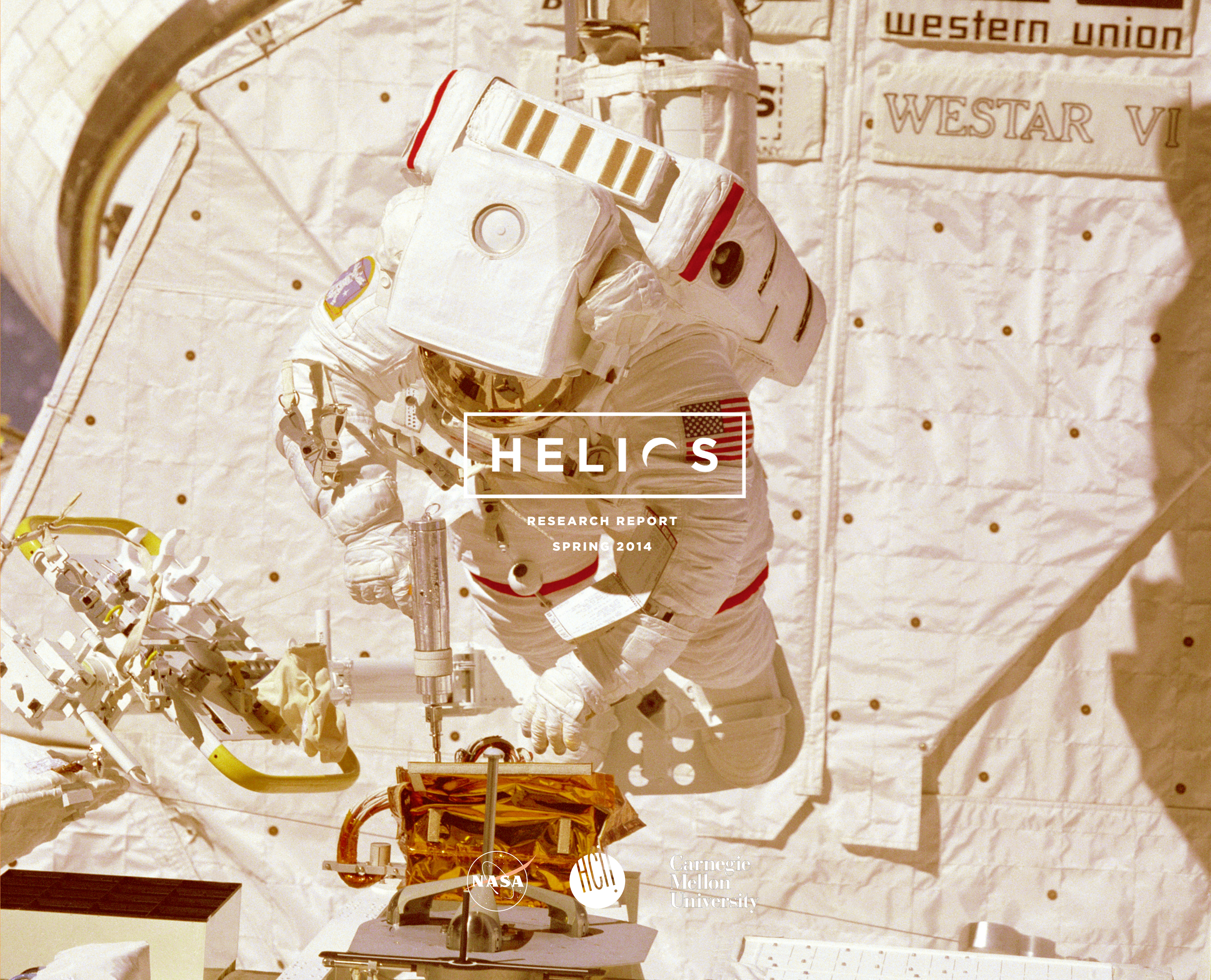
HELIOS

RESEARCH REPORT

SPRING 2014



NASA HCII Carnegie Mellon University

Carnegie Mellon University

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RESEARCH REPORT

SPRING 2014

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Executive Summary

NASA astronauts and engineers are advancing technology and science through space missions and scientific experiments, but the complex nature of their procedures creates difficulties in organizing tools and materials on the International Space Station (ISS) and in NASA test facilities.

PROJECT AND GOALS

We are Team Helios, five Master's students at the Human-Computer Interaction Institute (HCII) at Carnegie Mellon University, who have partnered with the NASA Ames HCI Group on an 8-month capstone project to develop a smarter, context-aware tool management system for astronauts and engineers. Over the last four months, we have researched the context in which they use tools during procedure execution. For the next four months, we will test and iterate on prototypes that increase astronauts' and engineers' tool management efficiency, so that they can devote more time to scientific exploration.

RESEARCH

Our field research examined how individuals used tools and materials when executing procedures. In order to deeply understand the work context of NASA astronauts and engineers, we conducted contextual inquiries at NASA facilities and in analogous domains, such as machine shops, test laboratories, science labs, and medical environments. We interviewed individuals when we could not directly observe them.

To acquire domain knowledge, we conducted a literature review to understand theories related to procedure execution processes including attention and interruptibility, spatial awareness, and collaboration. Moreover, we performed a competitive analysis to see how other industries and existing products attempt to solve aspects of the problem we are exploring.

DISCOVERIES

Based on our domain analysis and field research, we identified 6 key findings and 4 secondary findings, each supported by observations and analysis from analogous domains. We developed three high-level design insights that will guide us through our visioning and prototyping process.

- Ease in gathering key information for quick reference streamlines procedure execution
- Successful collaboration requires coordinated sharing of procedure process and status information
- Related physical objects and information become more meaningful when they are kept together

PRELIMINARY VISIONS

Based on these insights, we brainstormed over 200 ideas and turned them into five preliminary visions. We then created storyboards to describe the scenarios and technologies behind each vision. Once we have finalized which direction we would like to pursue, we will create and iterate on a high-fidelity prototype this summer.

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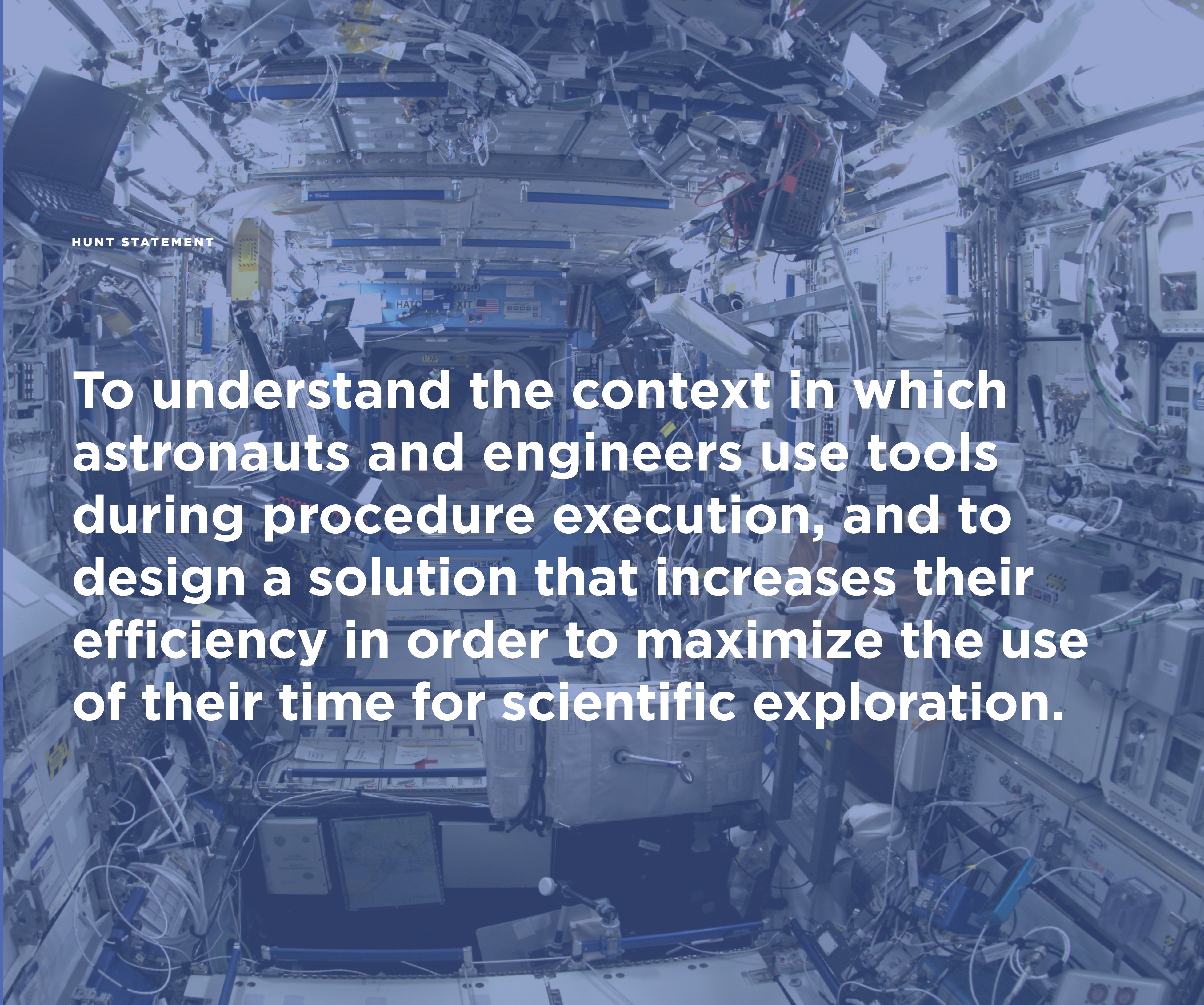


HUNT STATEMENT

To understand the context in which astronauts and engineers use tools during procedure execution, and to design a solution that increases their efficiency in order to maximize the use of their time for scientific exploration.

Project Background

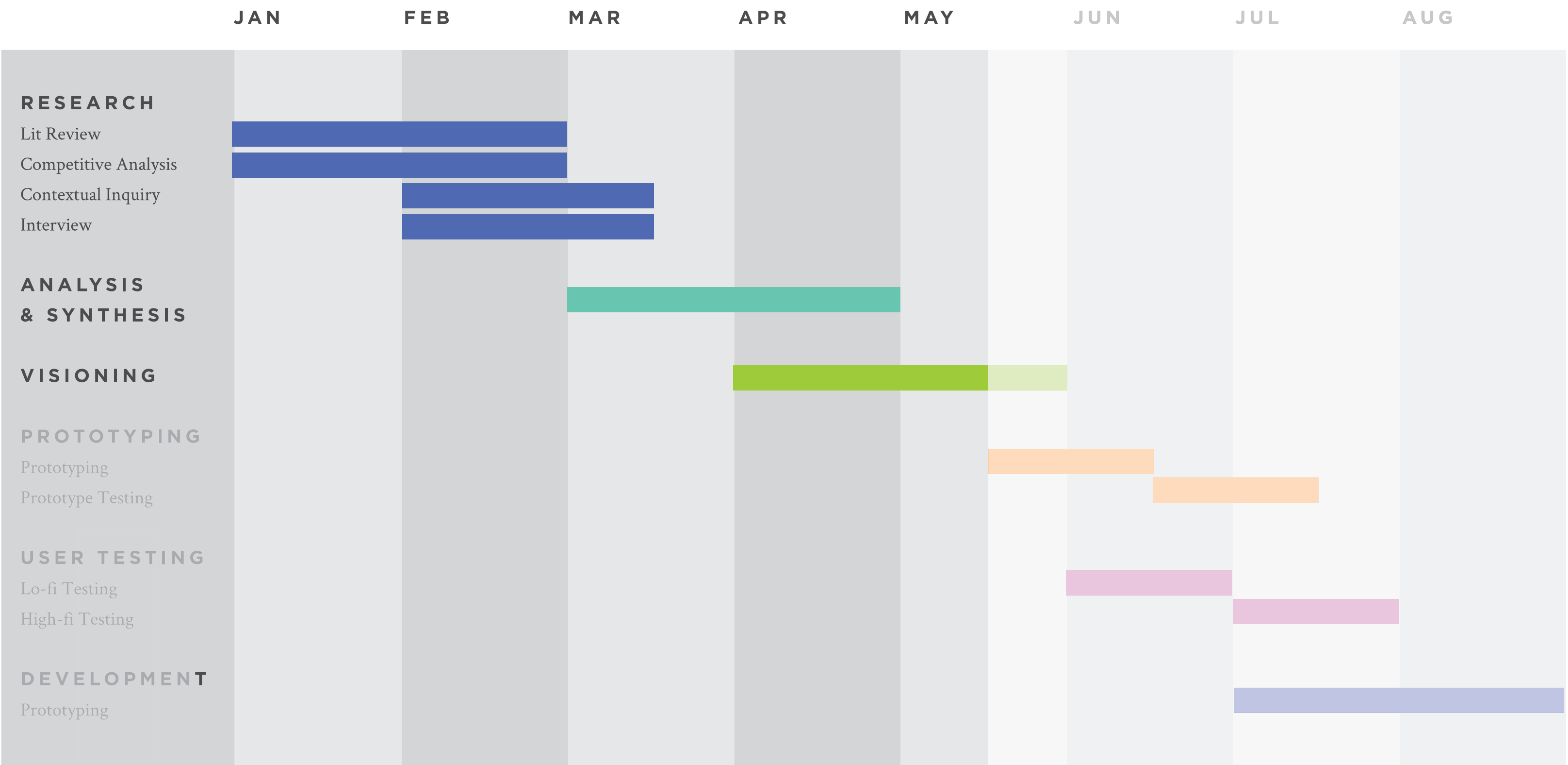
The work of NASA personnel on the International Space Station and at test facilities revolves around carrying out highly specific tasks and locating the tools, materials, and machinery needed to carry out those tasks.

Crewmembers and engineers perform detailed tasks for experiments and maintenance by gathering tools and following instructions on static or printed documents, called procedures. Currently, NASA personnel must manually track the location and status of their equipment, so tools are often misplaced, and logs, often unreliable.

On the ISS, a three-person crew can only spend 35 hours per week on scientific experiments, and the rest of the crewmembers' time is required to be spent on maintenance. In order to perform experiments, astronauts must first locate tools and materials stored on the ISS, which spans the size of a football field. Engineers at NASA's test facilities face many similar inefficiencies. To run tests, engineers must gather materials, verify the materials, gather tools, and inspect the machinery. Since their manual logs are often out of date and unreliable, astronauts and engineers waste precious time and cognitive energy on locating their materials.

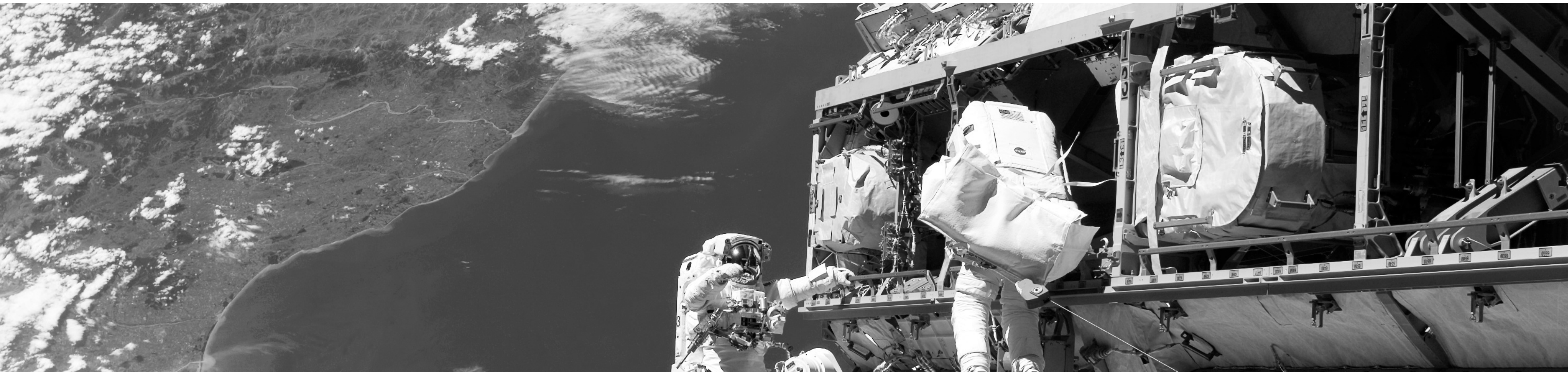
We are Helios, a team of five students at Carnegie Mellon University's Master's of Human-Computer Interaction (MHCI) program. For our 8-month capstone project, we partner with an industry client, who presents us a problem, and we work with them to research, design, and prototype a solution. Our client, the Human-Computer Interaction Group at NASA Ames Research Center, has asked us to understand the context in which astronauts and engineers find tools and carry out procedures on the ISS and in test labs, and to design a smarter, context-aware system that will increase their work efficiency. This book documents the research phase of our project, including domain research, field research, data synthesis and analysis, and visioning.

Spring Schedule



Project Kickoff

Our project began with a kickoff meeting with our NASA client. The meeting allowed us to share our initial interpretation of the problem, then hear about it from his perspective. In our meeting, we began identifying analogous domains that could provide insights into the problem, and brainstormed questions we would ask our research participants.



Domain Research

CONTENTS


mutualmobile

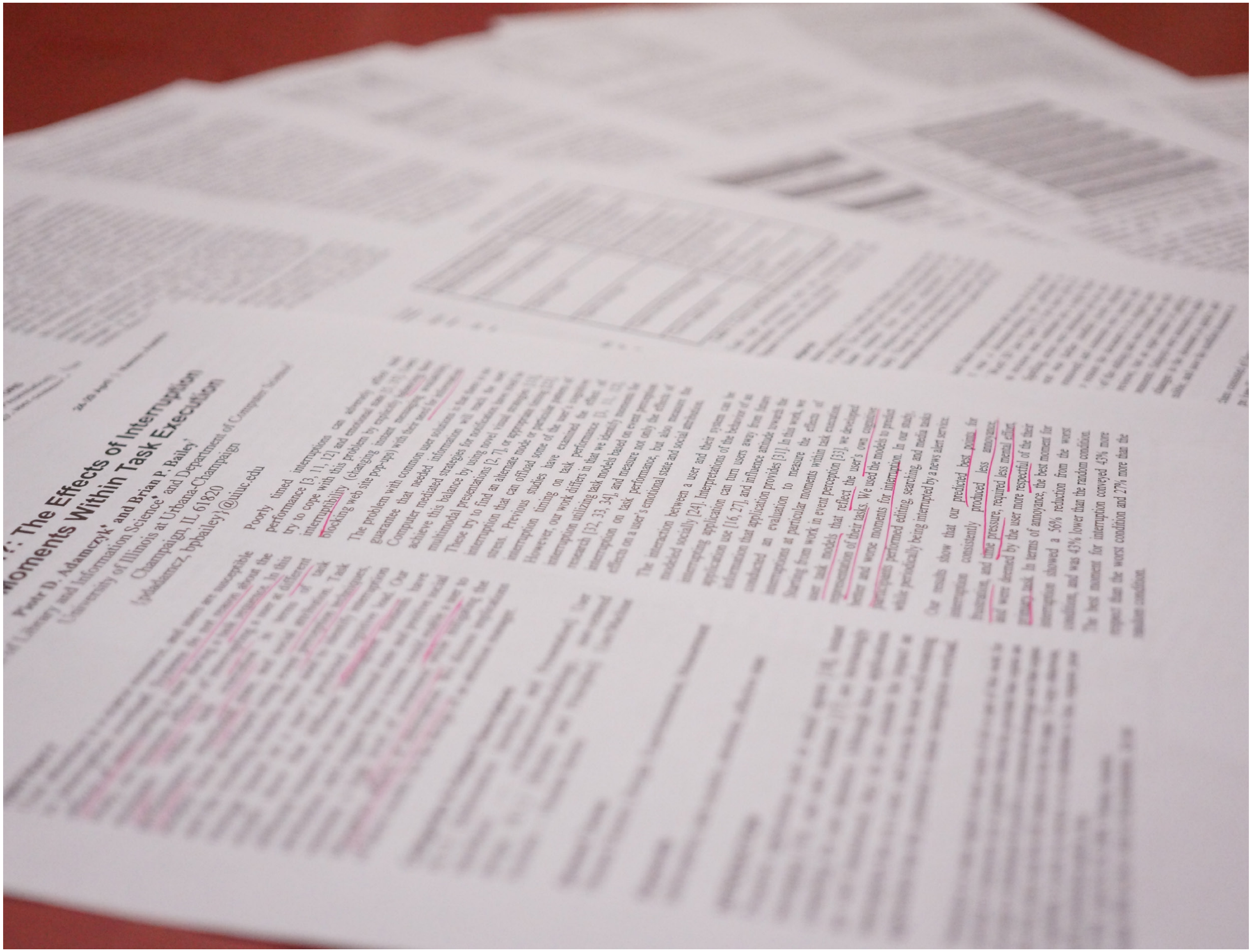
Domain Research Overiew

During the domain research of our project, we read academic literature pertaining to the problem NASA presented us with and conducted a competitive analysis.

For our literature review, we examined the following topics in order to develop broad domain knowledge: instruction manuals, spatial awareness, human-machine collaboration, attention and interruptibility, and contingency planning. Example findings include the impact of interruption on task execution and the complexity of different types of contingency plans.

Additionally, we reviewed technologies used in existing location awareness systems such as RFID, infrared, ultrasonic, bluetooth, and WiFi. Our research enabled us to understand the advantages and disadvantages of each technology.

To create our competitive analysis, we reviewed companies and products that focus on location awareness and asset tracking. We explored products from a variety of industries, including consumer, medical, and manufacturing. For example, we looked at Teletracking, a company that creates software that accurately tracks tools and equipment in hospitals, and Tile, a consumer product that helps locate lost keys and wallets. This analysis provided us with insights into existing solutions and their competitive advantages.



