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Backward-Designing the Perfect User Experience Internships for Deep Space Network Operations

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Abstract

"How do you imagine people will operate the Deep Space Network in ten years?" After introducing some problems of operating the global collection of space-leaning telecommunications equipment, this prompt was one of the first questions we asked students to set the stage of their 8- or 10-week internships. While inquiry methods are typically applied to classroom learning, we applied similar strategies to designing custom internships that would be meaningful to the student and beneficial to the project, drawing on students' unique background and experiences. Inquiry methods have the benefits to the student of giving them a scaffolded space to choose an investigation and deliverable which complements their strengths, or one that stretches them to learn new skills. Working backwards from initial project goals, we scoped the initial question-forming phase of inquiry design to those open issues the project needed addressing. The Deep Space Network was undergoing a major transformation in Follow-the-Sun, transitioning to daylight-only operation from 24/7 work. This resulted in many open questions requiring contributions in the fields of user research, design, and software development. We identified other objectives in the areas of leadership; teamwork; disability, equity, inclusion; and validation and iteration. This chapter describes the methods we used to design the internship project, how we facilitated it, prepared for each intern's arrival, and measured progress in the students' 8- to 10-week internships. This method has been used for all 18 interns over seven years to positive outcomes, resulting in four internal hires.

Keywords: backward design, internships, user experience research, UX

This document has been reviewed and determined not to contain export controlled technical data.

1. Introduction to the DSN and PDP

The Deep Space Network (DSN) is a collection of 13 antennas situated at three sites around the globe. The positioning of the sites, 120 degrees longitude apart, allows at least one site to always see every patch of sky, thus facilitating continuous coverage for any deep space spacecraft that partners with the DSN. The sites are located at Goldstone near Barstow, CA; Madrid, Spain; and Canberra, Australia. The DSN is operated by the Jet Propulsion

Laboratory (JPL) for the National Aeronautics and Space Administration (NASA) and European Space Agency (ESA). The Deep Space Network was formally born in 1965 and has been operating uninterrupted for over 50 years; its charter states, "[The DSN project] provides telecommunications products that support solar system exploration missions undertaken by the international community" (Jet Propulsion Laboratory, 2019).

One key role charged with the Deep Space Network support activities is the Link Control Operator (LCO). Among other duties, the LCO prepares the necessary hardware, manages the connection of spacecraft to the antenna (called a 'track'), and returns the antenna to a stow position after the track has passed. At the time of the internships described in this paper, a single LCO monitored and commanded one or two simultaneous antennas; however, their work was about to undergo massive change. To provide coverage to the ever-increasing number of spacecraft, including cube satellites, the number of antennas managed by each operator was expected to increase to three or more. Though the difference was only one or two tracks per person, the resulting strain on operator situation awareness had not yet been studied, and tools to address issues of situation awareness had not been designed nor developed.

While engineering teams worked to put in place the telemetry pipeline including the hardware and back-end software to deliver the data reliably and latency-free to the operators, the human-centered design team's focus was on the information and command software the LCOs used to understand what was happening in their tracks, to move the antennas and associated equipment into proper position, and to respond to anomalous behavior in tracking the spacecraft as it moved across the sky.

We were two engineers comprising the design team; as such, we prioritized studying and creating tools for situation awareness for LCOs at the Deep Space Network. We aimed to apply a user-centered design method in partnership with the development team and with participation of LCOs to create efficiencies and reduce uncertainty in worldwide Deep Space Network operations. In our design work, we aimed to understand and improve LCO processes and workflows and foster relationships between teams (LCOs, designers, developers). We made low- and high-definition prototypes and came up with new techniques to validate designs, processes, understandings, and ideas quickly and precisely.

The design team found many places where human-factors research, design research, participatory design, and rapid prototyping would be crucial in understanding LCOs' needs for their information and tracking software. The Deep Space Network project funding model presented significant budgetary hurdles (NASA Office of the Inspector General, 2015) which prevented us from increasing the team size. While every project we identified was worthy and needed, all this work was too much for a two-person team to take on, resulting in the recruitment of summer and year-round interns to take on some of the tasks. Junior designers could mock up wireframes for the information screens in collaboration with the LCOs, and junior software engineers could create prototypes for rapid testing with the operators. Junior researchers could investigate the human factors related to both maintaining situational awareness and to the designs created by other interns.

