groups down and draw out more intentional thinking and design. Facilitators should also encourage groups to reflect on their objectives after each iteration, and to evaluate their results considering their goal and optimality criteria. A more sophisticated program could also allow learners to impose their own constraints on the program, bringing in their own interests and values on top of the cost constraint we imposed in Phase II.

We suggest that prior to learners working in their focused investigation groups towards a full solution, individuals could spend some time thinking about how they could use their respective technology's power output to meet demand, in the absence of the other technologies. Then, in their teams, they could all explain to each other how they calculated their technology's output to meet the total demand. Doing so could help make each member's thinking visible to their teammates and allow for team members to get on the same page if any discrepancies or misunderstandings arose, especially around the distinction between energy and power.

Finally, we suggest dissolving the distinct boundaries between investigation phases I, II, and III described earlier. The PDP has since pushed teams to move away from this amount of formal structure in an inquiry activity. Instead, learners should be given the full design task at the outset of their focused investigation time, including all goals and constraints. The onus then falls on the group facilitators to push teams at an appropriate pace, potentially suggesting starting with smaller tasks akin to the separate goals for each of the phases described here. The jigsaw discussion phases can still be used as sign posts for team progress but would be more flexible in response to the various investigation pathways that teams take.

## 7. Legacy of the expert training model

The expert training model allowed multiple opportunities for learners to express their understanding that were in alignment with our content and practice goals. Additionally, we carefully designed our activity so that each team had only one "expert" in wind, wave, solar, or storage technology. We feel that this approach gives each team member an opportunity to make significant contributions to the group's progress while simultaneously managing group social dynamics and some cultural background considerations, and providing authentic roles for individuals to play in each team.

However, since its inception, this model that we developed has been adopted and modified by several PDP teams in subsequent years. Additionally, it was leveraged for instructional purposes in the PDP. Thus, this serves as an example of how models can be developed and adapted to fit within a variety of learning environments.

The PDP community has also discussed additional considerations we did not have at the time of our initial design, providing rich grounds for further discussion about truly equitable and inclusive pedagogy. For example, PDP participants have repeatedly brought up the valid concern that the use of the terms "expert" and "expertise" may put unintended pressure or induce additional anxiety on learners because of the implications that such a loaded term carries.

Another common pitfall is that the expert model can lead to the design of multiple, separate activities with distinct content goals within a single inquiry. For example, if we had assessed our learners based on their demonstrated understanding of their chosen technologies, we would have had to develop separate content goals and rubrics for each technology, equivalent to designing multiple inquiries. We carefully navigated this by focusing our assessment, and therefore our design overall, on the unifying concept of renewable energy intermittency. Activity designers should carefully consider the unifying concept before breaking it out into any expertise groups, and make sure that the depth of knowledge required in each expert grouping is much smaller than that of the overarching activity goals. We therefore encourage any practitioners to carefully consider the use of the “expert” and ”expertise” terms (and any alternatives) and the alignment of the activity goals with the expertise grouping design itself before implementing in a new context.

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# Appendix

**Table A1. Assessment Criteria for Content Learning Outcome:** Students will demonstrate an understanding of the intermittency of renewable energy sources by devising a strategy to meet a known power consumption demand.

| **Evidence of understanding** | **0 (didn't show)** | **1 (partially shown and/or partially correct)** | **2 (showed correctly and completely)** | **3 (showed with some extra nuance)** |
|---|---|---|---|---|
| **Evidence:** Calculated power output for each renewable energy source over relevant time scale | | Calculated power output correctly for only 1 or 2 of 3 sources. | Calculated power output for solar, wind, and wave sources with given data. | Discussed or indicated other time scales of intermittency (e.g. seasonal changes) |
| **Evidence:** Used multiple sources to meet demand curve at each time interval | Used one source. | Used a mix of sources but a negligible number of a source. | Used a mix of sources with significant contributions from each. | Used all sources. Took advantage of each source's peak production during the day. |
| **Evidence:** Used energy storage to provide power during times of low energy output from renewable energy sources. | Did not use energy storage at all. | Used a negligible number of batteries. | Used a significant number of batteries to compensate for low energy output during certain times of day. | Figured out how to calculate using batteries to store energy during times of excess and for energy during times of low RE output. |

**Table A2. Learning Outcome Assessment Criteria for the Practice of Optimization.**

| **Specific aspect of practice that students will engage in:** | **Example of what it looks like when a learner needs to work more on the practice** | **Example of what it looks like when a learner is proficient with the practice** |
|---|---|---|
| Identifying Variables | Learner deals only with number of renewable energy sources but does not identify any other variables that go along with each source (e.g. environmental impacts, noise impacts, etc.) | Learner can identify other variables associated with each technology. |
| Identifying guiding principles to calculate variables | Learner arbitrarily assigns values to variables without justification | Learner has reasoning for why a certain variable is associated with a technology (e.g. wind turbines will create much more noise than any other technology) |
| Identifying variable interdependence | Learner considers only one variable at a time and does not identify how one variable relates to another. | Learner identifies how one variable affects another (e.g. noise impact goes up as environmental impact goes up as well) |
| Evaluating Trade-offs | Learner considers only one variable and does not consider the change in other variables. | Learner considers how optimizing one variable does not optimize another, and attempts to optimize both simultaneously or identifies the trade-offs and provides justification for choices. |
| Exploring variable space | Learner does not iterate on design in a way that leads eventually toward a solution that optimizes at least one variable, the choices seem arbitrary. | Learners iterate toward an “optimal” solution, at least trying to get closer (e.g. minimizing cost) |
| Identifying optimality criteria | Learner does not acknowledge or reflect on optimality criteria | Learner identifies optimality criteria, and discusses solution in light of the optimality criteria (e.g. meets demand, minimal cost, etc.) |