Literature Review Overview

Because astronauts' and engineers' time is scarce and they work in high-stakes environments with expensive materials and equipment, they must execute procedures efficiently and minimize errors.

A procedure execution system that provides concrete task guidance, facilitates tool finding, encourages task collaboration, and helps them plan for unexpected events will facilitate these goals.

To understand how to design such a system, we read academic literature on the following topics and reviewed existing tracking technologies:

- Instruction manuals
- Spatial awareness
- Human-machine collaboration
- Attention and interruptibility
- Contingency planning

Our research gave us a foundational understanding of topics that are relevant to our problem space. We discovered insights about effective instruction manual creation, humans' mental mapping of spaces, and strategies people use to locate objects. We also learned about the impact of interruption on task execution, optimal conditions for human-machine collaboration, and different types of contingency plans. Our technology review helped us better understand the advantages and disadvantages of commonly-used technologies in location awareness and asset tracking systems.

Instruction Manuals

PROJECT RELEVANCE

Reference materials must be designed to account for limited human memory and attention. Researchers have explored how using icons and print on warning messages affect memorability, and which instruction manual formats improve learning outcomes.

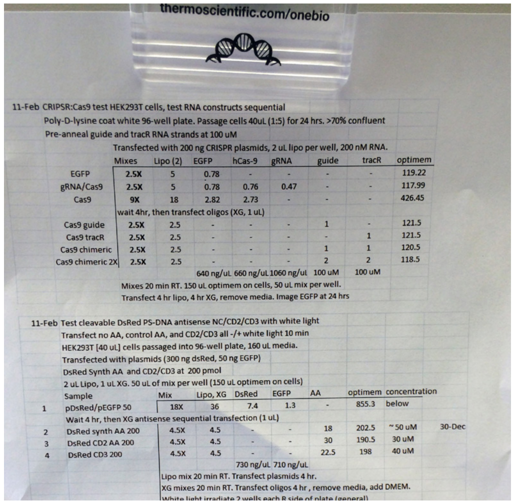
Icons and prominent text increase memorability

Icons and print warnings, combined, are more effective at cueing warning messages from memory than each is alone. A 1982 study showed that prominent print warnings altered subjects' task behavior, but did not impact their memory [1]. A 1988 study later illustrated how warning messages accompanied by icons and conspicuous print increased their recall [1], possibly because the pictorial information helped contextualize the warning.

Interestingly, researchers found differences in the effectiveness of icons and verbal warnings at cueing memory: the presence of icons in all the memory tests they conducted improved performance over conditions without the icons, while conspicuous print only improved memory in select tests [1].

Inferential learning manuals improve memory

An Inferential learning manual is one that makes users infer key information [2]. A 1987 study comparing the effectiveness of four different types of instruction manuals showed that participants learned the best from this version. The other versions researchers tested included the Skeletal Manual, which only states essential information; the Rehearsal Manual, which mirrors the Inferential Manual, while adding statements that make users review what they have already been told; and the Lengthy Manual, which adds extraneous details to the Skeletal model, making it around 50% longer than the other three versions [2]. Participants who read the Inferential Manual spent significantly less time reading it than the Rehearsal and Lengthy versions, and generally outperformed those who learned from the other manual types on three tasks (a simple learning task, a command sequence task, and a realistic task) [2]. Perhaps the Inferential Manual group outperformed the others since the manual's format encouraged participants to actively process its contents. Notably, these participants were also significantly faster on realistic tasks than any of the other groups.



11-Feb CRIPSR:Cas9 test HEK293T cells, test RNA constructs sequential
Poly-D-lysine coat white 96-well plate. Passage cells 40uL (1:5) for 24 hrs. >70% confluent
Pre-anneal guide and tracR RNA strands at 100 uM
Transfected with 200 ng CRISPR plasmids, 2 uL lipo per well, 200 nM RNA.

	Mixes	Lipo (2)	EGFP	hCas-9	gRNA	guide	tracR	optimem
EGFP	2.5X	5	0.78	-	-	-	-	119.22
gRNA/Cas9	2.5X	5	0.78	0.76	0.47	-	-	117.99
Cas9	9X	18	2.82	2.73	-	-	-	426.45
	wait 4hr, then transfect oligos (XG, 1 uL)							
Cas9 guide	2.5X	2.5	-	-	-	1	-	121.5
Cas9 tracR	2.5X	2.5	-	-	-	-	1	121.5
Cas9 chimeric	2.5X	2.5	-	-	-	1	1	120.5
Cas9 chimeric 2X	2.5X	2.5	-	-	-	2	2	118.5
			640 ng/uL	660 ng/uL	1060 ng/uL	100 uM	100 uM	

Mixes 20 min RT. 150 uL optimem on cells, 50 uL mix per well.
Transfect 4 hr lipo, 4 hr XG, remove media. Image EGFP at 24 hrs

11-Feb Test cleavable DsRed PS-DNA antisense NC/CD2/CD3 with white light
Transfect no AA, control AA, and CD2/CD3 all -/+ white light 10 min
HEK293T [40 uL] cells passaged into 96-well plate, 160 uL media.
Transfected with plasmids (300 ng dsRed, 50 ng EGFP)
DsRed Synth AA and CD2/CD3 at 200 pmol
2 uL Lipo, 1 uL XG. 50 uL of mix per well (150 uL optimem on cells)

	Sample	Mix	Lipo, XG	DsRed	EGFP	AA	optimem	concentration	
1	pDsRed/pEGFP 50	18X	36	7.4	1.3	-	855.3	below	
	Wait 4 hr, then XG antisense sequential transfection (1 uL)								
2	DsRed synth AA 200	4.5X	4.5	-	-	18	202.5	~50 uM	30-Dec
3	DsRed CD2 AA 200	4.5X	4.5	-	-	30	190.5	30 uM	
4	DsRed CD3 200	4.5X	4.5	-	-	22.5	198	40 uM	
				730 ng/uL	710 ng/uL				

Lipo mix 20 min RT. Transfect plasmids 4 hr.
XG mixes 20 min RT. Transfect oligos 4 hr , remove media, add DMEM.
White light irradiate 2 wells each R side of plate (general)

A detailed experiment document used by a biologist, which can be optimized for easier reading.

TAKEAWAYS

These findings can be applied to the procedure documents that astronauts and engineers reference on the ISS and in test facilities. Icons and conspicuous print warnings that highlight key content, as well as Inferential Manual techniques, may help NASA personnel remember when and how to execute key steps and perform critical safety checks.

1. Young, Stephen and Michael Wogalter. "Memory of Instruction Manual Warnings: Effects of Pictorial Icons and Conspicuous Print." Proceedings of the Human Factors and Ergonomics Society Annual Meeting (1988): 905-909. Print.

2. Black, John, John Carroll, Stuart McGuigan. "What Kind of Minimal Instruction Manual is the Most Effective". CHI '87 Proceedings of the SIGCHI/GI Conference on Human Factors in Computing Systems and Graphics Interface (1987): 159-162. Print.

Spatial Awareness

PROJECT RELEVANCE

Individuals create cognitive maps of their work areas and use different mental models to locate objects in a space. Cognitive maps are internal representations of a space, unique to an individual. Mental models of spatial layouts and object positions aid in orientation, navigation, and object location.

Individuals tend to group an object's location relative to other objects' positions

Two hypotheses explain the frame of reference people use when determining object location: egocentric (location of significant objects encoded relative to oneself) and allocentric (locations of significant objects encoded relative to each other) [5]. In Sargent's study, the researchers evaluated participants' spatial ability by having them learn the location of four objects, then blindfolding and disorienting them, and finally having them point to the objects again without removing the blindfold. The results suggested an allocentric view; when participants pointed, they indicated that the objects were in the same general area—located relative to each other—even if that area was wrong [5]. If the view had been egocentric, participants would have pointed to each object relative to themselves, which would have resulted in random directions. However, some evidence from the study contradicted the allocentric concept, so the results were not definitive. Objects tend to be grouped relative to each other, with some bias from the individual's orientation.

Cognitive maps are used to understand space

Cognitive maps are representations of an area that contain information about a space and the objects in it. Humans create and use cognitive maps when they are exposed to a space. These maps are dynamic and are updated as people familiarize themselves with an environment [3]. By using cognitive maps, people can orient themselves, navigate, and find objects in spaces. However, these maps are often inconsistent with the real world, and may even involve impossible logic [3, 4]. Despite these limitations, cognitive maps help humans understand spaces.

Reference objects are used to construct cognitive maps

Reference objects in an environment help one construct cognitive maps [3, 4]. For example, a brightly colored wall may act as a reference object inside a building. This wall is easily remembered, so the rest of the space and contained objects may be remembered and positioned relative to it. Furthermore, reference objects often stand out. The primacy and recency principles indicate that people most remember items at the beginning and end of lists, and least remember items in the middle. This translates directly to how people locate objects in spaces [2].

Additionally, people use objects in spaces for several other functions. The organization of objects aids with finding them, serves as a reminder to complete tasks, and helps construct a workflow through a space [1]. If people use an identical space for different functions, they will view and model it in disparate ways.

TAKEAWAYS

The work environments of astronauts and test engineers are complex and large. These individuals likely construct and use cognitive maps to help them execute their work. A careful design of a workspace could influence their cognitive map to help them work more efficiently.

1. Malone, Thomas W. "How Do People Organize Their Desks?: Implications for the Design of Office Information Systems." ACM Transactions on Information Systems 1.1 (1983): 99-112. Print.
2. Sommer, Robert, and Susan Aitkens. "Mental Mapping of Two Supermarkets." Journal of Consumer Research 9.2 (1982): 211-15. Print.
3. Tversky, Barbara (2005). Functional significance of visuospatial representations. In P. Shah & A. Miyake (Editors.), Handbook of higher-level visuospatial thinking. Pp. 1-34. Cambridge: Cambridge University Press.
4. Moeser, Shannon. "Cognitive Mapping in a Complex Building." Environment and Behavior 20.1 (1988): 21-49. Print.

Human-Machine Collaboration

PROJECT RELEVANCE

Effective collaboration enables individuals to work more efficiently and, in some cases, produce better outcomes than if they had worked alone.

Collaborators need to understand each others' intentions and actions

Successful collaboration requires a mutual understanding of intentions, actions, as well as immediate and final goals. Other requirements for effective collaboration are the ability to detect whether actions performed by collaborators deviate from expectations, and how to repair any errors.

Human-machine collaboration may produce better outcomes than entities working alone

In a study on human-algorithm collaboration, researchers compared humans' and algorithms' abilities to smooth simulated occluded missile trajectories, and the optimal conditions for their collaboration. Their first experiment revealed that algorithms were more accurate overall and had fewer missed trajectories than humans; however, they predicted more false trajectories [2]. The researchers then explored how results would change if humans and algorithms collaborated on this task. They found that the collaborative effort predicted fewer false trajectories than the algorithm, performed only slightly worse when detecting trajectories (97% vs. 99% for the algorithm), and displayed similar accuracy [2].

A machinist setting parameters on an automated CNC mill.

TAKEAWAYS

The researchers' experiment highlights the potential to apply human-machine collaboration to other situations. For example, dividing tasks based on humans' and machines' areas of expertise may improve NASA personnels' work efficiency on the International Space Station and in test facilities.

1. Bicho, E., et al. "The Power of Prediction: Robots that Read Intentions." Presentation at the 2012 IEEE/RSJ International Conference on Intelligent Robots and Systems, Vilamoura, Algarve, PT, October 7-12, 2012.

2. Rathje, Jason, Lee B. Spence, and Mary L. Cummings. "Human–Automation Collaboration in Occluded Trajectory Smoothing". IEEE Transactions on Human-Machine Systems 43.2 (2013): 5458-5449. Print.

Attention & Interruptibility

PROJECT RELEVANCE

With the proliferation of devices and apps, user attention has become a scarce resource. Several veins of research have focused on the effects of interruption on task execution, optimal timing for interruptions, as well as,the technology to determine that optimal timing.

Moments of interruption affect users' performance differently

In 1986, an influential study concluded that it is less costly to disrupt someone when his cognitive workload is lower.[1]. Subsequent studies have expanded upon that finding, such as the timing and sequence of the tasks and interruptions. One study showed that different interruption moments uniquely impact a user's performance and emotional state, positing that it would be possible to design a system that would allow for a high level of awareness and low disruptive effects of interruption [2].

Interruptions during primary tasks are most detrimental to task completion

Researchers have also explored the differences between primary and peripheral tasks, and the impact of one type disrupting the other. When peripheral tasks interrupt the completion of primary tasks, not only does the time it takes to complete the primary task increase by 3% to 27%, but participants in the study also committed twice the number of errors. The study also found that the peripheral tasks were completed 15% faster when they interrupted a primary task, perhaps since the user had extra motivation to return to the original task [3].

Speech detectors are a promising estimator of human interruptibility

From a technology standpoint, sensor-based estimators of human interruptibility are possible. Robust sensors working with several types of models can operate at about 75-80% accuracy. Speech detectors are among the most promising sensors and relatively easy to implement [4].

TAKEAWAYS

Astronauts on the ISS and engineers at test facilities must perform procedural tasks that sometimes require interruptions, and these research findings support the notion that there is theoretically an optimal time for different types of interruptions. Furthermore, NASA can install relatively lightweight sensors, such as speech detectors, to receive inputs and optimize when interruptions ought to take place, based on that information.

1. Norman, Donald A., and Stephen W. Draper. User Centered System Design: New Perspectives on Human-computer Interaction. Hillsdale: L. Erlbaum Associates, 1986. Print
2. Adamczyk, Piotr D., and Brian P. Bailey. "If Not Now, When?: The Effects of Interruption at Different Moments within Task Execution." Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '04) (2004): 271-78. 14 Feb 2014.
3. Bailey, Brian P., and Joseph A. Konstan. "On the need for attention-aware systems: Measuring effects of interruption on task performance, error rate, and affective state." Computers in Human Behavior 22.4 (2006): 685-708. Print.
4. Hudson, Scott, James Fogarty, Christopher Atkeson, Daniel Avrahami, Jodi Forlizzi, Sara Kiesler, Johnny Lee, and Jie Yang. Predicting human interruptibility with sensors: a Wizard of Oz feasibility study. In Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '03). New York, NY, USA, 2003: 257-264. 14 Feb 2014.

Contingency Planning

PROJECT RELEVANCE

Contingency planning is crucial for groups that work with high cost materials and equipment and in high stakes environments. Some contingency plans are programmed into a system (e.g. NASA rover systems) and are either static or dynamic. Static contingency systems follow a simple “if A then B” model. Dynamic contingency systems, on the other hand, are more complex and challenging to implement because they account for constantly changing variables.

Dynamic contingency plans have to account for a myriad of factors

When implementing contingency plans for a dynamic system such as NASA’s Mars rover, one must account for factors such as the system’s goals, starting conditions including temperature and energy available, and possible actions the system can take [1]. Other key factors that add uncertainty to outcomes include task duration, the possibility of continuous outcomes such as time and energy (in other words, actions do not have a number of finite outcomes), and problem size (the number of tasks a system handles) [2]. Accounting for the myriad of factors enables the system to create more comprehensive contingency plans.

Just-In-Case planning helps a system respond to unexpected events

Researchers at NASA use a dynamic technique called Just-In-Case (JIC) planning, which they modified to fit the needs of the Mars rover. The JIC-based system reviews a scheduled task, identifies the likely failure point, and adds a contingent branch [3]. Because the likely failure point may not be the optimal place to insert a contingent branch, the JIC system calculates the expected utility gain from inserting a branch at each point, as a function of available resources. The system then chooses a branch based on which one maximizes utility gain. A dynamic plan differs from a static approach, which adds an action with uncertain outcomes to a plan, and has the planner try to establish goals for different action outcomes.

TAKEAWAYS

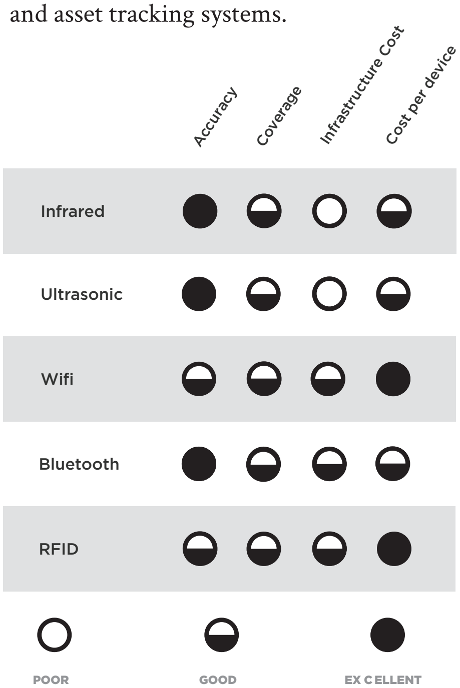
Successful contingency plans show the potential for "smart procedure" systems on the ISS or in test facilities. Similar to how contingency plans can divert one's intended path based on certain criteria, smart procedure systems may reroute astronauts or test engineers to help them execute procedures more efficiently.

1. Richard Dearden, Nicolas Meuleau, Sailesh Ramakrishnan, David E. Smith & Rich Washington. Incremental Contingency Planning. 2
2. Ibid. 2
3. Ibid

Existing Tracking Technologies

PROJECT RELEVANCE

In this section, we discuss some of the solutions and the technologies behind location awareness and asset tracking systems.



Infrared and ultrasonic systems

Infrared and ultrasonic systems are different location awareness technologies that operate on similar principles. The systems consist of emitters, which emit infrared or ultrasonic frequencies, and receivers, which detect and decode the emitted transmissions. By using a variety of techniques such as time-of-flight, these technologies can calculate objects' positions with high accuracy. The AT&T Active Bat is an ultrasonic system whose infrastructure consists of a large number of ultrasonic receivers installed as a grid on the ceiling of a physical space. The ultrasonic emitters are attached to objects and transmit identifying pulses. Time-of-flight calculations enable ultrasonic systems to precisely locate the object in 3D space. The system has also been extended to determine object orientation by using multiple emitters.

Wi-Fi

Using Wi-Fi, devices can estimate their location by utilizing properties of Wi-Fi such as variation in signal strength, range limitations, and communication with Wi-Fi access points. An example of such a system is RADAR, developed at Microsoft Research. This system depends on signal strength fingerprinting, in which the space is surveyed and Wi-Fi signals are mapped and recorded. This survey information enables a device to estimate its location with 1-3m accuracy in 2D space by comparing its current signal data to the survey results. Moreover, Wi-Fi based systems have a cost advantage since spaces are often equipped with Wi-Fi access points, and many devices are Wi-Fi enabled.

Bluetooth

Similarly, Bluetooth has been used used to create indoor positioning systems. Historically these systems have had limited accuracy. Bargh and Groote created a Bluetooth positioning system, which functions similar to Microsoft's RADAR system, using the response rate of Bluetooth inquiries. By fingerprinting the response rate of Bluetooth inquiries, Bargh and Groote determined room-level position accuracy for Bluetooth enabled devices. However, there have been many recent advancements in bluetooth technology, such as iBeacon, that allow for highly accurate indoor positioning. These systems utilize beacons placed throughout an area that can communicate information and location through Bluetooth Low Energy.

RFID

Finally, radio frequency identification (RFID) is used to create location awareness systems. RFID tags are batteryless objects that contain data and can be scanned by an RFID scanner. There are two types of RFID tags, short and long range. Short range tags are scanned at a range of a few centimeters, whereas long range tags can be scanned from up to 6 meters away. An example of such a system is the RFID Information Grid for Blind Navigation and Wayfinding, developed by Willis and Helal. This system installed a grid of RFID tags underneath the floor of a college campus. Each tag contained data about its surroundings. For example, a tag may note the location of a door five feet ahead, a desk and chair to the left, and a staircase to the right. System users wear a shoe containing an RFID scanner that interfaces with a tablet device. As the user walks along the grid, tags are scanned and information is relayed to their tablet, informing them of nearby objects. RFID tags are cheap and can easily be attached to objects, making them an appropriate solution for tracking assets in a physical space.

1. LaMarca, Anthony, and Eyal De Lara. Location Systems: An Introduction to the Technology behind Location Awareness. San Rafael, CA: Morgan & Claypool, 2008. Print.
2. Willis, Scooter, and Sumi Helal. "RFID Information Grid for Blind Navigation and Wayfinding." Wearable Computers (2005): 18-21. Print.

Competitive Analysis

In order to understand the existing products and gain inspiration for our solution, we examined procedure execution and asset tracking products that a variety of industries use. This is a summary of our findings—exact detail about individual products can be found in the appendix.

We reviewed products that are used in medical, manufacturing, construction, and consumer environments. While these products to not attempt to solve the same problems that NASA is focusing on, there are aspects of them that are relevant to our problem space. The products we are looking at all track information or objects in order to improve workplace or an individuals efficiency. Given our problem of increasing procedure efficiency in the context of using tools and materials, these products are appropriate for us to examine. Because NASA does not directly compete with these products, we determined that examining common themes and problems across these products would be more useful than performing a feature comparison.

We examined products spanning a range of industries and applications, including Tile, StickNFind, Teletracking AssetTracking, CenTrak, Enterprise Resource Planning, ToolHound, Ford Tool Tracking, ERPs, SmartThings Sensor, CribMaster, CAO Gadget, Nike+, and Fitbit. This revealed what is working across domains, enabled us to identify ideal solutions, and helped us incorporate ideas from tangential industries. Additionally, comparing products that are implemented using a range of technologies such as GPS, accelerometers, RFID, barcodes, infrared, RF, and Bluetooth enabled us to understand each product's strengths and applications.

Technology combinations allows for higher accuracy and supports system extensibility

While most products we looked at use only a single technology, CenTrak and Teletracking combine multiple technologies into a single product. This allows them to provide very precise tracking of equipment in hospitals. Products that relied on a single technology were usually only able to provide more general tracking information. Another advantage of incorporating several technologies, is that it allows for more flexible future feature development. The product development future is not limited by only supporting one technology.