1.1 PDP Teaching Plan

The Institute for Scientist and Engineer Educators (ISEE) hosted a learning program to teach inquiry teaching methods to those entering a science or engineering field. This program, called the Professional Development Program (PDP), spanned several days of classroom instruction, hands-on learning and post-program follow-on teaching activities. In the inquiry workshop, each participant learned about the physics of shadow and light in an inquiry activity facilitated by the PDP instructors. Following the learning component of the workshop, the participant studied the curriculum design to understand how the activity was put together and what made it effective as a teaching tool. Teams of three to four PDP participants then design and teach an inquiry activity of their own with guidance from the PDP staff.

Each team creates an activity teaching plan, the document containing a comprehensive outline for the activity. It guides the design of components of a PDP inquiry and defines how the learners' understanding of the learning goals will be evaluated.

The introduction component describes to learners what to expect they will do, how long it will take, and what role to expect the instructors to have during the activity. The introduction contains background information needed for the activity; how science, technology, engineering, and math (STEM) concepts are addressed in the activity; and how the activity mirrors authentic STEM practices.

The raising questions component is intended to stimulate curiosity, so that learners ask "why" or "how" questions which are relevant to the investigation and learning goals. A good raising questions component leads learners to questions which are specific enough to the activity yet broad enough to allow for different ways of getting to an answer and depth of subject matter investigation. While working toward their questions, learners practice thinking aloud and expressing what they know about the subject matter and thinking aloud.

Instructors vet the learners' questions for expected outcome, to ensure they address the learning goals of the activity; and for scope, so they can be completed in the time allotted for the activity. In a large group, similar or duplicate questions can be combined, and the question-askers can form teams to investigate the questions together.

Learners select their "why" or "how" research question and investigation team and set to work in making a plan to answer it. Instructors become facilitators at this point because they are no longer providing instruction but are facilitating the students' own **investigation** and learning. Facilitators observe and note learners' individual contributions while they work collaboratively to create and execute a plan of investigation.

The teams design a content rubric in the teaching plan to use for assessment of each learner's proficiency with the defined STEM content goal. The rubric clearly defines evidence of difficulty and proficiency which can be used in assessing the learner for competency.

In the **culminating assessment task**, learners are asked to use the evidence they gathered in their investigation to demonstrate their solution to the "why" or "how" question they raised earlier, and to provide supportive artifacts. The facilitator looks for evidence that the learner has sufficient understanding in several components. The culminating assessment task is evaluated with the content rubric to inform the assessment of each learner's individual score.

Finally, an inquiry **synthesis** puts together the collective understanding of the group and recognizes learners' contributions. The facilitator illustrates with learners' contributions the content goals for the inquiry activity. Each group of learners receives credit for their solutions. The facilitator is careful to point out STEM practices in which learners engaged and uses appropriate STEM language for learners' benefits.

1.2 Discussion: How internship design is like inquiry learning

Each part of the teaching plan is written in a learner-centered manner, with focus on what the learner will do, see, learn, or experience. For example, the role of the instructor is described through the learner's point of view. The teaching plan pays special attention to parts of the curriculum which might be challenging for students and asks the instructor to record ways to address those challenges, including with research-informed equity and inclusion (E&I) approaches intended to accommodate learners with different backgrounds and learning styles.

This focus on the learner-centric experience is notable because it mirrors a human-centered design approach in creating effective user interfaces and experiences. Designing with the user (person) in mind allows designers to ask deeper questions and make decisions that benefit the user. In several places, observing learners mirrors another common design technique. Think-aloud (Nielsen, 1993) is a common tool in user research and user experience design, used to understand what and how a person thinks about the task at hand; it helps a designer to isolate problem areas where a user struggles.