Solutions must support the work environment they will be used in

The work environment should be closely examined and the product must be designed to be useful in that context. For example StickN-Find uses audio to aid in location, but in noisy environments this becomes problematic because it cannot be used. Similarly Teletracking and CenTrak are designed to be waterproof and dustproof because their use in medical environments. NASA work environments are highly specialized, so our solution must account for this and work across each context we are designing for.

Automated tracking reduces human input error and input lag time

We found the main advantages that automatic tracking is that errors are reduced and processes run more efficiently. Automatic tracking removes the need to manual document which is error prone and often not performed. Additionally, this creates efficiency gains. Not only can an individual find a tool or material more quickly, but their co workers are informed on statuses across the workarea. Hospitals across the nation have seen an increase procedural efficiencies because of Teletracking providing automated tracking.

Integrated applications are easier for individuals to understand

Through our analysis of the products we discovered two primary styles of implementation. One where a single application contained and integrated the product features and another in which major features were split into unique components. We found that the products that were integrated into one unit were much easier to understand. We perceived products that had many separate components to be overly complicated and heavy.

A SAMPLING OF THE TECHNOLOGIES WE LOOKED AT

CENTRAK

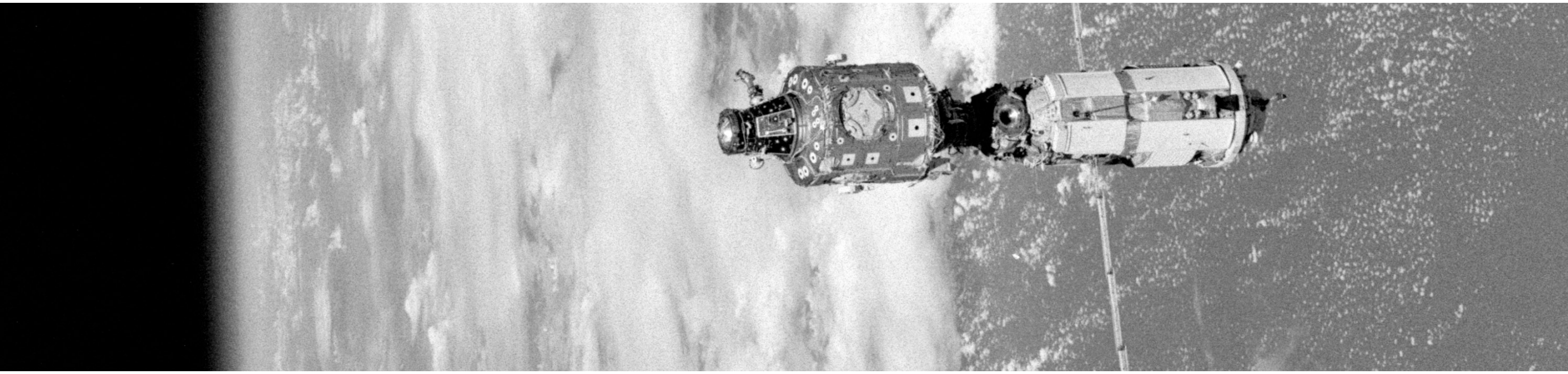
FITBIT

TILE

CONCLUSION

By examining these products, we gained insight into many systems and discovered how each performed.

Teletracking's RTLS for hospitals is an effective, comprehensive solution that improves many aspects of a nurse's workflow. Additionally, combining technologies enables Teletracking to provide more accurate and useful location information that any other product. Fitbit was another outstanding product. While it does not track objects, it tracks information. Moreover, all of the information FitBit tracks is automatically logged and collected in a history. Automatic tracking is extremely desirable because it eliminates human error. Additionally, historical information can be used to track progress and identify areas for improvement. These products will serve as a source of reference and inspiration as we construct our visions.



Field Research

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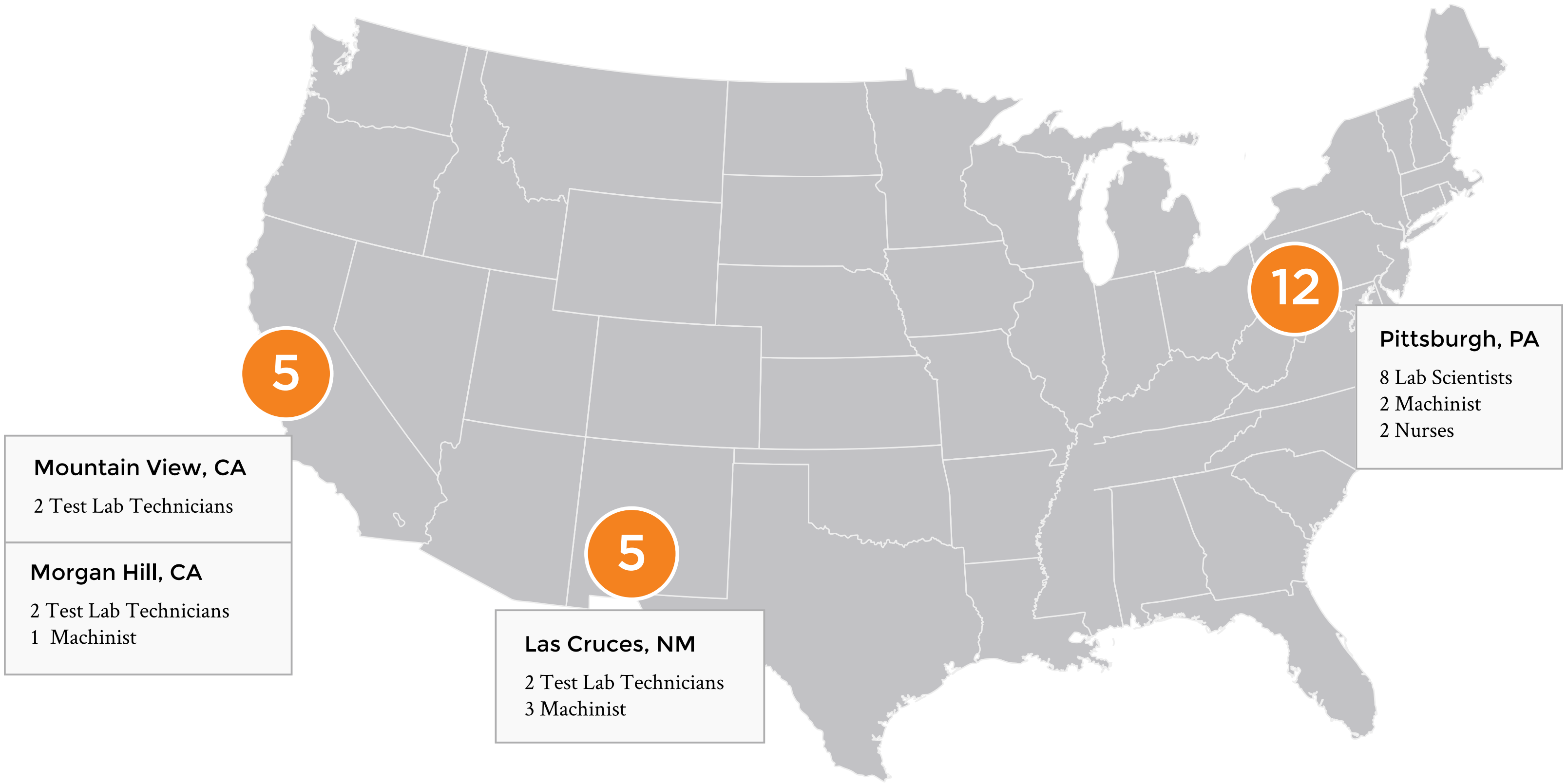
OUR OBSERVATIONS



Field Research Process

Our field research methods included contextual inquiries and semistructured interviews in analogous domains.

Because we could not observe astronauts in context, we conducted contextual inquiries in four analogous domains so that we could see individuals in their natural work environments: science labs, test labs, machine shops, and the medical domain. This approach enabled us to understand many aspects of procedure execution, including setup and cleanup processes, tools and reference materials, workspace organization, verification techniques, documentation, and collaboration with coworkers. We also conducted interviews when we could not directly observe individuals.

Because direct observation enabled us to see individuals' actual procedure execution steps, we treated interviews as supplemental information that could be used to support findings, but none served as the foundation of our insights.

At the conclusion of our field research, we had the opportunity to interview an astronaut who recounted her work in the ISS and NEEMO, an underwater simulation of space exploration. This interview yielded insight into an astronaut's work environment and confirmed that individuals in our analogous domains experience similar situations.

We interpreted our data by creating flow, sequence, physical, cultural, and artifact models, when appropriate, in order to understand different aspects of procedure execution. Moreover, we created an affinity diagram from our observation and interview notes in order to identify themes in our dataset.

Finally, we extracted insights by consolidating our models and identifying high-level themes.

Altogether, we performed 22 contextual inquiries and 7 interviews, broken down as follows:

CONTEXTUAL INQUIRIES

8 SCIENCE LABS

6 TEST LABS

6 MACHINE SHOPS

2 MEDICAL DOMAIN

INTERVIEWS

2 NASA SUPERCOMPUTING

2 DOCTORS

1 ASTRONAUT

1 NASA PHYSICIST

ANALGOUS DOMAIN COMPARISON CHART

	Collaboration	Unfamiliarity of task	High # of tasks	Multitasking	High stakes	Training	Need to find tools	Safeguards	Maintenance & upkeep	Process flexibility	Refers to documents
Lab Scientist	○	●	●	○	◒	●	●	○	◒	○	●
Test Lab Technicians	◒	◒	●	●	○	◒	◒	◒	◒	○	●
ER Nurses	●	◒	●	◒	●	●	●	●	○	◒	○
Machinists	◒	◒	●	●	◒	●	●	◒	●	◒	◒

A full glossary of terms can be found in the appendix.

○ **LOW / NONE**
the characteristic rarely occurs, if at all, in the domain

◒ **MEDIUM**
the characteristic occurs occasionally in the domain

● **HIGH**
the characteristic occurs regularly in the domain

Analogous Domains

Due to the difficult nature of observing astronauts and NASA engineers, we performed observations in analogous domains.

In this project, we focused on astronauts on the International Space Station and test engineers at NASA facilities. For the former, we have no way of observing our actual users, and for the latter, we have limited access to test facilities. Therefore, we have identified characteristics of the work domains we are designing for. in order to identify analogous domains to conduct contextual inquiries.

The set of work characteristics we identified include: task unfamiliarity, numerous tasks, multi-tasking, high-stakes environment, training, tool finding, safeguards, maintenance, process flexibility, and procedure reference. Next, we identified work environments that qualify as analogous domains and plotted them against the characteristics that we identified (left). Based on this information, we settled on lab scientists, machinists, test lab technicians, and medical personnel as our domains of focused research.


Adam performing an observation in the Hypervelocity Lab at the White Sands Test Facility in New Mexico.

Contextual Inquiry

Due to the highly specialized nature of NASA's work, we chose to use contextual inquiry as our primary research method.

For each observation, we visited individuals at their work site and focused on how they used tools and executed procedures.

Each session took approximately 1.5 - 2 hours. During this time, we followed an individual as he carried out a procedure, only interrupting to clarify his actions or motivations for performing a task. We recorded notes about everything we observed: what tools he used, how he kept track of which tools he would need, how he organized these tools, what reference materials he used while executing procedures, and how he collaborated with co-workers, if at all. To inform our future designs, we noted what processes worked well for individuals and what did not. Observing individuals in-context provided us with a deep understanding of their work environments and needs.

In some cases, we could not directly observe individuals due to unique circumstances such as patient privacy restrictions in the medical domain. As a workaround, we conducted semistructured interviews that focused on individuals' tool management strategies and procedure execution processes.

Altogether, we observed four domains with similar work environments to NASA's, including test laboratories, science laboratories, machine shops, and medical environments. During these observations, we collected a large amount of qualitative data that we used to construct our key findings, which are the basis for our design ideas.For each observation, we visited individuals at their work site and focused on how they used tools and executed procedures. Each session took approximately 1.5 - 2 hours. During this time, we followed an individual as he carried out a procedure, only interrupting to clarify his actions or motivations for performing a task. We recorded notes about everything we observed: what tools he used, how he kept track of which tools he would need, how he organized these tools, what reference materials he used while executing procedures, and how he collaborated with coworkers, if at all. To inform our future designs, we noted what processes worked well for individuals and what did not. Observing individuals in-context provided us with a deep understanding of their work environments and needs.

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Brad, a machinist, repairing a CNC mill before continuing with his procedure.

CONTEXTUAL INQUIRY

Machine Shops

6

CHARACTERISTICS

Machine shops share many characteristics with NASA environments. For example, machinists often create a single part for a one-off procedure. These specialized tasks are common for NASA personnel because of the unique nature of their work.

The equipment in machine shops can be costly, raising the stakes of machinists' work.

Additionally, machinists keep track of a large number of tools and materials in order to perform their tasks, similar to NASA test lab environments.

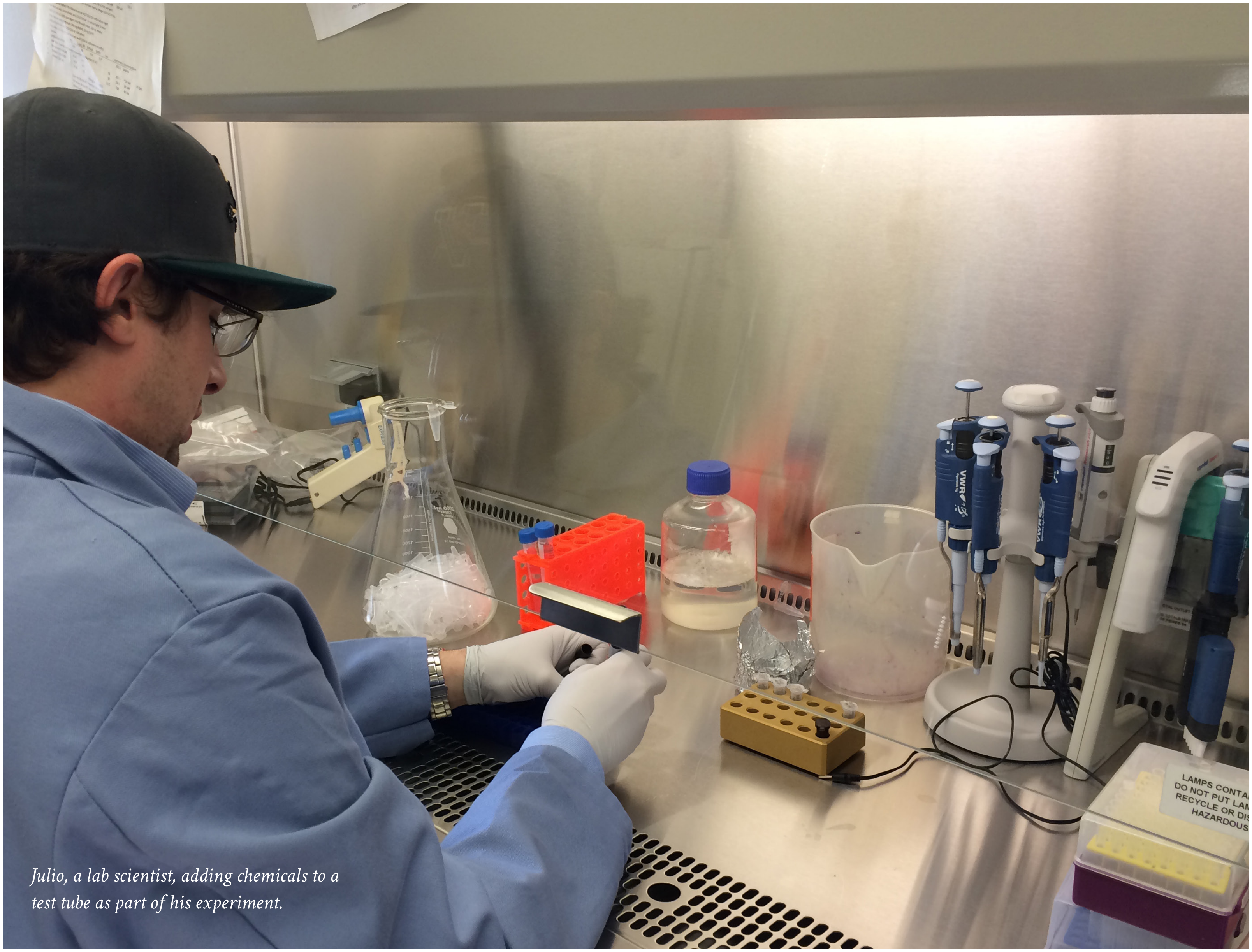
Finally, machine shop equipment requires a high level of upkeep, so machinists spend a large portion of their time on maintenance, similar to how astronauts spend their time in the International Space Station.

OBSERVATIONS

We observed six machine shops across a variety of organizations and industries: Specialized Bicycles, Angstrom Sciences, and Carnegie Mellon University. Additionally, we observed three machinists working in a machine shop at NASA's White Sands Test Facility.

DAY IN THE LIFE

Brad, a machinist, generally receives part requests, in the form of text descriptions or CAD models, from engineers. If necessary, he will make a CAD model to guide his work. Once Brad has part specifications, he sets up and calibrates the CNC machine to mill the part. While the CNC machine is running, he works on another task that requires more manual labor, such as creating a part on a lathe. This manual task also requires working off of engineers' requests, so Brad may reference his computer or a procedure document. While Brad is working on the lathe, his co-workers will often ask for advice or assistance making a part. After the machine finishes milling the part, Brad cleans the machine and disposes of any debris he has generated in order to keep his workstation clean.



Julio, a lab scientist, adding chemicals to a test tube as part of his experiment.

CONTEXTUL INQUIRY

Science Laboratories

8

CHARACTERISTICS

Similar to NASA astronauts and engineers, lab scientists collect materials and tools in order to carry out experiments.

Lab scientists generally design their own experiments and determine in advance the tools and materials needed to perform the procedures.

Furthermore, experiments range in length, so lab scientists often multitask by performing multiple experiments at the same time. In doing so, they must keep track of procedure steps, measurements, and time for each simultaneous experiment.

Lastly, many scientists share common laboratory space, so communal tools and materials must be organized and their statuses, communicated.

OBSERVATIONS

We observed 7 biology and chemistry scientists in laboratories at University of Pittsburgh and Carnegie Mellon University for a period of 1.5 to 2 hours each.

DAY IN THE LIFE

When Irena, a lab scientist, starts a procedure she begins by referencing a procedure document on her lab notebook. She jots down chemical quantities that she will need to reference during the experiment. Next, she sets up her workspace, which involves gathering communal tools, equipment, and materials that will be used during the experiment. She then sets up and runs her experiment, which can consist of creating chemical solutions, constructing an apparatus, or growing cell cultures. If an experiment requires a waiting period, she checks on the status of other experiments or cleans up her lab space. Running several procedures at once is a key part of her routine. After cleaning she returns to her lab notebook to document the results of any completed experiments.

There is never any rest in the Emergency

A vacuum chamber at NASA's White Sands Hypervelocity Test Lab, which is used to test whether spacecraft can withstand high-velocity debris impact

CONTEXTUAL INQUIRY

Test Laboratories

6

CHARACTERISTICS

Since test engineers are one of our target users, test labs were an obvious choice for observations. We saw teammates collaborate and share communal tools and materials.

Because the procedures require test parts and measurements, test lab technicians searched for a variety of tools, carried out procedures, and documented the results.

We also saw varying levels of process flexibility, depending on the importance of the test and equipment.

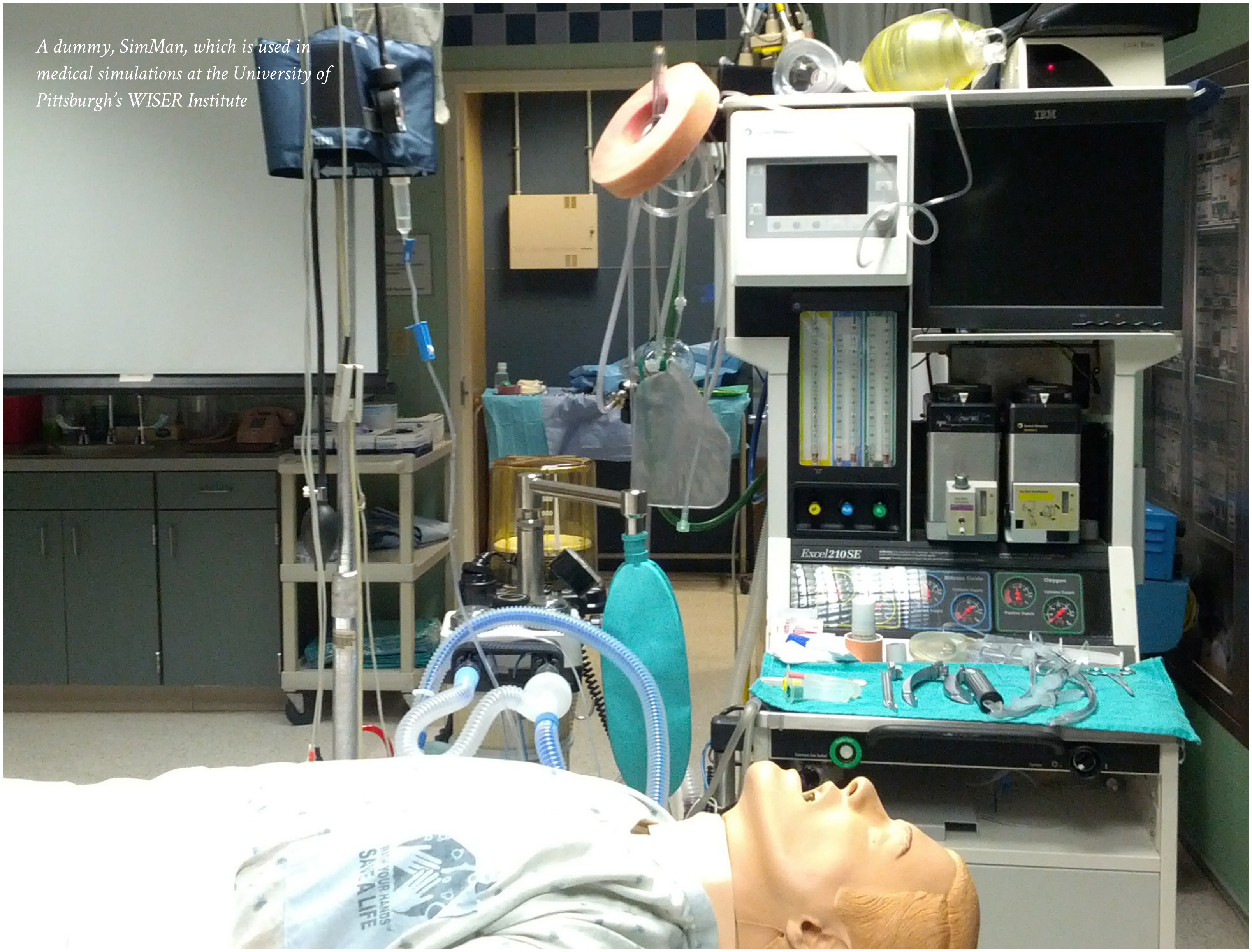
Similar to machine shops, we observed sporadic use of document procedures, depending on a technician's familiarity with the test.

OBSERVATIONS

We observed two NASA test labs — the Arc Jet Complex at the Ames Research Center and the Remote Hypervelocity Test Laboratory at the White Sands Testing Facility. In both NASA test facilities, technicians operated expensive machinery in high-stakes environments. In order to gain a wider perspective, we also visited the test lab at Specialized Bicycles and observed technicians perform a series of stiffness tests on mountain bike frames.

DAY IN THE LIFE

Ryan, a test lab technician, spends most of his time setting up tests. The test that he performs is high stakes and expensive, so much of this time is spent making sure the test is setup correctly. Therefore works closely with a designated verifier who carefully checks his work. The tasks he performs often require two individuals working together to complete. These tasks involve steps such as setting up a material to be tested, aligning cameras to record the test, and preparing the testing machine. Given the high stakes nature of the test, he must carefully document the results and share the data with engineers.



A dummy, SimMan, which is used in medical simulations at the University of Pittsburgh's WISER Institute

CONTEXTUAL INQUIRY

Medical Domain

2

CHARACTERISTICS

The medical domain shares many characteristics with the NASA work environment, including high-stakes procedures, collaboration, and the extensive use of tools.

Similar to astronauts and NASA test engineers, medical personnel must perform tasks in a time-sensitive and high-stress environment.

Also, the medical domain requires a high degree of collaboration between doctors and nurses to keep hospitals running smoothly.

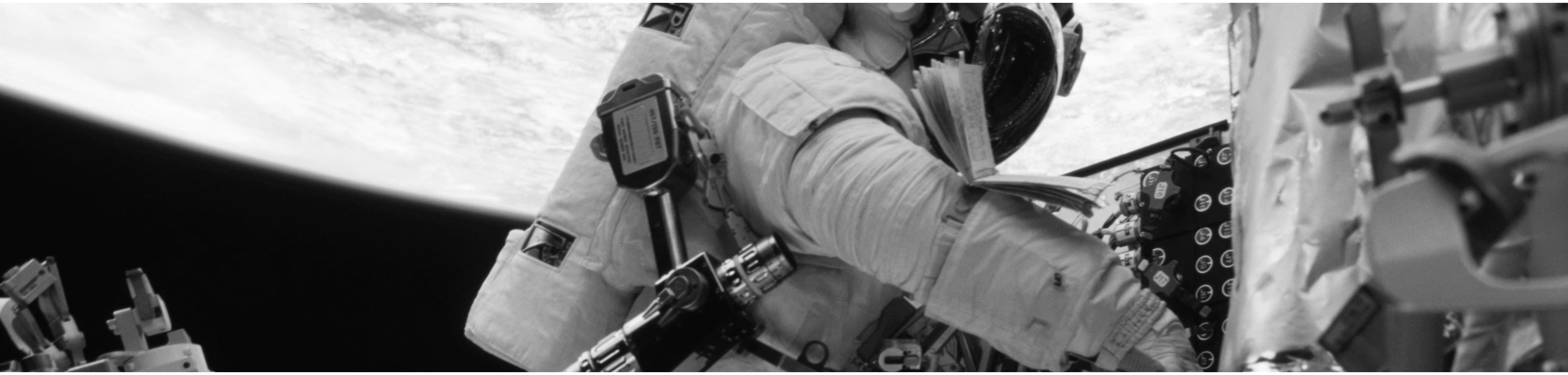
Finally, a significant amount of resources is devoted to organizing, tracking, and preparing the tools necessary for medical procedures.

OBSERVATIONS

We performed 3 observations in the medical domain. These individuals included an emergency department nurse at the University of Pittsburgh Medical Center (UPMC) and several anesthesiology student nurses at the University of Pittsburgh's WISER Institute. In addition, we interviewed two Stanford University medical doctors, an anesthesiologist and a pediatric orthopaedic surgeon.

DAY IN THE LIFE

There is never any rest in the Emergency Department. Donald, an ER nurse, constantly checks on patients, helps during surgeries, updates patient information, and cleans up. He checks the patient's vitals monitor display. As he goes around checking on patients, hurried co-workers walk by asking questions, and Donald responds quickly. The PA system asks for a doctor in the trauma room, and Donald, sensing the gravity of the situation, rushes there to help. In the trauma room, he and a team of nurses and doctors rush around yelling for tools, materials, and vitals information while stabilizing the patient—it's organized chaos. Afterwards, Donald must transfer a patient to another department and check the system to see if there are any open rooms. He eventually calls the other department to make sure they have enough open beds since the system information is outdated.



Discoveries

CONTENTS


Test Lab Flow
Flowsss

Discoveries Process

During the field research of our project, we gathered data based on observations, modeled the data, and synthesized them into key findings.

To distill all of our data down to a manageable set of key findings, we consolidated our Flow and Sequence models and used an affinity diagram to organize our observations notes. Next, we developed 10 research findings that highlight the most salient and interesting observations from our field research.

With those findings, we generated 3 key design insights and 4 secondary insights to surface the biggest challenges and opportunities that our solution will tackle. The key insights, each supported by evidence from 2-4 domains, will provide focus and guidance as we develop our visions and explore them in depth. The secondary insights, each supported by evidence in one domain, are nevertheless relevant to our project and will serve as additional context in the design process.

INSIGHT

Ease in gathering key information for quick reference streamlines procedure execution

On the ISS and in NASA test facilities, astronauts and test engineers must reference long, detailed documents to perform procedures. In many cases, they are familiar with the procedure but need to reference key information during specific steps. We can streamline their procedure execution process by developing a solution that provides quick access to that key information.

SUPPORTING OBSERVATIONS

Key information needs to be extracted for easy access

Procedure documents are ill-suited for quick reference during task execution

Necessary status information is difficult to gather

INSIGHT SUPPORT

Key information needs to be extracted for easy access

During observations in several domains, we witnessed interruptions when an individual referenced documents or software programs mid-procedure to retrieve a key specification, such as a dimension of a part, the mass of a chemical, or a status of a machine. These individuals would then bring the collected information over to their work area, and reference the information as they continued their procedures.

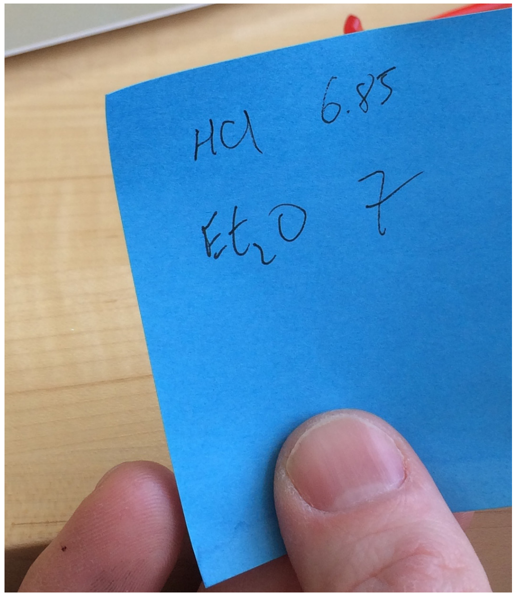
DOMAINS OBSERVED

CHEMIST RECORDS VALUES ON STICKY NOTES TO TRANSFER KEY INFORMATION TO WORKSTATION

When Joe, a chemist, realized he needed specific values during an experiment, he removed his safety equipment, moved to a different workstation to access his computer, retrieved a procedure document, found the values he needed, and wrote those values on a Post-it note. He then carried the note over to his work area and affixed it to a fume hood, providing quick reference as he worked. Each time the scientist stepped away from his experiment, he removed his safety gear and put it back on once he gathered the necessary information.

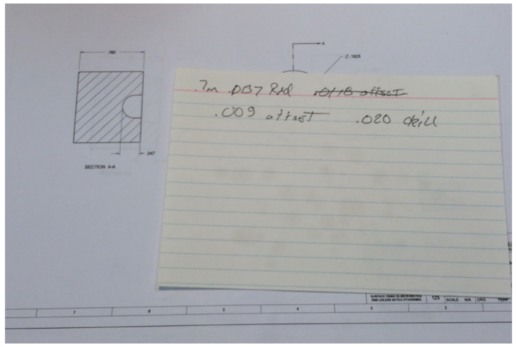
"Some people print it out, but I'm a fan of the sticky note."

– **JOE**, a chemist, on how he prefers to reference key information from a procedure



Joe, a chemist, writes values for quick reference on his sticky notes, as seen above.

Right: Notecard where Bryan, a machinist, writes down measurements to use while working at a lathe.



CHEMIST WRITES KEY MEASUREMENTS ON HIS GLOVE FOR QUICK REFERENCE MID-PROCEDURE

One lab scientist, Ken, devised a creative way to carry the key information with him in a non-obtrusive way. For an experiment, Ken needed to measure out specific quantities of a few chemical materials. Rather than bringing his lab notebook to the workstation or writing key data on a Post-it note, Ken wrote the specific measurements with a Sharpie onto his latex glove, which provided quick and constant access to the information.

Left: Ken, a chemist, referencing his lab notebook and writing key measurements on his glove with a Sharpie.

MACHINIST GOES BACK AND FORTH BETWEEN WORK AREAS TO COLLECT INFORMATION

Machinists extracted and applied key information in ways similar to lab scientists. Bryan worked on parts incrementally and referenced the computer as he needed more information. We observed Bryan as he employed a lathe to build a custom part for the Hypervelocity test lab. First, he retrieved a CAD model on his computer and measured the model with a ruler function in the software. Then, he wrote the measurement on a notecard and carried the card to the lathe station. A few minutes later, Bryan returned to the computer to make another measurement, wrote it down, and returned to the lathe. This inefficient process required Bryan to travel back to the computer for each step in fabricating the part.

INSIGHT SUPPORT

Procedure documents are ill-suited for quick reference during task execution

Contrary to our expectations, we rarely observed individuals in each analogous domain working directly off of procedure documents. Due to their familiarity with the procedures, individuals only consulted reference materials to extract specific pieces of information, such as a measurement.

DOMAINS OBSERVED

TECHNICIAN AVOIDS INTERRUPTIONS TO PROCEDURE BY REFERENCING DOCUMENTATION DURING SETUP

At NASA, we observed ArcJet and Hypervelocity lab technicians carrying out routine maintenance procedures. During the few occasions when lab techs observed documented materials, they did so during the setup phase of a procedure. If a lab tech needed more information after initiating a procedure, he frequently consulted another co-worker instead of interrupting the procedure to read through the documentation. This is likely because getting the information from his coworker was faster and, therefore, had a less detrimental effect on his procedure execution. Our literature review on attention and interruptibility showed that when peripheral tasks interrupt a primary task, the time it takes to complete the primary task increases, and individuals make more errors. At the Hypervelocity test lab, the documentation for a test procedure spanned 14 pages.

ickel-Hydrogen Battery ORU Test Plan 03 February 2014

Hypervelocity Impact Test Plan for ISS Nickel-Hydrogen Battery ORU

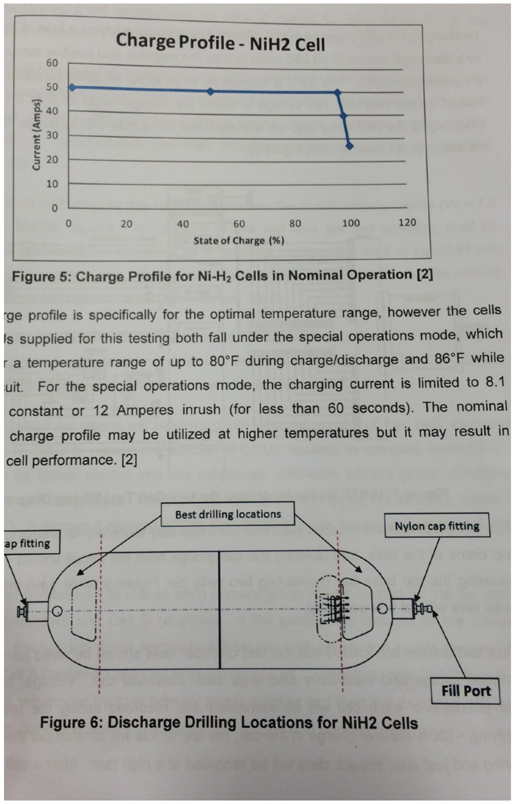
ASA-JSC/Eric Christiansen Boeing/Russell Graves
oeing/Samuel Treadgold NASA-JETS/Frankel Lyons

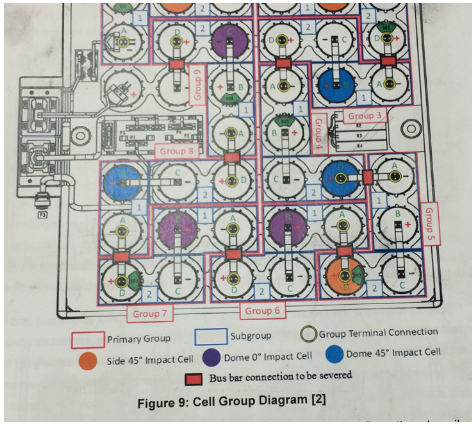
ıtroduction

he International Space Station (ISS) presently uses nickel-hydrogen ($Ni-H_2$) batteries to ıpply power during the eclipse (or dark) phase of its orbit. The batteries charge henever the station is in sunlight and discharge during the orbital eclipse periods. The attery Subassembly Orbital Replacement Units (ORUs) consist of 38 $Ni-H_2$ cells urrounded by an aluminum honeycomb enclosure that protects them from the space nvironment. All of the ORUs reside on the outboard truss segments, Figure 1, with little hadowing from other hardware, so they are at an increased risk of damage from licrometeoroid Orbital Debris (MMOD), which could potentially result in loss or egraded performance of critical power storage and generation capabilities.

(left) and Tom Marshburn work to

Above and right, various pages out of a 14 page procedure document used in the Hypervelocity test lab.





TECHNICIAN HALTS WORK IN ORDER TO COLLECT INFORMATION

A technician at Specialized, Ryan, needed a crucial measurement from an Excel spreadsheet in the middle of a test procedure. To retrieve that data, Ryan had to halt the procedure, walk over to his desk, find and retrieve the spreadsheet on his computer, and write the measurement on a piece of paper to bring back to the workstation. The observations from NASA and Specialized suggest that detailed documentation are inadequate and inefficient for quick reference mid-procedure. This is consistent with our literature review on reference materials, which indicate that icons and prominent text on warning messages increase memorability, while lengthy instruction manuals do not.

"I don't carry my lab notebook with me, I find that to be a little in the way of what I am doing."

–**IRENA**, a lab scientist, explaining why she doesn't bring along document procedures to her workstation

INSIGHT SUPPORT

Necessary status information is difficult to gather

In the domains we observed, individuals often needed to gather status information from machines or from other collaborators. Much like the key information they needed to extract from procedure documents, individuals experienced difficulty accessing that information.

DOMAINS OBSERVED

MACHINIST USES HIS SENSES TO GATHER STATUS INFORMATION WHILE MULTITASKING

We witnessed a machinist, Brad, setting up and running a procedure on a CNC machine and moving on to other tasks while he waited for the machine to mill the part. While multitasking allowed machinists to use their time more efficiently, it also forced them to keep track of machines and procedures that might not be in their immediate vicinity. When multitasking, Brad remained alert to any noteworthy noises or smells that might signal a status change with the machine. Once Brad detected any unexpected changes, he immediately walked back to the CNC machine to investigate.

Brad, a machinist, checks on the CNC machine after detecting an audible change in the milling process.

MACHINIST DISTRUSTS AUTOMATED CALIBRATION ON HIGH STAKES EQUIPMENT

Similarly, we observed a couple of machinists who did not trust the status information provided by machines, especially in high-stakes environments with expensive equipment. Andy, a machinist, used an automated lathe that could self-calibrate and show updates on its digital display, but we witnessed machinists manually measuring and verifying the calibration inside the machine cavity. The possibility of an incorrect calibration that breaks an expensive machine prevents machinists from completely trusting automatic calibrations.

A machinist is manually calibrating the lathe because he distrusts the readout from the display.

"There is a computer system that informs whether values are open or closed, but you want to go down and check it for yourself."

–MARIA, ARCJET OPERATOR

INSIGHT

Successful collaboration requires coordinated sharing of procedure process and status information

Tools and materials aboard the ISS and in NASA test facilities are shared among many individuals who must coordinate their location and use. To prevent delays, our solution will need to make it easy for co-workers to share their procedures and the status of their tool use, so that the information remains relevant and reliable.

SUPPORTING OBSERVATIONS

Collaboration breakdowns are caused by poor coordination and inaccurate system information

Maintaining shared tools and spaces requires consistent coordination among collaborators

INSIGHT SUPPORT

Collaboration breakdowns are caused by poor coordination and inaccurate system information

When individuals cannot gather vital information during a procedure, breakdowns often occur. In cases where we observed breakdowns, an unavailable co-worker held this key information, and the procedure grinded to a halt while the main tester waited for the co-worker to return or respond. These observations are consistent with our literature review on collaboration, which implies that collaboration deteriorates when partners do not understand each other's intentions and goals.

DOMAINS OBSERVED

TECHNICIAN NEEDS APPROVAL FROM COLLABORATOR TO CONTINUE HIS PROCEDURE

At the Hypervelocity test lab, in the process of setting up a test, Philip realized he needed approval from a verifier in order to proceed. However, the verifier had just left the building, unaware of the step in Philip's procedure that required his presence. Philip spent several minutes trying to contact the verifier by telephone, intercom and paging systems. Eventually the verifier walked by, unaware that Philip had been trying to reach him. After the verifier confirmed that he had completed his work, Philip said, "All that for that," suggesting that the effort spent finding the verifier was disproportionate to the importance of the verification.

"All that for that."

–**PHILIP**, technician, after searching and waiting for a verifier to give a quick go ahead to proceed to the next step in his procedure

As Philip, a technician, is setting up this procedure, he requires approval from a colleague.

“[I’m looking for] a file someone sent me one and a half years ago that may or may not have the information.”

–**FRANK**, a lab scientist, trying find information to share with a collaborator

DELAY IN INFORMATION SHARING PREVENTS A TECHNICIAN FROM COMPLETING HIS TASK

At Specialized, engineers often collaborate between facilities in different countries, including the sharing of results from different test labs. Ryan, a Specialized test lab technician, performed a series of stiffness tests repeated by other lab techs at a different location. After completing his procedures, Ryan documented his own results and sought to compare them with results from a different test lab. However, those results had not yet arrived, preventing Ryan from wrapping up this particular task. In this case, careful coordination of statuses and information between the test labs could have prevented the delay.

WHEN STATUS INFORMATION IS DEEMED UNRELIABLE, A NURSE HAS TO CALL SOMEONE TO VERIFY

Collaboration breakdowns also occur when individuals experience difficulty gathering and sharing status information. Donald, an emergency wing nurse, needed to verify the availability of rooms in other departments in order to transfer patients who needed different operations. He became confused when trying to transfer a patient to another department because the system that showed room statuses displayed inaccurate information. To clarify the confusing status information, Donald had to to call the other department to see if they could accept the patient.

INSIGHT SUPPORT

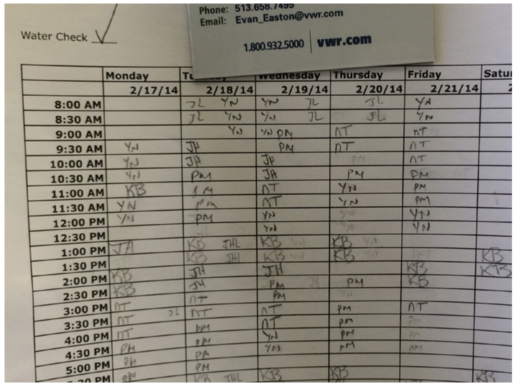
Maintaining shared tools and spaces requires consistent coordination among collaborators

Although most of the individuals we observed performed their work alone, they often depended on collaborators to maintain shared workspaces and tools, in order to execute their procedures.