For a user-experience and software internship project, “why” or “how” questions can be paired with a deliverable. For example, “Why do users avoid this tool?” can be paired, through rigorous user research, with a design for a better tool. In design, a single “why” question may yield a basic result, but typically will fail to get to the underlying issue causing the problem. One design research method is the Five-Whys exercise (Serrat, 2009), in which a designer asks the question “why” five times in succession to get to a deeper understanding of an issue which initially presented as trivial.

In Section 3, we show how we applied much of the same inquiry structure from the PDP described above to the design and implementation of a summer internship. The inquiry structure helped to create a successful and engaging internship experience for a variety of students.

2. Student demographics

In order to craft an internship which drew on the students’ unique strengths, it was important to understand the background of each intern. Despite admirable progress, women and people of color remain underrepresented in science and engineering occupations compared to their representation in the United States population (CEOSE, 2019).

Most of our applicants came through various JPL internship offices. We selected these programs for their support of minority-serving institutions. Of our 18 interns,

- five came through the Summer Internship Program (SIP), the largest internship program on lab;
- five were recruited through the Student Independent Research Internships (SIRI), a program partnering with local community colleges to increase participation in STEM;
- five students came through Summer High-school Internship Program (SpaceSHIP), aiming to bring children from an underrepresented high school in south Los Angeles, CA to STEM research at JPL;
- one student was recruited via Maximizing Student Potential (MSP) in STEM, which offers research opportunities to underrepresented students;
- one student came through a NASA merit-based scholarship program;
- one student performed extended dissertation work toward a master’s degree through the Master’s Thesis Fellowship Program (MTFP).

With the exception of the SIRI interns, who received course credit only, all interns were paid by their internship program for the work done with our group.

Of the 18 students who worked with us over seven years:

- thirteen were from a historically underrepresented group (72%),
- seven identified as female (39%),
- five were high school students (28%), and
- two self-identified as neurodiverse.

We noted a broad range of intersectionality amongst our interns, with all of the female-identified students also self-identifying as a member of at least one ethnic minority and most self-stating that they came from lower socioeconomic status. Figure 1

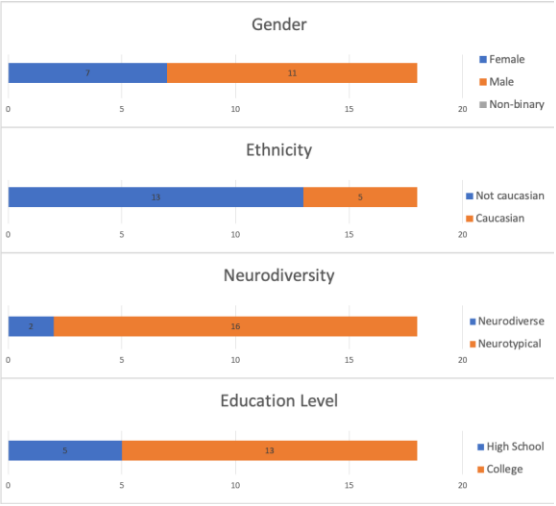

Figure 1: Student intern demographics, 2014–2020.

shows the gender, ethnicity, neurodiversity, and education level figures.

2.1 Summer High-school Internship Program (SpaceSHIP)

JPL's Summer High-school Internship Program (SpaceSHIP) aims to bring high-achieving underrepresented students from Los Angeles-area high schools to STEM research at JPL. JPL SpaceSHIP offers talented students the opportunity to develop their technical skills while contributing to exciting space exploration missions. Students selected for the competitive and distinguished JPL SpaceSHIP internship get the opportunity, at an early age, to try out a career role they think they might want to pursue and determine whether it is a good fit. Every SpaceSHIP intern is exceptionally talented, yet they may not have had many opportunities to interact in a professional STEM workplace and prove their mettle. As a consequence of growing up in an underserved environment, most SpaceSHIP interns have had few opportunities to explore technical career options. At JPL, these promising students are mentored by a scientist or engineer on a technical project that demands they acquire new skills and function in a fast-paced professional environment. Students rise to the occasion, accomplishing more than they could have ever imagined, and leave with increased confidence, established professional connections, and a better idea of which career path they want to pursue.