DOMAINS OBSERVED

INCONSISTENT UPDATES OF STATUS INFORMATION CAN CAUSE PROBLEMS FOR COLLABORATORS

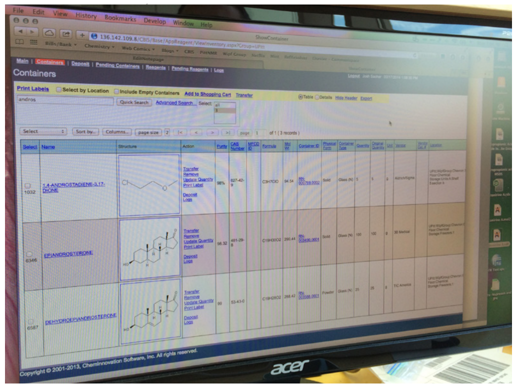
The laboratories we observed consisted of numerous scientists working primarily on independent projects. However, the lab itself served as a space for shared tools, materials, and work areas, all of which were used by multiple scientists throughout the day. Labs commonly used documentation to track the usage of these communal objects. This documentation required constant updating and coordination. In Ken's lab, the scientists used a Google Docs spreadsheet to keep track of the material locations and inventory. However, when Ken used the remaining material in one container, he simply placed the empty container back on the shelf, neither refilling the container nor updating the inventory spreadsheet. When scientists at the lab do not carefully update the inventory documents, the data becomes obsolete and less useful to the group, causing a breakdown in the sharing of communal materials.

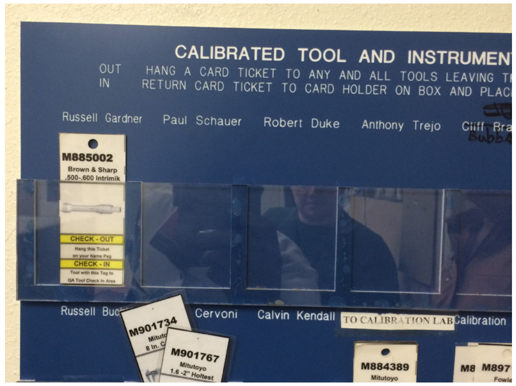


A sign up sheet in a biology lab used to coordinate times for working a the fume hood.

"[The sign up sheet is] the most important thing in the lab."

–**IRENA**, lab scientist, The sign-up sheet for fume hood time in the biology lab, placed right above the hood itself, so scientists can access it as they work





COMMUNAL INFORMATION CAN EASILY BECOME OBSOLETE

At Frank's chemistry lab, the scientists used a chemical inventory software to track their communal materials. The software could track locations, quantities, bottle size, and several other attributes. However, each category of information required manual updates, so nearly all of the information eventually became obsolete as collaborators grew tired of the process. Frank stated, "Theoretically we could update [the inventory system] every time, but no one does because it's a pain in the a**." Coordination requires much effort for individuals to perform, and thus, is often neglected.

COLLABORATORS CAN MAKE TOOL FINDING MORE COMPLICATED

At Specialized's test facility, lab technicians used a shared set of tools and relied on each other to return those tools to the correct locations. Ryan, a technician, searched for a wrench to install a bike onto a test stand. However, he failed to find the wrench in the designated wrench drawers located throughout the test lab. After Ryan spent about five minutes searching for the tool, a colleague mentioned that he had seen another technician use the wrench. Ryan followed the tip and eventually recovered the wrench he needed to continue his procedure.

Top, the chemical inventory software, which keeps track of locations and quantities, but requires manual updates. Bottom, a checkout system that the machine shop at White Sands has implemented to organize communal tools.

"Theoretically we could update [the inventory system] every time, but no one does because it's a pain in the a**."

–FRANK, LAB SCIENTIST

INSIGHT

Related physical objects and information become more meaningful when they are kept together

In our field research, we noticed that physical proximity can enhance the informational relationship between two objects. In the context of this project, we see an opportunity to create a closer association between tools and their related content, such as a relevant procedure step or status information.

SUPPORTING OBSERVATION

Individuals create associations between information and physical objects

INSIGHT SUPPORT

Individuals create associations between information and physical objects

In three of the four analogous domains, we observed the placement of physical objects with its corresponding information. Sometimes an object and a procedure document occupied the same space. In other examples, objects carried a tag that could be matched to a document in another location. In each case, correlating objects and information enriched both with more context and reduced the amount of time and attention required to perform the associated task.

DOMAINS OBSERVED

BIOLOGIST WRITES KEY INFORMATION ON A TEST TUBE

Julio, a biologist, labeled test tubes, containers, and beakers to keep track of materials, measurements, and results. These values written on the objects provided a quick summary of the contents within and sometimes served to pass information from one person to another. We observed Julio collecting and reading the values written on a test tube. When asked about the values, he explained that a labmate who had performed a prior experiment wrote the values on the test tube. He wrote the experiment bottle and notebook page number onto the same test tube. Writing information on the physical object allowed Julio to stay organized and decreased the likelihood of an error due to incorrect information.

Julio, a biologist, injected a couple of solutions into a test tube and recorded data relating to the materials and measurements on the lid of the test tube.

At White Sands, a piece of calibration equipment with a sticker that tracked calibration and expiration dates.

Red bin used by machinists to keep parts and related procedure documents physically associated.

A MACHINIST PLACES A PROCEDURE DOCUMENT NEXT TO ITS ASSOCIATED MATERIALS

At the Angstrom machine shop, we observed Andy place procedure documents and parts for an order in red bins positioned around the work areas. For physically smaller orders, the parts and documentation were kept together in the bins. Keeping related objects and information physically close to each other allowed machinists to stay organized. In addition, we noticed that when the parts of larger orders did not fit inside the red bins, Andy placed the procedure documents underneath, or next to the part.

AD HOC LABELS ARE COMMONLY USED TO TRANSFER INFORMATION

At Specialized, we observed a technician, Ryan, performing a series of three stiffness tests on bike frames of different sizes. Ryan often consulted the stickers affixed to each frame, that tracked which tests had been performed and which ones still needed to be completed. Depending on their schedules and agreed timelines, Ryan and his colleagues shared information about test statuses verbally and through the stickers.

Secondary Findings

Unlike each key insight, which appeared in multiple domains, each secondary finding typically arose several times in one domain. These findings are important because they show the challenges individuals in a specific domain face while they execute procedures and the individuals' strategies for increasing work efficiency. Our solution should address these challenges and support individuals' techniques for increasing procedure efficiency.

OBSERVATIONS

The cleanup and documentation phase for one procedure is the preparation stage for another

Standardizing procedures is challenging due to unique individual needs

Multitasking and procedure interruptions occur frequently

Procedure processes are adapted to minimize tool gathering

SECONDARY INSIGHT

The cleanup and documentation phase for one procedure is the preparation stage for another

In science labs, we observed how the cleanup process for one step may affect the next work process. When lab scientists ended experiments, they cleaned their equipment, put away materials, and documented their results. They then based subsequent procedures, whether a minor variation of the experiment or a continuation of the previous one, off of these results. Frank, a biologist, duplicated a procedure document in his digital notebook and changed a few values in order to continue with his next step. We also observed how the cleanup stage may affect the setup process for a subsequent experiment. For example, when a scientist did not carefully clean up after an experiment, he created more work for himself when setting up a new one.

DOMAINS OBSERVED

Frank, a chemist, documenting the results of his experiment. He bases subsequent procedures off of a modified version of these results.

"There is never a beginning or an end, we are always just working."

– FRANK, LAB SCIENTIST

Materials laid out for use during an anesthesia nurse exam. The variability in tool use among anesthesiologists makes the setup process for actual surgeries inefficient.

DOMAINS OBSERVED

SECONDARY INSIGHT

Standardizing procedures is challenging due to unique individual needs, making setup inefficient and information sharing difficult

In the medical domain, we discovered that standardizing procedures can be challenging because of unique physician preferences and patient needs. Our interview with the anesthesiologist revealed that, while anesthesiologists use some common tools such as arterial lines, intubation tubes, and laryngoscopes, they choose other tools based on personal preference. Furthermore, standardizing procedures can be difficult in anesthesiology because the type and dosage of drugs administered depend on individual patient traits such as weight, age, and history of drug use. However, one area that Stanford's anesthesiology department has attempted to proceduralize is crisis management. Stanford created a book called the Emergency Manual, which outlines critical cases and high-level steps for how to handle each crisis. This is an important reference material during crises since people's memory worsens, and they may deviate from planned actions, when they face stressful situations.

SECONDARY INSIGHT

Multitasking and procedure interruptions occur frequently, requiring individuals to switch contexts often

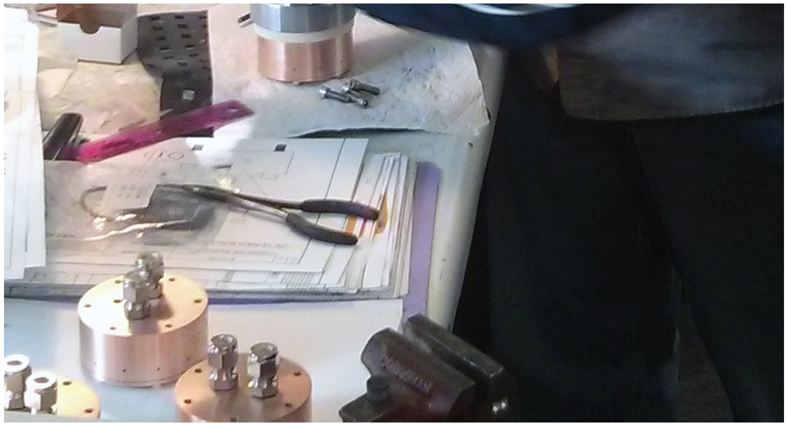
Machinists often worked on several different processes at one time. A machinist might set up a CNC mill to run an automatic procedure, and then work on a manual task, such as drilling a part on a lathe. By multitasking and interspersing automatic and manual procedures, the machinist can manage his time more efficiently. Machinists also multitasked when interruptions occurred. In one instance, Brad, a machinist at Carnegie Mellon, needed to create a drilling jig. When he encountered the broken band saw, Brad had to put his procedure on hold, fix the broken equipment, and then proceed with the original task. Brad's workflow required him to switch contexts frequently and manage several tasks simultaneously.

Brad, a machinist, had to work on several tasks before he could finish creating a drilling jig.

DOMAINS OBSERVED

"[Performing the same step on each bike frame, before moving on to the next step] makes things easier. I don't have to move [the tools] around."

–**RYAN**, Specialized technician, explaining why he prefers to change bike frames and not the tools associated with each test



Tony, a machinist, is working on four identical parts incrementally.

SECONDARY INSIGHT

Procedure processes are adapted to minimize tool gathering

While NASA test lab technicians operated with much higher stakes and less process flexibility, the technicians at Specialized had more room for improvisation. At Specialized, we observed technicians performing 3 stiffness tests on 3 different sizes of bike frames. The setup for each test involved 2-3 minutes of removing one frame and fastening the next frame to the workstation. Rather than going through this process once for each frame, the technician opted to perform one test at a time and frequently changed the frames. Based on this observation, we hypothesized that technicians prefer repetitive steps to constantly gathering different tools for each test.

DOMAINS OBSERVED

Summary of Findings

Our research has led to these three key insights, which are supported by findings from multiple analogous domains. We will use these insights as the foundation for our visions and as a guide for developing our prototype. Additionally, we developed secondary findings. While these findings did not always span multiple domains, they are notable observations that we will account for in our future designs. We have noted which of our findings improve or lead to breakdowns in workflows. Our design will incorporate and enhance workflows that lead to improved efficiency, and address sources of inefficiencies.

	Key Insights & Findings	Machine Shops	Science Labs	Test Labs	Medical Spaces
	Ease in gathering key information for quick reference streamlines procedure execution				
+	Key information needs to be extracted for easy access	✓	✓	✓	✓
–	Procedure documents are not well-suited for quick reference during task execution		✓	✓	✓
–	Necessary status information is difficult to gather	✓		✓	
	Successful collaboration requires coordinated sharing of procedures and status information				
–	Collaboration breakdowns are caused by poor coordination and inaccurate system information			✓	✓
–	Maintaining shared tools and space requires consistent coordination among collaborators	✓	✓		

		Machine Shops	Science Labs	Test Labs	Medical Spaces
	Related physical objects and information become more meaningful when they are kept together				
+	Individuals create associations between information and physical object				

Secondary Findings

		Machine Shops	Science Labs	Test Labs	Medical Spaces
+	The cleanup and documentation phase for one procedure is the preparation phase for another				
−	Standardizing procedures is challenging due to unique individual needs				
−	Multitasking and procedure interruptions occur frequently				
+	Procedure processess are adapted to minimize tool gathering				

Visions

CONTENTS


Google glass for tool info, procedures

Visioning Overview

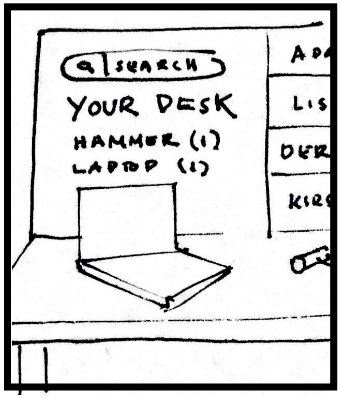
After discovering our findings and insights, we began visioning through a variety of brainstorming methods. We began with a free-form brainstorming session where we came up with our initial set of ideas. Then, in order to generate more unique solutions we moved on to bodystorming, storytelling, word association games, and brainstorming based on our affinity diagram.

After numerous visioning sessions, we were able to focus our ideas and select the most feasible and impactful solutions: auto detection, digital labels, information wristband, tool aware procedures, and noisy tools.

Tool-detecting Workspace

During our observations, we noticed individuals in each domain spending a substantial amount of time searching for specific tools recently used by others. We witnessed individuals searching the same place repeatedly, and asking multiple coworkers where a tool was last seen. This vision addresses that problem by displaying the items located on your desk. An individual can also view the contents of their coworkers' desks from their own display. Not only does auto detection decrease time spent searching for tools and materials, but it's also feasible with current technology. In our competitive analysis, we researched companies, like Teletracking, that combined a host of technologies under one suite. This resulted in highly accurate automated tracking, which reduces human input error and input lag time.

Juan works in a lab with lab scientists, including Adam and Lisa. Juan is about to mill a part but has to loosen pieces from it. However, he needs a wrench but he is unable to find it.

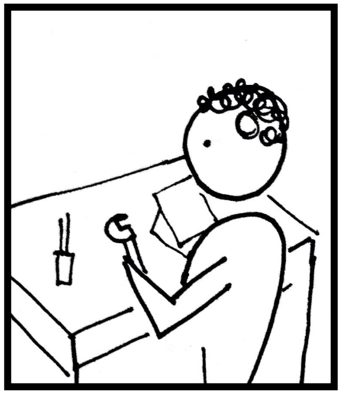


Juan goes over to the display located above his desk to see if the wrench is somewhere on his desk underneath clutter. Sadly it's not.

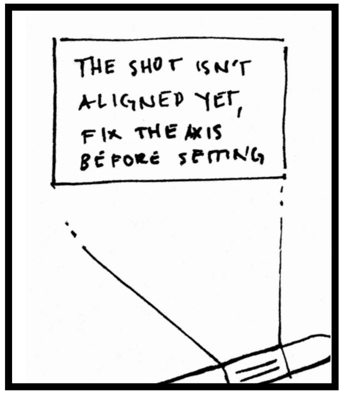
Realizing that the tool is nowhere near him, Juan searches the system for a wrench on any of his coworkers' desks. The system returns two results: Adam and Lisa both have at least one wrench on their desks. Juan decided to borrow the wrench from one of them instead of spending time searching for his.

Intelligent Tools

During our observations, we noticed individuals directly and indirectly collaborating with coworkers frequently. In science labs, technicians would label test tubes with content information, such as procedure dates and measurements. The information was used for personal purposes and to pass information to the coworker who would use the test tube next. However, we saw breakdowns occur when individuals needed to access necessary status information from coworkers or machinery. At a test lab, one of the technicians finished his portion of a procedure, but needed another coworker to verify the results for him. The coworker had unintentionally left the area without notifying anyone. Findings from our literature review on collaboration provided concrete evidence suggesting that collaboration can deteriorate when partners are unaware of, or do not understand, each other's goals and intentions. Digital labels eliminates that problem and facilitate successful collaboration.



Ceasar is working on setting up a test shot in the Hypervelocity lab. He is leaving for lunch, but he needs to let his coworker, Toby, know the status of the test setup so Toby can pick up where Ceasar left off.

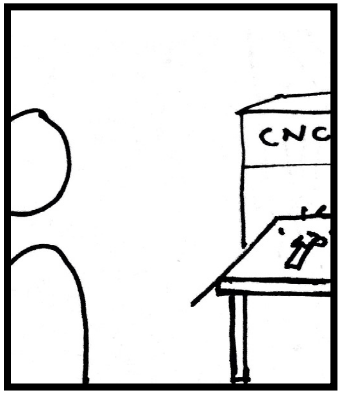


He makes the digital label on the setup rig say "The shot isn't aligned yet, fix the x-axis before setting up the cameras," and leaves.

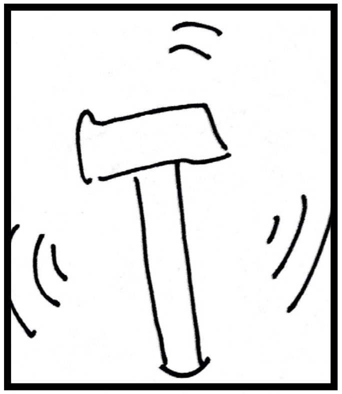
Toby arrives at the Hypervelocity lab. The label from the setup rig recognizes his presence and display the message from Caesar. He realizes that he needs to finish aligning the shot before setting up the cameras.

Noisy Tools

Collaboration can complicate tool finding because communal information can easily become obsolete. Individuals complained about coworkers misplacing communal tools and materials, or coworkers forgetting to update the inventory system. Out-of-date inventories made tool finding difficult and dissuaded some individuals from using the system altogether. In our competitive analysis, we discovered that products emitted sound to help individuals locate objects. Noisy tools serves as a solution because individuals are audibly prompted when they do not return a tool back to its proper location.



Jackson is working on a task and needs to use a calibration tool that is shared among the whole lab. After finishing a step and using the tool, he forgets to return the tool back to its original location, sets it down, and he goes away to work on another step.

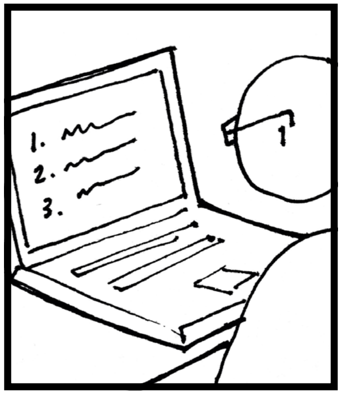


After a couple minutes of inactivity, the tool begins beeping audibly. Jackson hears it from his desk.

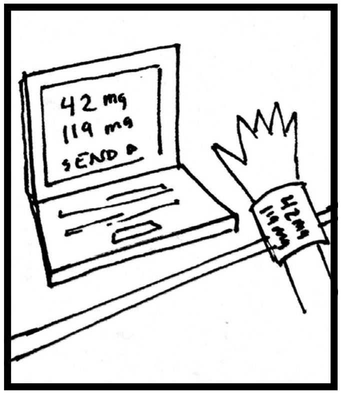
Jackson returns to pick up the tool and takes it back it to the communal area, and the tool is silent again.

Information Wristband

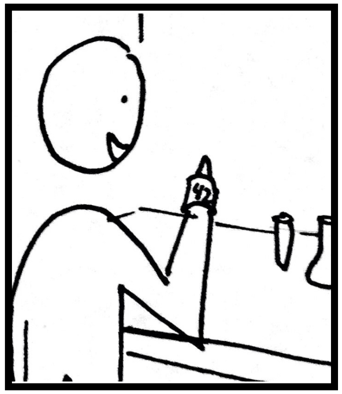
The information wristband vision addresses our first insight: ease in gathering key information for quick reference streamlines procedure execution. During our observations, we saw individuals write down key information from their procedure documents onto other sources, such as sticky notes and gloves, to avoid carrying the entire document. We also saw individuals frequently traveling between workspaces to verify procedure information. This inefficient process wasted valuable time and caused breakdowns. With the information wristband, one can highlight key information from a procedure, and avoid having to travel between workstations to transcribe and verify information.



Julio reads his experimental procedure document to familiarize himself with the steps before he runs the experiment, as he is reading, he highlights information in the document that he will need later.



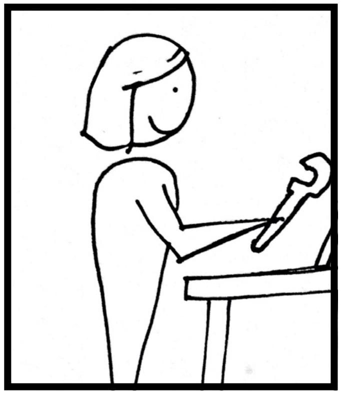
Julio transmits these key details to his wristband so that he can quickly reference them as he runs the experiment.



During his experiment, Julio doesn't remember how much sulfur he needs, so he looks at his wristband which tells him 42mg of sulfur. With all the key information available, Julio is able to run his experiment efficiently.

Tool-Aware Procedures

Collaboration and tool sharing is important in any work environment, particularly at NASA. With tool-aware procedures an individual does not have to worry about transcribing key information from their procedure document. Additionally, this solution facilitates the understanding collaborators have of each other's intentions and goals. With tool-aware procedures, tools "inform" the procedure document about an individual's current step. This allows the procedure document to make the key information of that step prominent. This eliminates the need for an individual to halt their progress to find the necessary information or ask a coworker.



Jenna, a test engineer, is setting up a test. As she is working, her procedure document detects what tools she is using and can show her the relevant information for the step she is on.

Alex, her co-worker, is also working on setting up the same test. He needs to ensure that Jenna completed a step before he can continue his work. He uses his procedure document to view which step Jnna is on.