2.2 Maximizing Student Potential (MSP) and Student Independent Research Internships (SIRI)

Maximizing Student Potential in STEM (MSP) is a portfolio of programs that provides research opportunities to underserved and underrepresented minorities pursuing science, technology, engineering, and mathematics (STEM) degrees. The objective of MSP is to develop relationships with students and organizations to achieve increased participation of minorities in STEM courses of study and careers. These initiatives provide research and training opportunities for participants attending Minority Serving Institutions (MSIs).

In addition to MSP, the Education Office offers local community college students attending MSIs opportunities to gain real-world work experience as part of the Student Independent Research Internship (SIRI) program. Students are partnered with JPL scientists or engineers, who serve as the students' mentors. Students complete designated projects outlined by their mentors, gaining educational experience in their fields of study while also contributing to NASA and JPL missions and science.

Together, the MSP and SIRI programs are designed to cultivate a diverse student intern population at JPL. By way of their unique backgrounds and experiences, each MSP and SIRI participant brings a valuable perspective to the Lab. Their contributions provide diverse approaches to problems, questions, and solutions to STEM research.

3. Backward-design project creation

The internships were held at the Jet Propulsion Laboratory, California Institute of Technology between 2014 and 2020.

In advance of each internship, we developed a clear set of learning objectives customized to the individual intern. We based these assessments on the intern's resume, previous projects, asserted and surmised (via interview) skillset, and interests. We then prepared a selection of possible projects for the intern to choose from, all of which aimed to achieve the learning objectives.

We identified three key project areas requiring intern contribution:

1. User research: Talking to the LCOs, observing their work, discussing potential solutions, and conducting well-formed investigations into potential interventions that could help their work;
2. Design: Iteratively translating research findings into drawings, mock-ups, and wireframes using pen-and-paper as well as software tools; and
3. Software development: Working with back-end systems such as telemetry handling and databases, or front-end tools such as design implementations.

For each intern, the "project menu" included a range of projects with loose requirements but specific pre-defined outcomes including (1) project deliverables meeting internship goals, and (2) demonstrated investigation, development, and validation skills. This formula allowed the students to choose their learning path along multiple dimensions – the project area, the level of autonomy, and whether they would be collaborating with a fellow intern or working alone — while learning or cultivating new skills and meeting project deliverables and deadlines.

In addition to the ISEE PDP teaching plan, we adapted Caltech Project for Effective Teaching (Boyle & Silva, n.d.) methods to establish learning goals in the skill areas of design and/or software development, communication, people and collaboration, and work and life ethics. We set and adjusted expectations in these areas based on each individual's experience. For example, by the end of an internship, a high school student was expected to have become familiar with user-centered design techniques; a college student would have conducted user-centered design research; and a graduate student would have designed new techniques by looking at the literature.

We aimed to create a healthy ecosystem of inclusive mentoring (Packard, 2016) to provide students with the best chance for success. This was especially important because most of our interns came from underrepresented backgrounds and underrepresented genders in STEM fields.

3.1 Expectations and time allocation

There were three sets of expectations each intern had to juggle (see Figure 2). The program's expectations included products which had to be turned in to the internship office or the student's school or university. These included assignments such as the project proposal, reports, final presentation, feature articles for the school, etc. In some cases, the student's grade or salary depended on the completion of this work. The mentors' (our) expectations included work we wanted the student to complete or skills we wanted the student to develop. The most important expectations were the student's. These were things the student wanted to learn or do while completing their internship at JPL, and areas in

Figure 2: Expectations for an intern's project and professional development: A Venn diagram of what the mentor, program, and student expects, with only some overlap.

which the student wanted to grow or solidify their proficiency or professional skills.

To this end, we created a scaffolding for time management (see Figure 3). We expected 60% of a student's time to consist of work towards deliverables (our requirements), 20% to be presentation and documentation toward the student's intern office, school, or other groups within JPL, and the final 20% to professional development. In this 20%, a student might meet and observe people in other career paths, interview with other groups, go on lab tours and intern events, and have coffee breaks with other interns within and outside their program.

Our professional development expectation was both radical and different from any other mentor group we spoke with at the time, due in part to (1) the custom project creation, tailored to the student's experiences and growth goals, and (2) the 20% time allocated to professional growth. Despite its critical reception among other mentors and supervisors, we believed both elements to be critical to our students' internship success as well as beneficial to their careers. We created a slide deck to help popularize the 20% idea with other groups who were expecting interns, and to encourage other groups to build on their students' backgrounds and create meaningful and positive environments for their students' success.

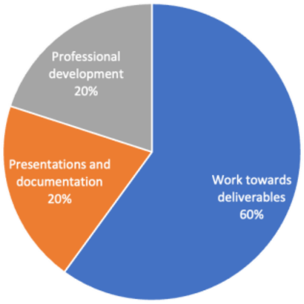

Figure 3: Expectations for an intern's time allocation while at JPL.

3.2 Student projects

We aligned student projects with our funding source by selecting one of the tools being developed, and then separating the work into the three project areas we defined: user research, design, and software development.

Students expressed interest in one or more of the areas during the phone interview, and then committed to a path once arriving at JPL. This approach let the student decide whether to pursue a project that stretched their abilities, by trying something different than their previous project work, or honed existing skills, by selecting a project in an area they already knew well.

Each project area contained at least three potential contribution paths (projects), tied loosely to tools being developed. One such tool, the all-in-one display, required work from multiple angles.

In the following section, we walk through an intern's project scope in the context of the all-in-one display, a tool that was in development during the time of the case study internships.

4. Case study: All-in-one tool

The following case study presents four internship students in 2016 working on the all-in-one display (tool). This tool was being designed and developed to assist Deep Space Network operators in observing telemetry data from each antenna, and commanding the antennas during a spacecraft support. In order to make better use of the operators' digital workspace, the all-in-one tool combined five distinct displays into a single one, and allowed the operator to add multiple antennas to the display. Effectively, the all-in-one display gave operators an at-a-glance view of everything they were responsible for.

We interviewed and hired four interns. Due to their stated interests (user research and design, and design and software development), we divided the students into two teams of two students each (Team

A and Team B). Each team consisted of one college undergraduate and one high school student. The more experienced student in each team mentored the other student, so in essence each high school intern had the support of three mentors: the team leader (experienced student), and the two project mentors.

For the first four weeks, Team A worked on formative user research while Team B created a backend architecture for the tool. Then, the teams switched roles at the midway point and Team A worked on UI development and design while Team B performed user testing and evaluative research (see Section 4.4).

Our expectation of a successful outcome was that the students would deliver a prototyped data visualization, which should:

- Incorporate, or directly address needs of its users; and identify the most necessary data items for an all-in-one display (user research objective)
- Create a digital representation of an all-in-one display with the data items identified, and test it with at least one user (design objective)
- Display changing simulated data, for the data items identified, that approximate a real Deep Space Network tool (software engineering objective)

We additionally had the following objectives:

- Have at least two iterations of design and user testing (iteration & validation objective)
- Be congruent with existing understanding of color meanings and other visual and interaction choices designed for inclusion (disability, equity, inclusion objective)
- Individually estimate and self-assign work appropriately scoped to (1) the student's own learning goals, (2) the team's expected deliverables, and (3) the time available (leadership objective)
- Self-assess work completed, and make adjustments as needed during the next work cycle (leadership objective)
- Provide daily and weekly status updates to teammate and broader team, respectively (teamwork objective)
- Measure likelihood of success weekly, and pivot as needed if the current project or project structure was not likely to succeed (iteration & validation objective)

4.1 Introduction

To introduce the problem, we explained the workings of the Deep Space Network and its charter. We showed photographs and other artifacts from previous research we conducted at the DSN, and presented results from prior investigations.

We showed photographs of operators' increasingly cluttered workspaces as they go from one track (Figure 4) to two tracks (Figure 5), and our prediction for what will happen when operators have three tracks to support with only the same tools (Figure 6). We based the prediction on a prior experiment conducted with operators in which we asked them to tape up paper cut-outs of the displays they would need.