He see thats Jenna completed the step he is depending on, so he can continue working and setting up his test.

OTHER VISIONS GENERATED

1. TOOLS EMIT SIGNAL WHEN IT NEEDS MAINTENANCE SO SOMEONE CAN GO FIND THEM AND CALIBRATE
2. DEVICE THAT YOU WRITE STUFF DOWN ON AND AUTO SWITCHES TO THE INFO FOR WHATEVER OBJECT YOU ARE BY
3. YOU CAN LEAVE "NOTES" IN AREAS TO PASS INFORMATION TO OTHER PEOPLE, LIKE STATUS.
4. CHECK OUT / CHECK IN TOOLS WITH QUICK TAGGING SYSTEM
5. STICKER ON TOOL THAT IS LIKE A G-FORCE METER BUT FOR MAINTENANCE NEEDS
6. DOT ON TOOLS WILL GLOW LIGHTER / DARKER DEPENDING ON HOW FAR AWAY THEY ARE FROM THEIR INTENDED LOCATION
7. TOOLS / MATERIALS HAVE TAGS THAT BEEP WHEN THEY'RE NOT IN THEIR ORIGINAL PLACE AFTER CERTAIN TIME.
8. SCREEN ABOVE WORK SPACE SHOWS KEY INFO + WHAT TOOLS YOU HAVE / NEED NEXT.
9. PROCEDURES FADE OUT BUT DON'T DELETE INFORMATION THAT IS NOT RELEVANT.
10. NOTIFY INDIVIDUALS THAT A COWORKER NEEDS XX KIND OF INFORMATION. INDIVIDUALS CAN SWIPE AND SEND INFORMATION DIRECTLY TO COWORKER
11. YOU KNOW WHAT TOOL YOU ARE USING SO INFORMATION ABOUT KEY STATUS IS PRESENTED TO YOU
12. LIST OF ALL AVAILABLE MATERIALS / TOOLS INCLUDING STATUS, LAST USE, AND LOCATION, DISPLAYED BEFORE PROCEDURE STARTS
13. EACH TOOL AUTO TRACKS WHERE IT IS, WHO HAD IT LAST ETC + YOU CAN GO LOOK AT AUTO UPDATED
14. REMINDERS OF WHAT STEP A TOOL IS NEEDED FOR NEXT WHEN SOMEONE PUTS IT DOWN
15. SYSTEM KNOWS WHAT PROCEDURES AND TOOLS OTHERS ARE DOING, THEN INFORMS YOU IF YOU WILL HAVE CONFLICTS SO YOU CAN DO SOMETHING ELSE
16. PEOPLE CAN QUEUE UP FOR A TOOL, SO ONCE YOU'RE DONE, BRING IT TO NEXT PERSON / ALERT THEM
17. PERSONAL MONKEY FOR EACH WORKER THAT FINDS THEIR TOOLS
18. CABINET THAT ORGANIZES MATERIALS BASED ON THEIR QUALITY (NOT WORN DOWN) AND QUANTITY (IF THERE'S ONE JAR THAT'S ALMOST EMPTY, PRESENT IT SO IT CAN GET FINISHED).
19. SMART CABINET THAT REORGANIZES BASED ON UPCOMING PROCEDURES
20. LABEL EVERYTHING
21. SYSTEM THAT SHOWS WHAT COLLABORATORS ARE WORKING ON IN REAL TIME.
22. YOU CAN SEND TOOLS TO THEM VIA THE DISPLAY ON YOUR DESK OR REQUEST TOOLS.
23. TOOLS TALK TO EACH OTHER AND PASS DATA BETWEEN THEMSELVES.
24. EACH PERSON UPDATES STATUS (GOOD TO BAD) AND YOU CAN SEE EVERYONE ELSES.
25. PRESET LOCATION TO RETURN TOOLS TO. TOOLS WILL BEEP / EMIT A SIGNAL IF THEY'RE NOT RETURNED TO THE PROPER LOCATION AFTER THE PROCEDURE IS DONE.
26. EVERYONE HAS A TABLET THAT'S BASICALLY A BLANK SHEET OF PAPER AND CAN BE WRITTEN ON AS WELL.
27. TAGGING SYSTEM THAT LINKS PROCEDURES AND TOOLS AUTOMATICALLY.
28. SENSORS THAT INDICATE IF RELATED TOOLS AND MATERIALS BECOME SEPARATED BEYOND SOME THRESHOLD.
29. PROCEDURE DOCUMENTS WITH EMPLOYEE LOCATION AND STATUS, AS WELL AS ANYONE NEEDED FOR A PROCEDURE.
30. TABLET THAT LEARNS WHAT YOU ARE DOING AND TOOLS NEEDED FOR EACH PROCEDURE.
31. A SHARED DOCUMENT THAT HAS KEY INFORMATION FOR ALL PROCEDURES, AND CAN BE UPDATED BY EMPLOYEES.
32. EASY RETURN OF TOOLS AND MATERIALS (BRING IT BACK TO ONE PLACE, AUTOMATED DOCUMENTATION).
33. MAGNETIC TOOL WALL FOR EASY VISUAL LOOKING.
34. SCREENS AROUND LAB THAT SHOW WHAT OTHERS ARE WORKING ON.
35. DUDE AT THE COMPUTER WHO RELAYS YOUR KEY INFORMATION WHEN YOU NEED IT.
36. KNOWING WHERE ALL THE TOOLS YOU NEED ARE AT ANY TIME.
37. TOOLS KNOW THEIR MOTION/ACTION AND HAVE SENSE OF TOUCH. THEY ALSO UPDATE A USER ON WHAT STEP HE IS ON.
38. TOOLBOX THAT FLIES ABOVE AND BRINGS OR PICKS UP TOOLS.
39. MANUALLY GO THROUGH AND LABEL EVERY TOOL, TUBE, OBJECT, ETC, AND COLOR CODE THEM.
40. KEEP ALL THE TOOLS IN A CHINA CABINET WITH CHINA, SO YOU HAVE TO PUT THE TOOLS BACK VERY CAREFULLY WITHOUT BREAKING ANYTHING.
41. EVERYONE HAS A MORSE CODE MACHINE TO COMMUNICATE THROUGH.
42. EVERYDAY AFTER CLOSING, UPDATE EVERY LABEL AND CHECK MAINTENANCE STATUS.
43. CARRY AROUND TYPEWRITER AND WRITE DOWN KEY INFORMATION.
44. READING PROCEDURES OFF OF PAPERS.
45. WRITE ON STICKY NOTES AND ATTACH TO OBJECT.
46. NOTEBOOK MADE BY LETTERPRESS.
47. PUTTING TOOLS ON CARTS AND WHEELING THEM TO THEIR INTENDED LOCATION.
48. EVERYONE WEARS TOP HATS THAT DISPLAY WHAT PROCEDURE STEP THEY'RE ON.
49. WHEN YOU'RE DONE WITH A TOOL YOU DROP IT ON THE FLOOR AND IT FLOATS AWAY TO ITS ORIGINAL LOCATION.
50. INSTEAD OF PACKING EVERYTHING BACK INTO ITS "RIGHT" PLACE, WHEN FINISHED WITH A TOOL, YOU DROP IT OFF WITH THE PERSON WHO NEEDS IT NEXT.

Conclusion

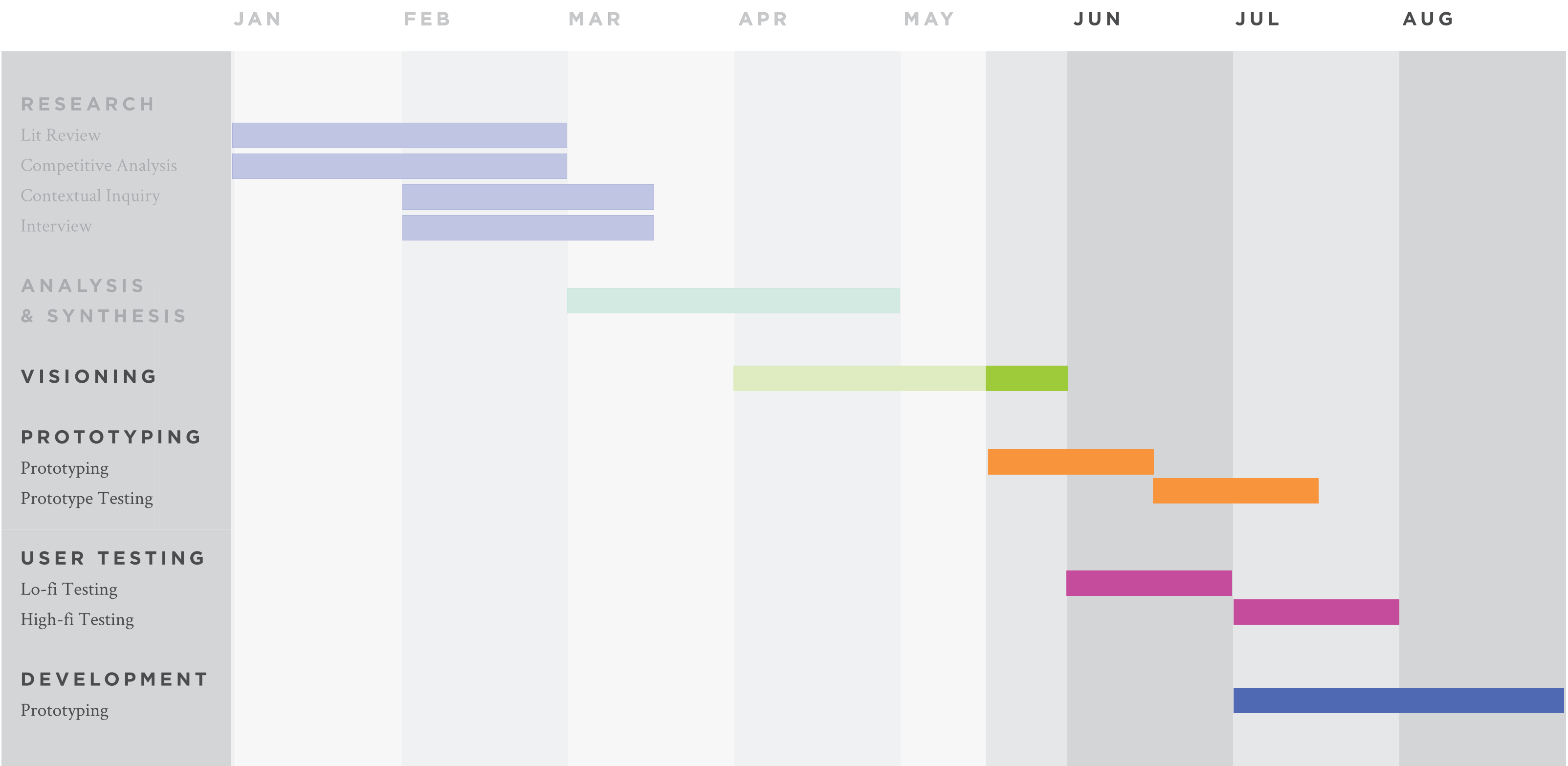
CONTENTS

Next Steps

Next, we will begin the design and development phases of our project. After we present our research findings, we will hold a visioning session with our clients at the NASA Ames Research Center in Mountain View, CA.

Once we generate more visions and agree upon a focused direction, our team will develop several iterative prototypes. After each prototype is created, we will conduct field tests with real users at NASA's test facilities. Field testing and analysis of those results will inform our next iterations of prototypes, helping us to improve the quality and functionality of our designs. After 3-4 cycles of prototypes and user tests, we will deliver a final working prototype in early August 2014.

Summer Schedule



The Team

Adam Menz

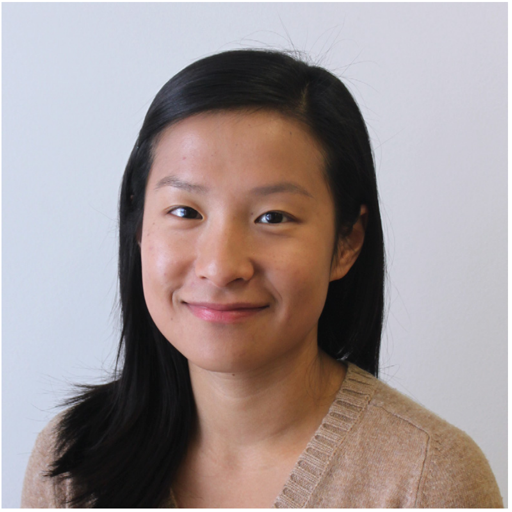
PROJECT LEAD

Before studying Human-Computer Interaction, Adam completed his undergrad degree in computer science. He likes to build and design mobile apps, rock climb, and read.

Kirsten Yee

USER RESEARCH LEAD

Kirsten is a native Californian who worked at Google for 6 years before discovering a passion for user research, which inspired her to study HCI at Carnegie Mellon. She's interested in creating interfaces that all types of people can enjoy.



Lisa Ding

UX DESIGN LEAD

At Google, Lisa built user communities and created tools to support their interactions. She also moonlighted as a UX designer for the Google UX team, constructing dashboards for data pipelines and enhancing the Search ad experience.

Maggie Bignell

VISUAL DESIGN LEAD

As an accelerated masters student, Maggie is about to finish up her undergrad in Communication Design and HCI. Last summer at Apple she designed interfaces and constructed user flows for the iTunes team.

Derin Akintilo

TECH ARCHITECT

Derin is CMU grad with a B.S. in Information Systems and experience in HCI. He has experience building small to large scale systems and recently worked with Clickbrands as a front end engineer.

About the HCII

The Carnegie Mellon Human-Computer Interaction Institute is an interdisciplinary community of students and faculty dedicated to research and education in topics related to computer technology in support of human activity and society. The master's program is a rigorous 12-month curriculum in which students complete coursework in programming, design, psychology, HCI methods, and electives that allow them to personalize their educational experience. During their second and third semesters, the students participate in a substantial Capstone Project with an industry sponsor.

The Capstone Project course curriculum is structured to cover the end-to-end process of a research and development product cycle, while working closely with an industry sponsor on new ideas or applications that may work with their existing human-to-machine technology. The goal of this 32-week course is to give each student the opportunity for a "real-life" industry project, similar to an actual experience in a research/design/development setting. Company sponsors benefit from the innovative ideas produced by the students, to fix existing systems or reach into new markets.

For questions about the content or to learn how to sponsor a project, please contact:

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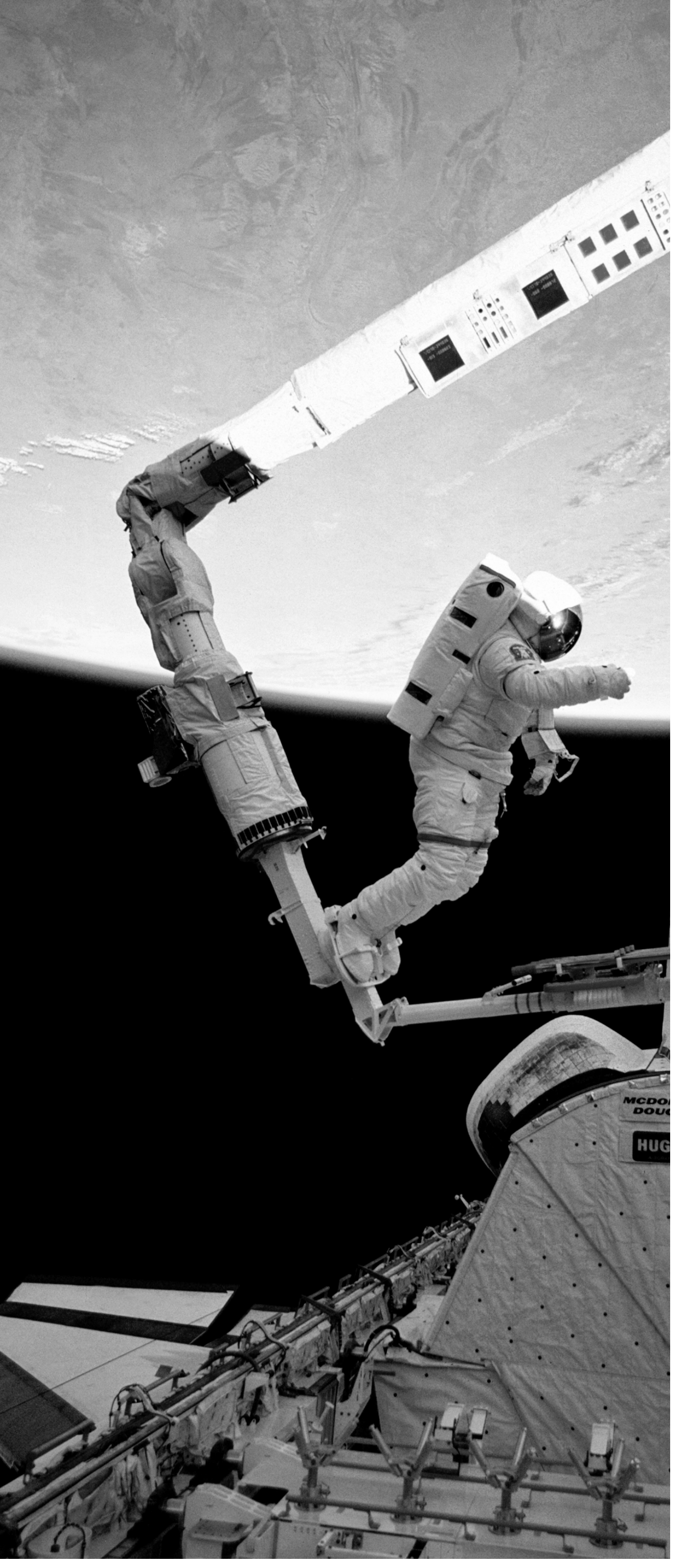

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Appendix

CONTENTS

Competitive Analysis

Tile

Tile allows consumers to track everyday objects. An individual must add small, square tiles with bluetooth technology to objects they want to track. They can then use their mobile device to track the objects if they are nearby or within the range of another consumer who has the Tile app.

TECHNOLOGY	INDUSTRY
BLUETOOTH	CONSUMER

DETAILS

INVENTORY MANAGEMENT

Tile supports tracking of up to 10 different objects, and can track anything that a Tile is attached to.

LOCATION TRACKING

Tile provides the location of tracked objects on a map for coarse tracking. To locate an object exactly, the application only provides distance to the object, not direction. Additional tiles have built-in speakers to aid in location. Tile enhances the distances that objects can be tracked by using every Tile user's phone to track objects.

EASE OF INSTALLMENT

Tile is attached with adhesive to a surface or added to a keyring. Then it can be paired with a mobile device that will provide tracking information.

MULTIPLE USERS

Tile is designed for an individual to track their personal items; however, information about objects' locations can be selectively shared.

SAFEGUARDS

Tile does not provide any safeguards.

StickNFind

StickNFind Stickers are about the size of a quarter and can be installed onto nearly any item to provide location information. The stickers have a buzzer and a light, and they show up on a radar-like display on your device. They use bluetooth low energy, which has a range of about 100 feet. The Stickers last about a year before the battery needs to be changed.

TECHNOLOGY

BLUETOOTH

INDUSTRY

CONSUMER

DETAILS

INVENTORY MANAGEMENT

StickNFind can track up to 20 objects. StickNFind has a "leash" feature that will provide a notification if an object leaves or enters a radius around a phone.

LOCATION TRACKING

StickNFind uses trackable stickers that send data to mobile devices and can be displayed in a map as "last place seen." When location objects, a radar screen is presented, showing how close to an object you are. Similar to tile, the stickers communicate with others' phones to provide a larger tracking area.

EASE OF INSTALLMENT

Due to the relatively low number of objects that can be tracked, the installment process is straightforward. Stickers must be attached to the object, and paired with the StickNFind application. No other infrastructure is needed because any phone that uses StickNFind acts as a locator.

MULTIPLE USERS

Multiple users are supported, but the app is needed on multiple devices in order to track the same objects.

SAFEGUARDS

A "leash" can be added to tracked objects, which will provide a notification if the tracked object enters or exits the tracking range of the StickNFind application.

TeleTracking

The TeleTracking Real-Time Locating System allows medical staff to locate and manage hospital assets, and quickly determine if equipment is available. TeleTracking provides accurate asset locating using a combination of infrared and RFID technology.

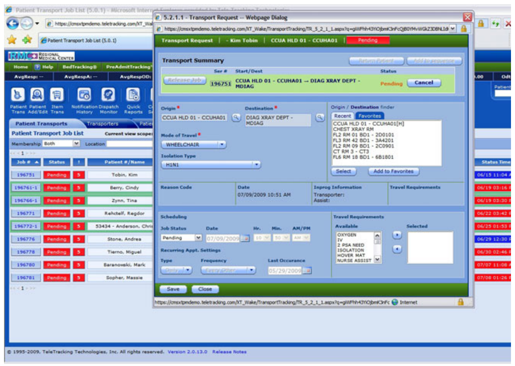
TECHNOLOGY

INFRARED

RFID

INDUSTRY

MEDICAL



DETAILS

INVENTORY MANAGEMENT

Allows hospitals to inventory their equipment and displays the availability of shared items. Additionally, TeleTracking gathers usage information on assets, which can help hospitals better manage equipment needs and distribution.

LOCATION TRACKING

TeleTracking can accurately locate equipment in a hospital to room-level accuracy using IR and RFID.

EASE OF INSTALLMENT

In order to use the TeleTracking RTLS, all assets should be tagged. Additionally, the infrastructure system must be installed, which allows these objects to be tracked in each room and corridor.

MULTIPLE USERS

Hospital staff and administrators can access data that helps them locate equipment and understand equipment utilization in order to better manage the hospital. Additionally, desktop and mobile interfaces enable tracking on the go.

SAFEGUARDS

TeleTracking not only tracks objects, but can also monitor temperature and send notifications if temperature-sensitive materials deviate from an acceptable range. Similarly, it can send alerts for preventive maintenance of equipment.