Afterwards, we discussed the timeline for the 8- to 10-week summer internship, marking out program

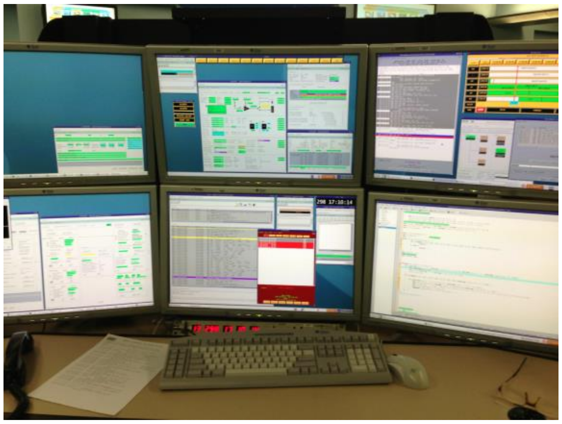

Figure 4: Deep Space Network operator console with tools to support one track.

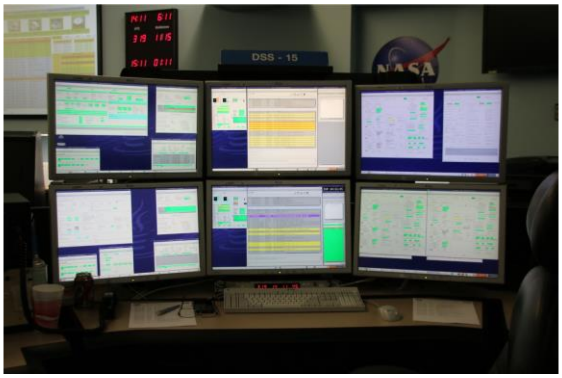

Figure 5: Deep Space Network operator console with tools to support two tracks.

office milestones of project proposal, midterm report(s), and final presentation and report. We included dates we would expect little work to get done (holiday weeks, mentor outages). Finally, we presented clear expectations about how much time should be spent on the project, per Section 3.

In this way, we described what the interns should expect from the Deep Space Network project assignment and the scope of activities they may be expected to perform during their internship.

For each individual intern, we worked with the student to build a 10-week plan, working backward from their chosen final deliverable. We helped the intern deconstruct their task week by week, providing them with guidance about the steps needed to complete the work, but allowing them to determine their own pace. At the midpoint of the internship, we checked in with each intern and replanned their remaining weeks if needed.

Figure 6: Deep Space Network operator console following a predictive exercise to imagine what three tracks will look like.

4.2 Raising questions

Once familiar with the Deep Space Network and its operators, operations, and tools, students were invited to ask questions. We gave the first example: What will it be like to operate the DSN in five years?

Then, students came up with their own questions. “How do operators know everything is all right?” “What are the benefits of combining the time stack [display] with the log [display]?” “How do operators interpret the antenna information?”

And in this case: “How can we fit all the stuff an operator needs to see on one screen?”

Each question could be deconstructed into multiple pieces. “Why” questions required user research to understand what operators do and why. “What are the benefits” meant user study – testing the effectiveness of one thing against another with experiment design.

And in this case, “How can” questions required user research followed by design and software development.

At this point, two self-selected teams emerged. Team A chose to investigate the operator workflow, understand the information pieces the operators used to make their assessments and issue commands, and feed those data into a design. Meanwhile, Team B set out to build a back-end which would emit simulated data to be used by a front-end. The goal was for the two teams to meet in the middle: when the back-end provided data for the front-end to visualize.

4.3 Investigations

Team A’s project objective was designing the interface for the operators to use while supporting their tracks. We expected the team to learn user research methods of observation, interview, and artifact walkthrough; user study methods of A/B testing;

participatory design; and general design methods such as grid, composition, color, and design for accessibility. To support these learning objectives, we provided literature, learning sessions, and weekly practice.

Team A examined how operators used each screen and where data inefficiencies were visible (e.g., the same data displayed in different places: “Why?”). Screenshots of existing tools gave the team an idea of the number of data channels, and videos of existing screens provided an idea of how quickly the displays needed to update.

Team B’s project objective was creating the software to display the design which Team A was tasked with codifying. The team’s learning objectives included database design, data collection flow, and server maintenance. The team identified specific technology to learn and use, such as JSON for data transfer, xampp for data flow, and server setup and maintenance with node. These learning goals were supported by online and print literature and coordination with software engineers throughout the lab (including within the design group) and the teammates often consulted with software engineers to meet their project objectives.

Both teams had access to learn user research techniques through mock interviews, co-design sessions, time with other designers, interviews with a lead operator at JPL, and (once per internship) a field trip to the Goldstone Deep Space Network facility over three hours away.

4.4 The change-up

Half-way through the internship, Team A and Team B swapped roles. That is, Team A switched from formative user research and design to software development, and Team B switched from software development to user research and interface study.

While the switch happened organically, with both teams naturally changing from one set of roles to the other, swapping tasks had the added benefit of creating continuity in tool design while allowing each team multiple types of experiences. By the internship midpoint, Team A had built the back-end, piping data to a front-end which did not yet have a display. Team B had designed a front-end which did not have a physical interface nor data to drive it.

In the change-up, Team A, the user research team, was given the opportunity to translate paper prototypes and sketches into tangible software objects. This required them to learn JavaScript and the ReactJS framework in addition to some of the APIs (interfaces) exposed by Team B, the software engineering team, in the data pipeline. In the remaining 4 to 6 weeks, they connected Team B’s data back-end to the front-end they had built and worked out bugs.

Meanwhile, Team B, the software engineering team, iterated on Team A’s design. They brought the design to DSN operators to validate the data and its representation, user interactions, and information design; and they iterated with the design community at JPL to further hone the tool’s utility for its users. This team then learned to synthesize feedback, recommendations, and issues found during testing the designs into discrete improvements, to prioritize those improvements using research data, and present them to Team B as constructive and actionable items.

4.5 Assessment

We can understand the effectiveness of an internship by (1) along-the-way assessments through the 8- to 10-week session, (2) its utility after the student departs, and (3) the student’s individual outcomes. In this section, we discuss the along-the-way assessments and the overall outcome of the tool designed and prototyped by the students. We discuss other outcomes in Section 5.

We worked in iterative two-week “sprints”, in which we collaboratively planned activities for the following two weeks. For each activity, we assigned units of effort to ensure no one teammate was taking on too much work, and no teammate was being left behind. Within two sprints, each student learned to budget their own work allocations. With our facilitation, students assigned themselves work to complete for the sprint. At the end of each sprint we held a review to celebrate work completed, and a retrospective to discuss what went well and what we could improve as a team going forward. Each student had a chance to assess their own progress, get feedback from their teammate, the other team, and their mentors to make changes as needed for the next sprint. Each student also had the opportunity to provide feedback to their peers, in a safe and structured environment.

The final result (Figure 7) included hundreds of identified data items on the all-in-one display. This high-fidelity prototype was semi-functional, with interactive interface elements and flowing realistic data, and met the project objectives we had in mind when starting the internships.

Team A had determined that operators will need to see real or realistic numbers, colors similar to what they usually see, and components grouped in subsystems similarly to how they arrange the subsystems on their existing displays. We advised that colors which communicate non-urgency, such as "everything's all right" green, can be muted, so they do not take the operator's attention. The counterparts, "something's wrong" orange and "everything's broken" red, stand out because they often require note-taking or action.

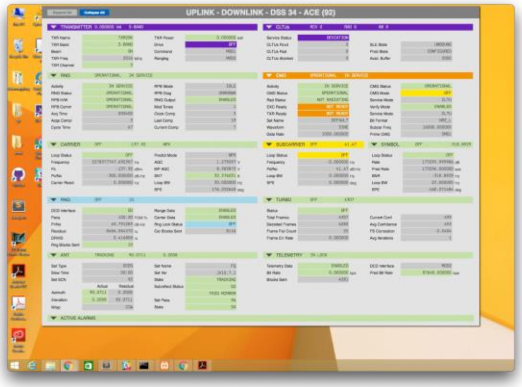

Figure 7: Resulting all-in-one display prototype.

Team B had devised a method to not only capture real data, but also to generate realistic data within certain parameters for simulation purposes. Team B built fault injection which could change nominal data to off-nominal in close to real time. This allowed the team to design several visualizations of problem supports, and to test those visualizations with operators.