Centrak

Centrak develops real-time locating systems for hospitals. Using a combination of IR, Wi-FI, and RF, assets can be tracked to a room, or even a hospital bed level. In addition to tracking assets, CenTrack provides the ability to locate staff and patients, improve workflows, and monitor sensor data. The system includes desktop and mobile interfaces that allow staff to monitor these features and provides automatic notifications.

TECHNOLOGY

INFRARED

RFID

RADIO FREQUENCY

INDUSTRY

MEDICAL

DETAILS

INVENTORY MANAGEMENT

The system allows hospitals to track equipment inventory and provides utilization data for increased productivity. By placing tags on each asset, hospitals can automatically manage their inventory.

LOCATION TRACKING

CenTrack can track assets down to the bed level. Staff can also be automatically located down to the room level through their badges. Moreover, the badges can be used to call and signal other staff.

EASE OF INSTALLMENT

The CenTrack system requires tagging each asset with a physical asset tag and installing fixed infrastructure in hospital rooms and corridors. However, it can use existing WiFi systems.

MULTIPLE USERS

The entire staff is connected to the system through their staff-locating badges. iPad and desktop clients allow multiple staff members to simultaneously use the system.

SAFEGUARDS

The CenTrack system has several safeguards built in. For example, staff members are notified when refrigerator temperatures are out of range. The system can also track hand-washing in hospitals and encourage more frequent hand washing.

ERP

Enterprise Resource Planning software allows businesses to track and manage nearly all aspects of the business, from payroll to resource planning. Here, we primarily focus on inventory and asset management.

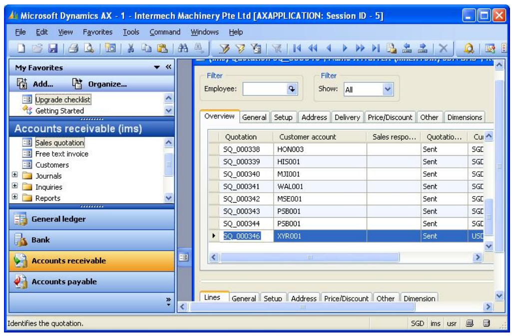
TECHNOLOGY

BARCODE

GPS

INDUSTRY

COMMERCIAL



DETAILS

INVENTORY MANAGEMENT

ERP systems can track large amounts of inventory. Many ERP systems use barcodes, which allow businesses to identify all of their assets.

LOCATION TRACKING

Some ERPs track location using GPS systems and manual input of immobile equipment locations

EASE OF INSTALLMENT

The infrastructure installment time and cost can be high due to the large scope of ERPs.

MULTIPLE USERS

All members of the business use ERPs on desktop and mobile devices.

SAFEGUARDS

ERPs can provide a variety of safeguards such as preventive maintenance alerts and equipment usage reports.

ToolHound

Toolhound is designed for companies who utilize many different tools and assets in various locations. Every time an item is scanned with the barcode or RFID scanner, the system notes that it is being used, who is using it, the time of use, and whether the system needs to order more. It works with employees' badging to understand who is using what and when. The RFID technology also tracks whether items need to be repaired or maintained.

TECHNOLOGY

BLUETOOTH

INDUSTRY

CONSUMER

DETAILS

INVENTORY MANAGEMENT

StickNFind can track up to 20 objects. StickNFind has a "leash" feature that will provide a notification if an object leaves or enters a radius around a phone.

LOCATION TRACKING

StickNFind uses trackable stickers that send data to mobile devices and can be displayed in a map as "last place seen." When location objects, a radar screen is presented, showing how close to an object you are. Similar to tile, the stickers communicate with others' phones to provide a larger tracking area.

EASE OF INSTALLMENT

Due to the relatively low number of objects that can be tracked, the installment process is straightforward. Stickers must be attached to the object, and paired with the StickNFind application. No other infrastructure is needed because any phone that uses StickNFind acts as a locator.

MULTIPLE USERS

Multiple users are supported, but the app is needed on multiple devices in order to track the same objects.

SAFEGUARDS

A "leash" can be added to tracked objects, which will provide a notification if the tracked object enters or exits the tracking range of the StickNFind application.

Fitbit

Fitbit is a consumer device that tracks an individual's activity. It automatically gathers information about steps taken, distance traveled, calories burned, and sleep quality. Additionally an individual can manually track food and water intake. The application can provide detailed statistics and historical data. There are several Fitbit trackers that range in functionality and price.

TECHNOLOGY

ACCELEROMETER

GPS

BLUETOOTH

INDUSTRY

CONSUMER HEALTH

DETAILS

INVENTORY MANAGEMENT

While not traditional inventory management, Fitbit is a metaphorical inventory management system for a person. It tracks activity, sleep quality, and caloric intake data for an individual and also shows historical data.

LOCATION TRACKING

Fitbit does not track location, but it provides distance traveled.

EASE OF INSTALLMENT

Fitbit is simple to install. It only requires wearing a tracking device and pairing the device with a phone.

USERS

Fitbit is designed for use by one individual, but they can choose to share some of their data with friends.

SAFEGUARDS

Not applicable.

Glossary of Analogous Domains

COLLABORATION
Individuals need to work with others to get their work done.

UNFAMILIARITY OF TASK
Individuals need to carry out unfamiliar procedures.

HIGH NUMBER OF TASKS
Individuals need to complete a variety of tasks and procedures.

MULTITASKING
Individuals need to complete several tasks at the same time.

HIGH STAKES
Mistakes and delays can lead to major negative consequences.

TRAINING
Individuals received training to operate in the workspace.

NEED TO FIND TOOLS
Individuals need to find tools in order to execute procedures.

SAFEGUARDS
When procedures do not go as planned, there are ways to overcome the error.

MAINTENANCE AND UPKEEP
Individuals need to perform maintenance to tools and machinery as a part of their work.

PROCESS FLEXIBILITY
When circumstances change, individuals can alter their procedures.

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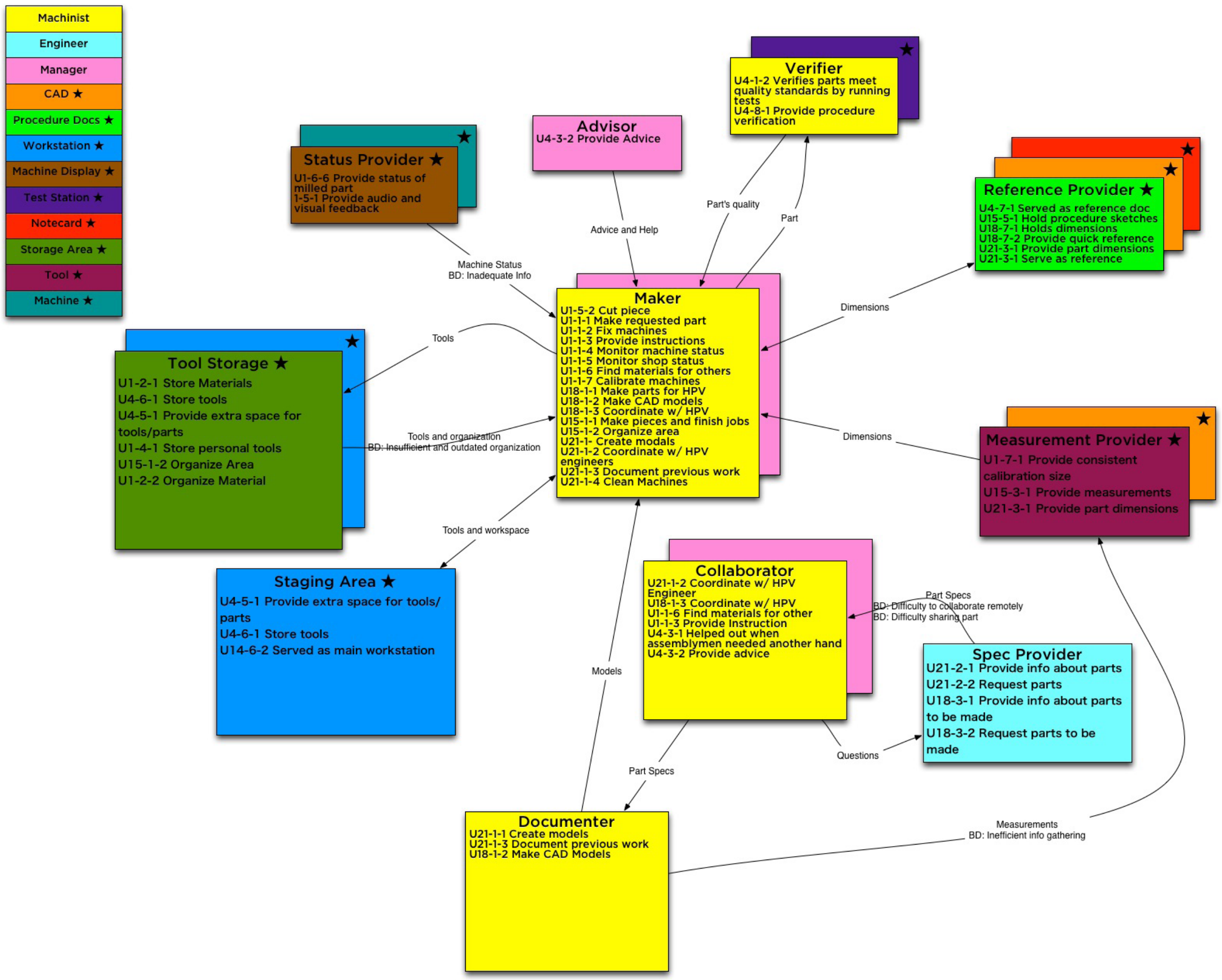
Consolidated Models

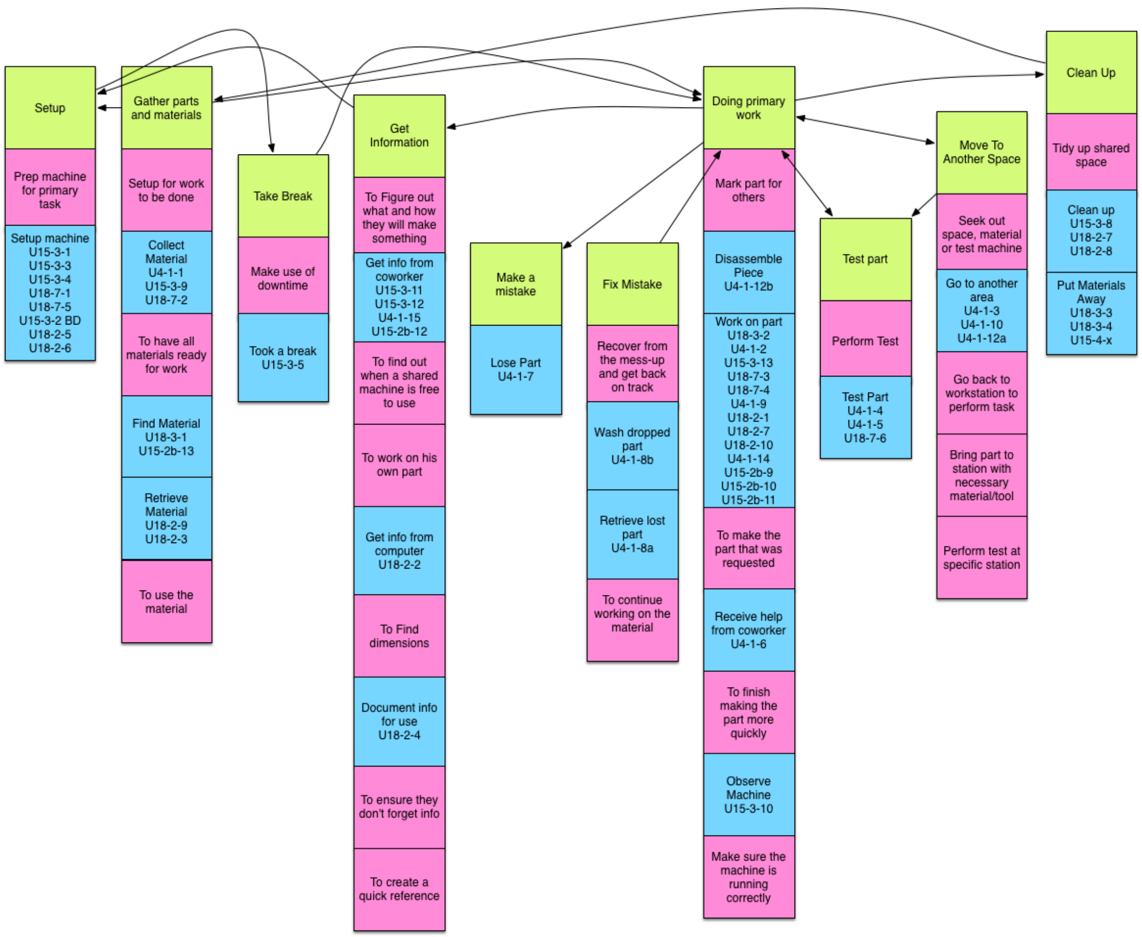
This is a collection of the consolidated flow and sequence models that were generated from our domain observations.

The flow diagrams model the flow of information between individuals and artifacts. The sequence diagrams outline the workflows, steps, and intents of individuals. We used these models to develop our findings and insights.

MACHINE SHOP FLOW



MACHINE SHOP SEQUENCE:
PRIMARY WORK FLOW



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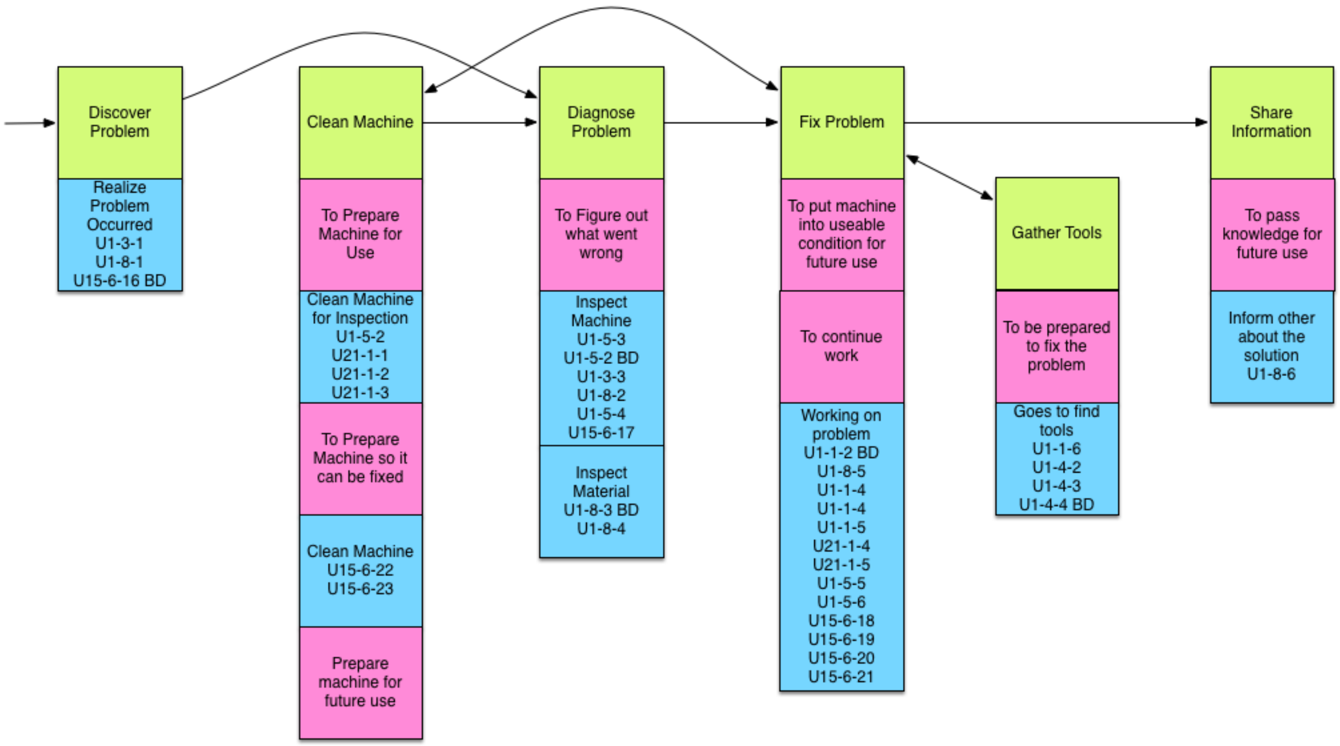

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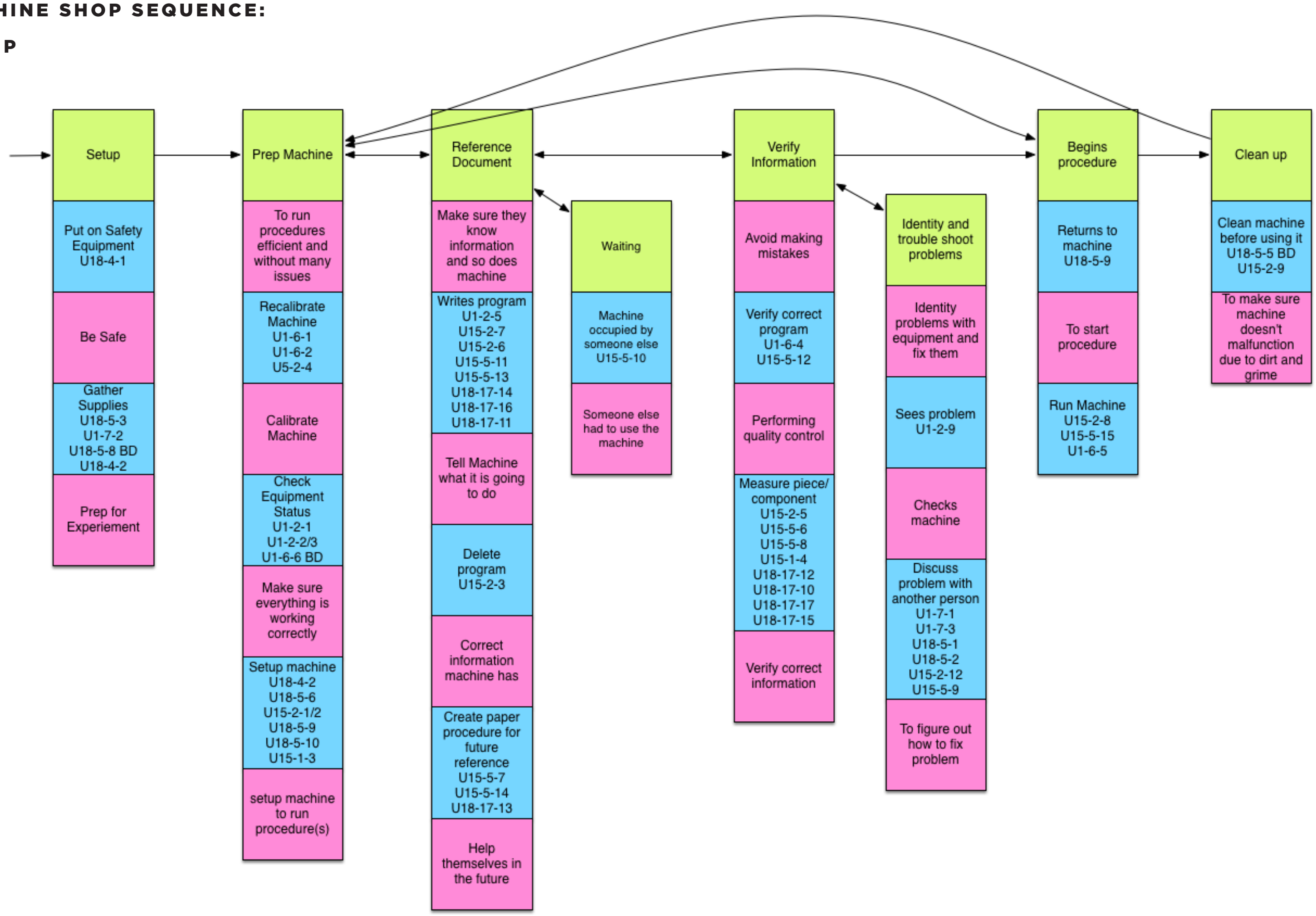
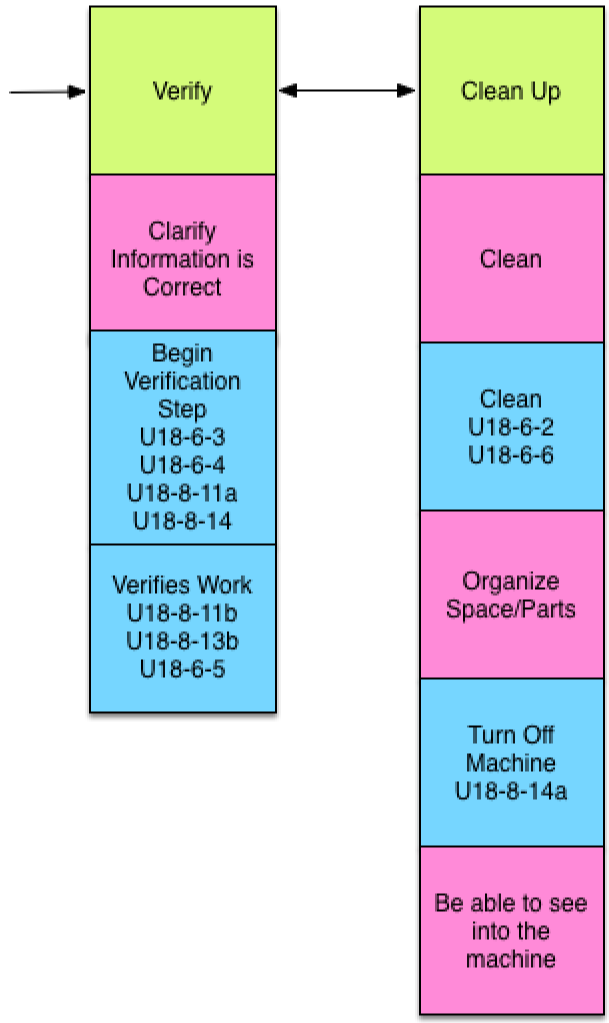
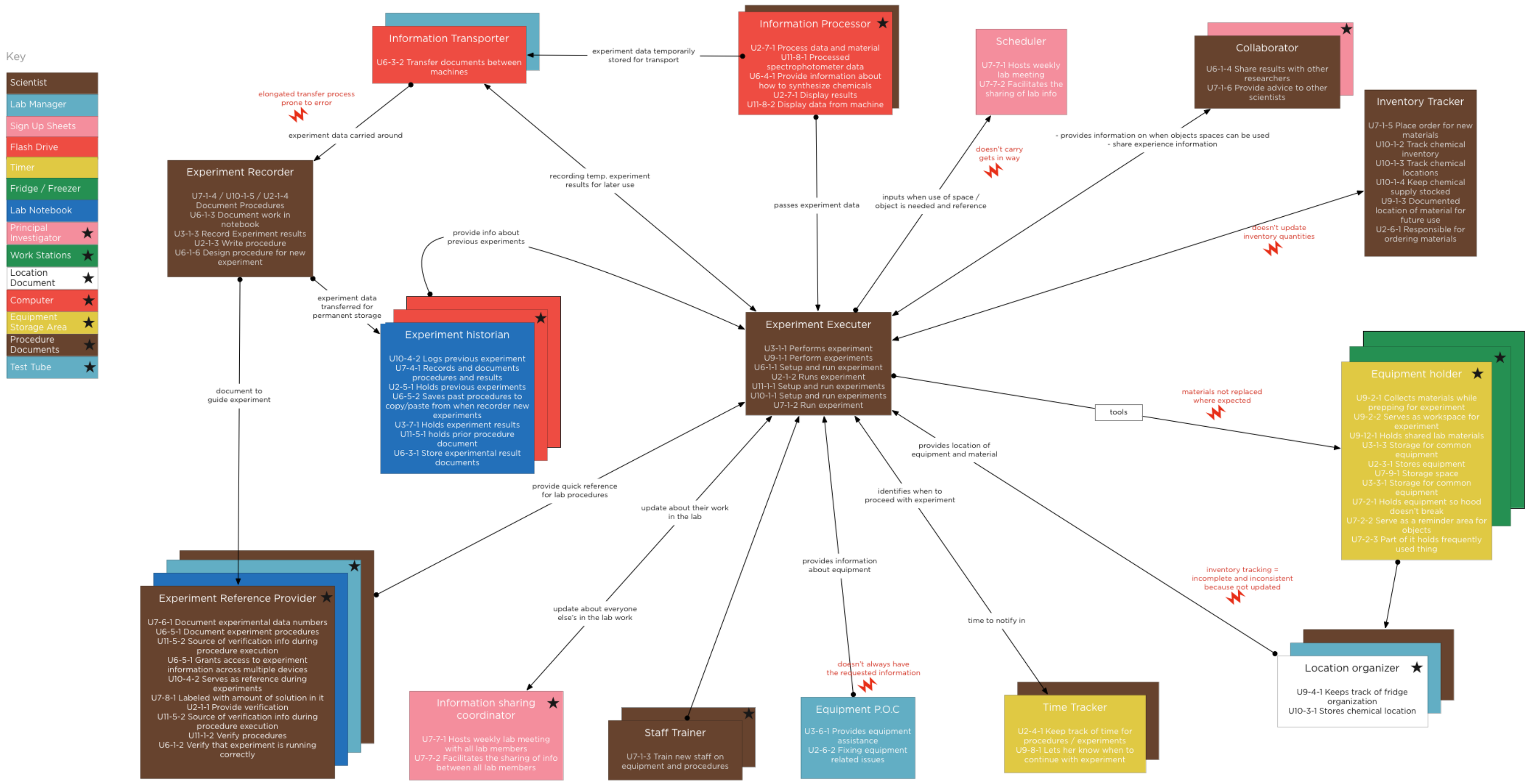
SETUP