Each intern demonstrated understanding of user research, design, and software engineering learning objectives congruent with their experience and interest.

By the end of the internship we observed each individual setting tasks and goals for themselves for the two-week period (leadership objective) and changing plans as needed, especially when presented with new technical challenges or user research (iteration & validation objective). We observed students thinking about color choice and even installing a tool to help understand how someone with colorblindness sees their designs (disability, equity, inclusion objective). Each student worked together to divide work, provide encouragement, and communicate with each other several times a day within teams; we observed both teams' teammates pair programming, with both students at one computer working together on the same task, and cross-team collaboration where needed (teamwork objective).

4.6 Synthesis

At the end of the internship, each student gave a separate final presentation of their work, providing context of each other students' contribution. In this way, each student had to understand at a high level the contribution of each other student. Figure 8 shows one student from the internship presenting the all-in-one display prototype to the designers and software developers associated with our group.

Because the students were using a human-centered design approach, they felt confident that their solution would be embraced by end users. Whichever team happened to be in the design role at the time (Team A for the first half, Team B for the second)

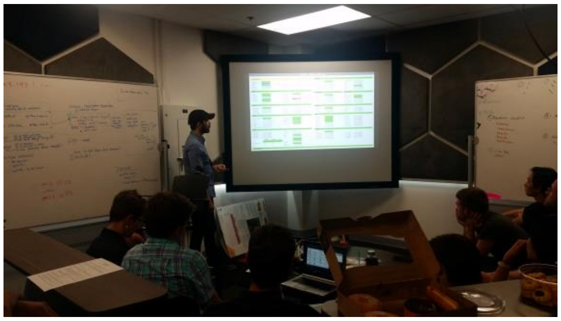

Figure 8: One intern presents the all-in-one display prototype to software engineers and designers at JPL.

had weekly contact with the LCOs, and all interns were able to participate in field observation of operations.

5. Outcomes

Out of 18 interns over seven years of the Deep Space Network internship program, four were hired as full-time engineers at the Jet Propulsion Laboratory following their internship. One returned to work with the design team on a different project prior to being hired at a major tech company in Silicon Valley. Two received competitive, merit-based scholarships toward their studies. Two of the college interns communicated their acceptance into a graduate program (both University of California). Four of the five high school interns went on to attend four-year colleges (Stanford University, University of California, California State University, and Western Washington University).

6. Discussion

Our experience demonstrates the applicability of PDP inquiry methods to internship design, with excellent benefits both to the project and to the individual students.

We found this approach required the cooperation of everyone involved in the internship mentoring process. We enjoyed the enthusiastic support of both line and project management, and collaboration with the designers and software engineers who agreed to serve as additional resources for our interns.

Facilitation for these interns was much more hands-on, especially in the initial stages, than mentorship of our non-inquiry intern for other tasks. For the inquiry interns, we talked through questions and helped students navigate to answers on their own, rather than give a solution and ask the student to move on as quickly as possible. For traditional interns, we have a rule: if you are stuck for more than 30 minutes, ask for help and move on to something immediately doable. For inquiry interns, we encouraged the students to ask for help from each other and from us; we provided answers in the form of questions. Additionally, we had to let the students fail some tasks in order for them to learn to pivot.

Project results were difficult to compare because the internship projects differed significantly from each other. However, with the inquiry students, we observed learning early on, as well as enthusiasm for the subject area and increased empathy toward the users, resulting in strong projects which were well-received by the users.

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References

Boyle, K. & Silva, R. (n.d.). Translating Teaching Pedagogy to Mentoring. Caltech Project for Effective Teaching.

Jet Propulsion Laboratory. (2019). Deep Space Network (DSN) Project, Rev. 6. Internal document.

NASA Office of the Inspector General. (2015). NASA'S Management of the Deep Space Network. Report # IG-15-013

Nielsen, J. (1993). Usability Engineering. Academic Press. San Francisco, CA.

Packard, B. W. L. (2016). Inclusive, Intentional Mentoring. Psychology, 43, 663-670.

Serrat, O. (2009). Five Whys Technique. Asian Development Bank Administration and Governance.