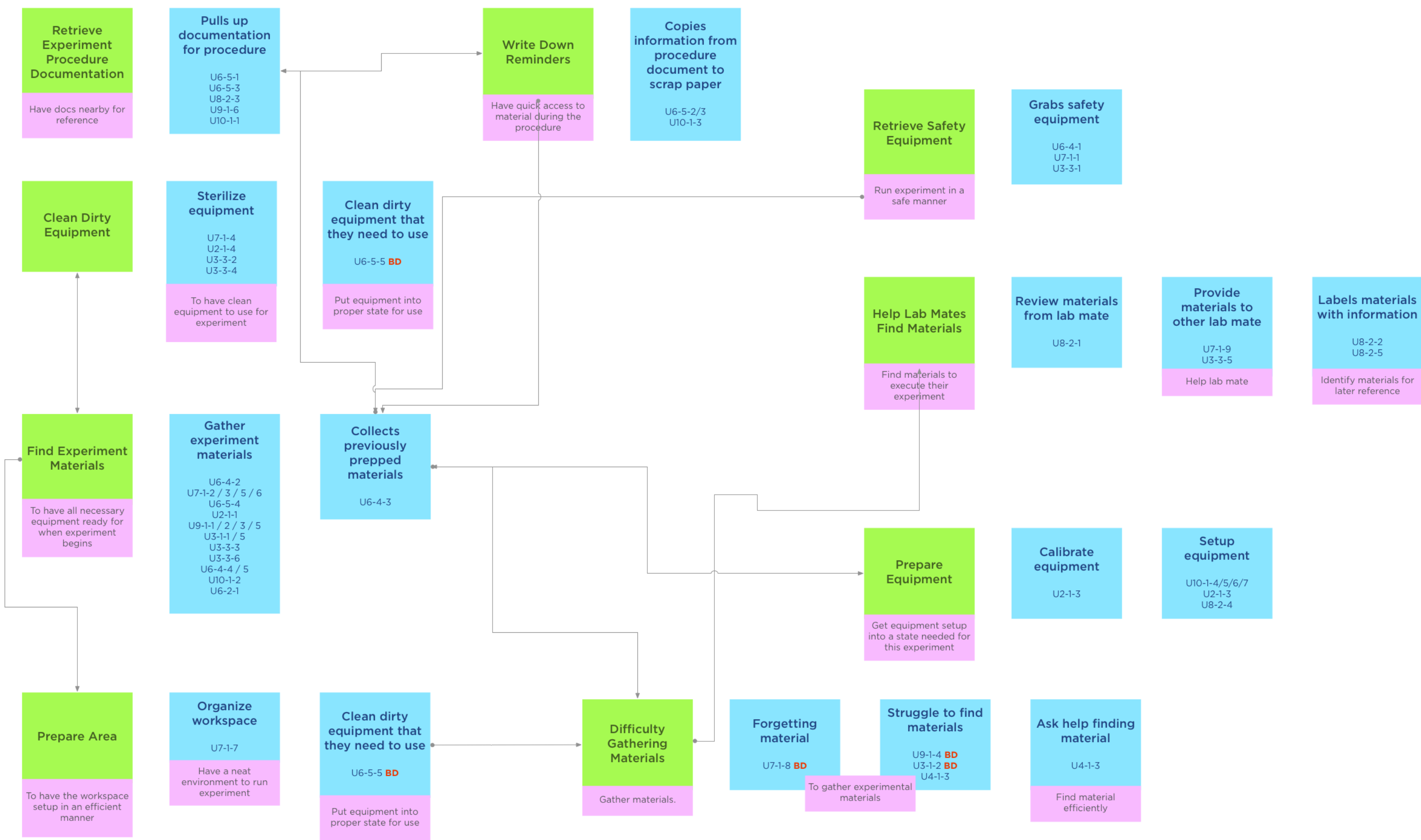
MACHINE SHOP SEQUENCE: VERIFICATION AND CLEAN UP



SCIENTIST LABORATORY FLOW



LAB SCIENTIST SEQUENCE: SETUP



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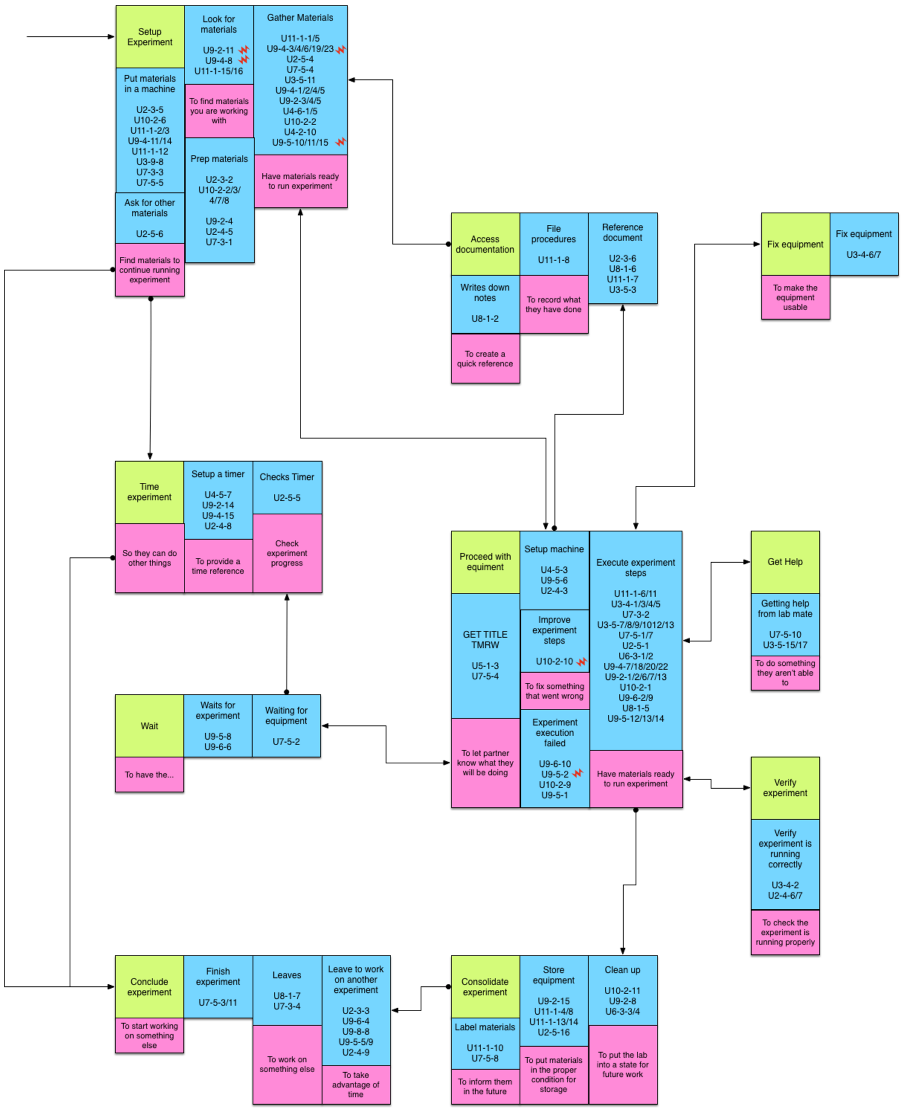
EXECUTE EXPERIMENT



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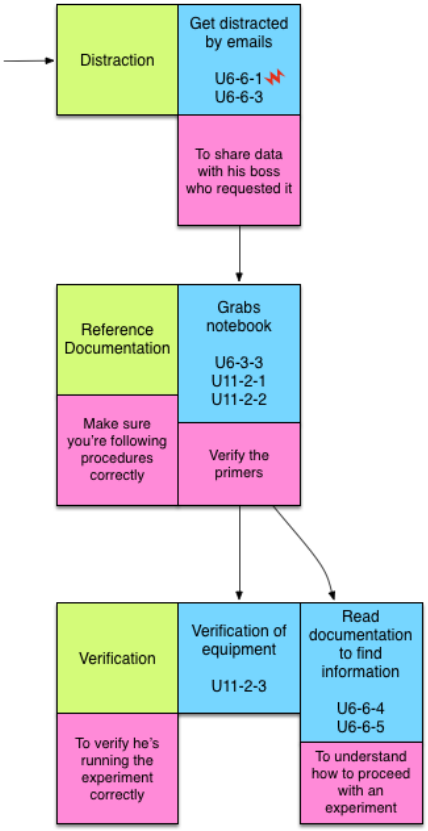

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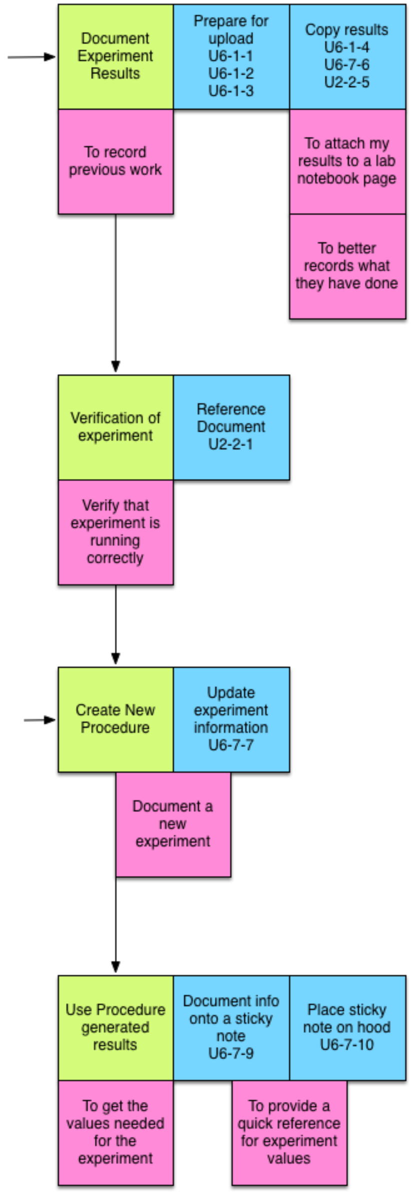

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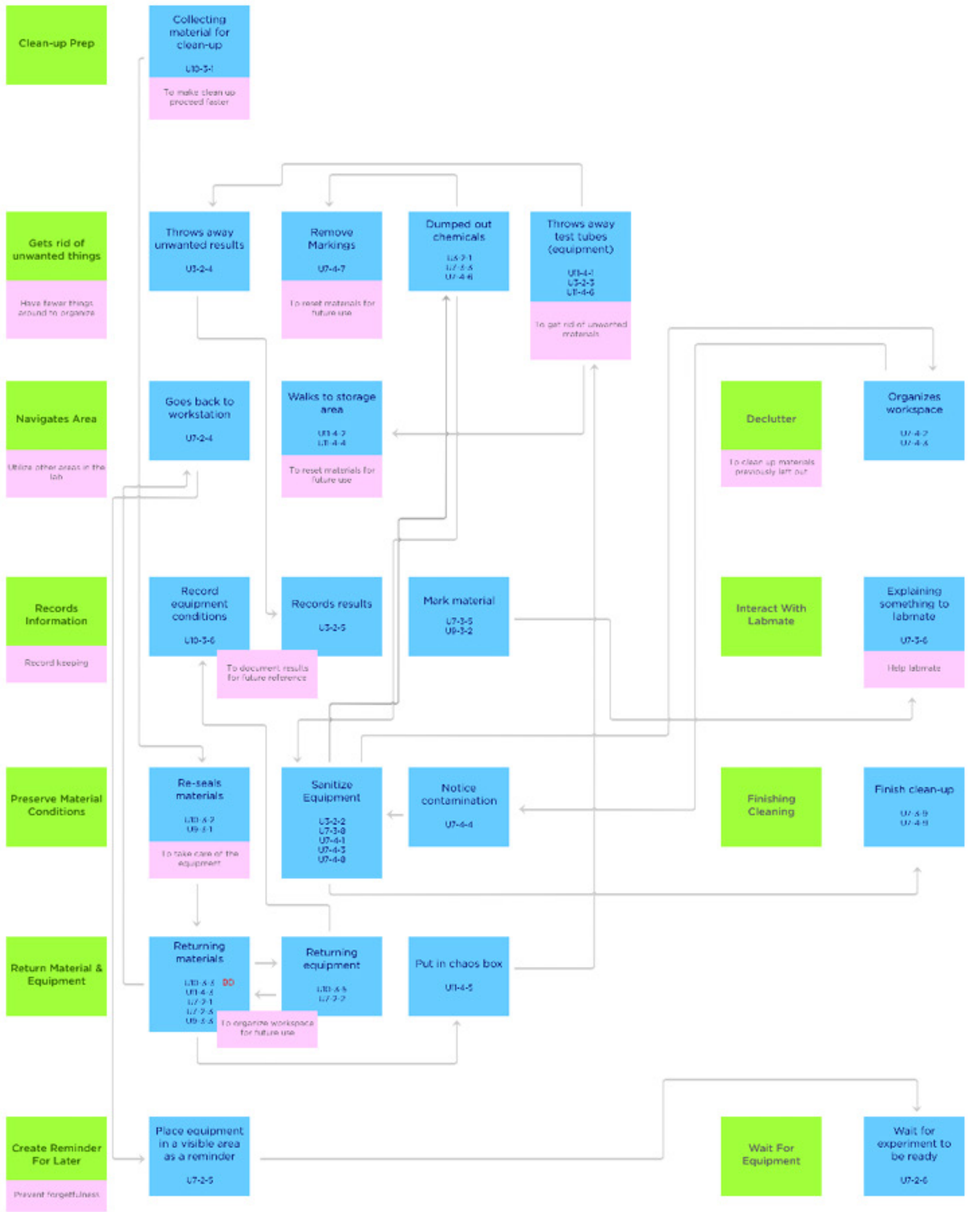
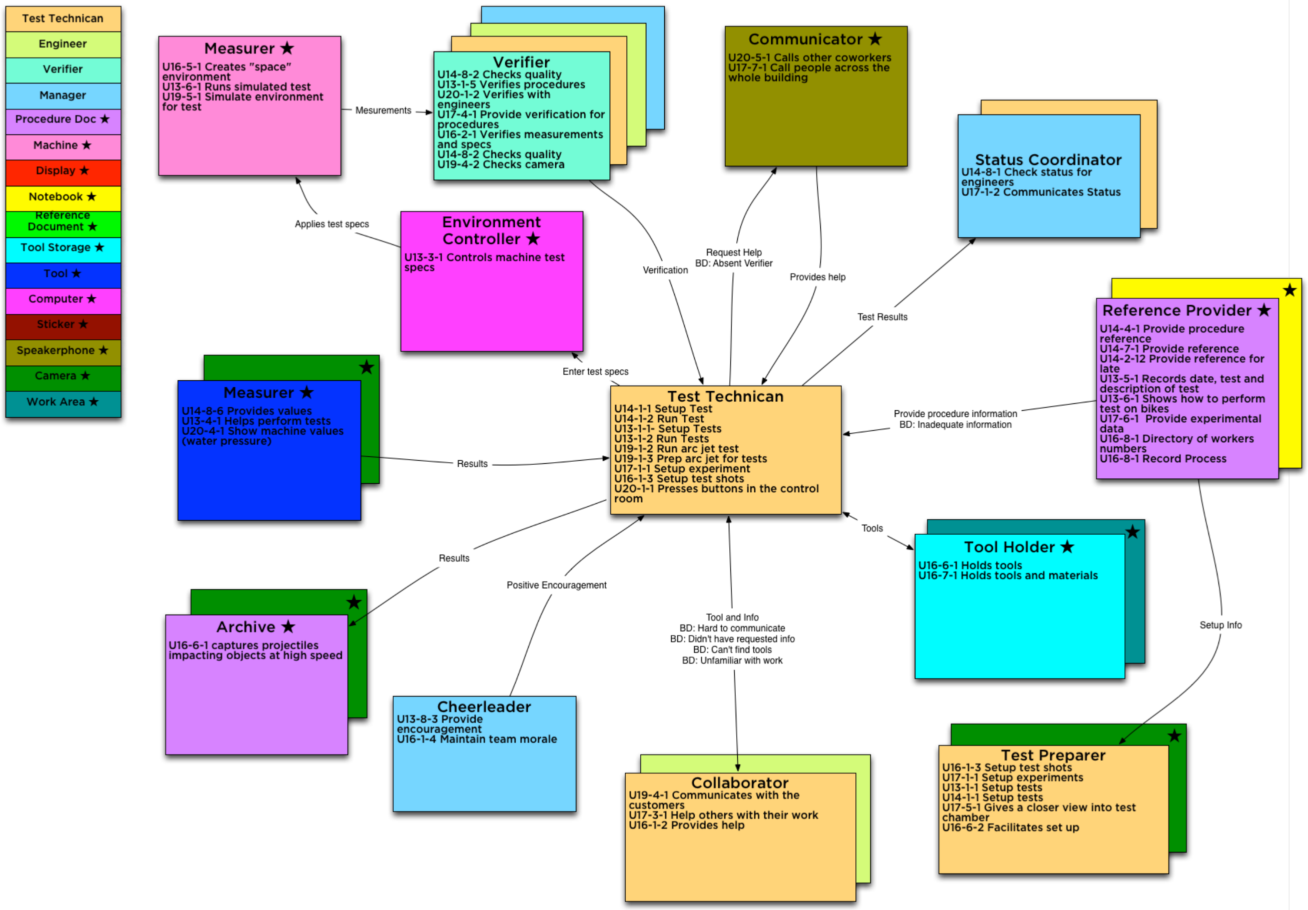


TEST LAB FLOW



THE IMPORTANT THING IS NOT TO STOP QUESTIONING. -ALBERT EINSTEIN