A Design Thinking Approach to Identifying User Input Needs for Augmented Reality Devices in Manufacturing Environments

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A thesis submitted in partial fulfillment of the requirements for the degree of Master of Fine Arts in Design Thinking in the Department of Design in the College of Visual and Performing Arts at Radford University

Fall Term
2023

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ABSTRACT

Augmented reality (AR) is an innovation on the brink of mass adoption. In order to facilitate its full integration in enterprise, especially in manufacturing facilities, a human-centered approach is necessary. This approach is likely to help the technology overcome barriers such as suboptimal user experiences and slow market adoption. Design thinking is uniquely positioned to help drive adoption of AR in the enterprise domain.

This study examined how design thinking methodologies could be used to guide the design and selection of input modalities within manufacturing environments. Eight manufacturing workers participated in ethnographic research methods leading to the extraction of insights on user input needs for AR systems in manufacturing settings. Design thinking methodologies were also utilized for synthesizing the data collected from participants.

Four key user archetypes were identified, each accompanied with specific user input needs. The overarching revelation was that for most users, hand-tracking or voice control emerged as the preferred input modality. The appeal of these input modalities lies in the ability to eliminate the burden of carrying and managing additional hardware during hand-on work. For advanced users, such as manufacturing engineers with a demand for precision in CAD model manipulation and marker placement, the inclusion of a controller, 3D pen, or stylus was deemed necessary.

for my late father,
Dr. Shaik Jeelani

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TERMS

Augmented Reality – Applications that will "implement[s] visual, auditory and other sensory information into the world to enhance your experience" (Cureton, 2022).

Gaze Interaction – To "integrate eye tracking technology to detect gazes as an input modality to enhance immersion and provide natural and implicit interaction" (Kocur et al., 2020, "Introduction" section).

Hand Tracking – An input modality that "analyzes discrete hand poses and tracks the position of key points on the hands" delivering "a new sense of presence, enhances social engagement, and delivers more natural interactions with fully tracked hands and articulated fingers" (*Set up Hand Tracking*, n.d.).

Head Mounted Display (HMD) – "small displays or projection technology integrated into eyeglasses or mounted on a helmet or hat" (*Head-Mounted Displays*, n.d.a).

Input Device (Human Interface Device) – "User-controlled device that transmits information to a system" (International Organization for Standardization, 2020).

Interaction Method (Input Modality) – "A sensor or device through which a computer can receive the input from the human" (Pleva et al., 2007, p. 286).

New Product Development – "Effective activity of organization and management to bring products to market with low development costs and short development time" (Wheelwright & Clark, 1992, Chapter 1).

Sense – "A group of sensory cells that responds to a specific physical phenomenon, and that corresponds to a particular region of the brain where the signals are received and interpreted" (Francis, 2020).

Solution – "An implementation of people, processes, information and technologies in a distinct system to support a set of business or technical capabilities that solve one or more business problems" (*Solution*, n.d.).

Spatial Input Device – "Input devices that can sense how a user moves them" (Bowman et al., 2008, p. 20).

Speech Recognition – "A type of human-computer interaction technology that leverages artificial intelligence algorithms and natural language processing to enable computers to understand languages like English" ("What Is Speech Recognition Technology in VR?," 2022).

Use Case – "All the ways of using a system to achieve a particular goal for a particular user" (Jacobson et al., 2011, p. 4).

Use Conditions – How users "will use a product and the environmental conditions during expected use" (Jeelani, 2022, p. 38).

User Model – "Any representation of the potential user, created by or available to the designer, to assist him in making predictions about the actual user" (Hasdoğan, 1996, p. 20).

User Scenario – "Detailed descriptions of a user – typically a persona – that describe realistic situations relevant to the design of a solution" (DeClavasio, 2022).

CHAPTER ONE: INTRODUCTION

Technological advancements are enablers for innovation and have transformed the way we live. Experimentation with electricity, for example, began in the early 1700s leading to the public distribution of electricity and mainstream usage of light bulbs almost 200 years later ("The history of electricity," n.d.). As with most technological advancements, electricity had to reach a certain point of technological maturity before its value as an innovation was realized by consumers, notably the development of alternating current (AC). As Autry (n.d.) explained, innovation not only considers the capabilities of the technology but also the consumers and recipients of the technology and is not synonymous with technology.

At the beginning of the 21st century, several emerging technologies are on the brink of revolutionizing the way we live, including artificial intelligence (AI), machine learning (ML), virtual reality (VR), augmented reality (AR), and autonomous driving. As these technologies continue to develop, we must expand our focus from just proving technological capabilities to determining how these technologies can be used by humans to replace the current alternatives for meeting their needs and solving their problems. This requires a paradigm shift from using a product centered design (PCD) process, which focuses first on technological development (Bix et al., 2009), to more of a human-centered approach. Design thinking integrates human needs with technological capabilities and business requirements ("Design thinking defined," n.d.), and is uniquely positioned to transform technological advancements into innovative market disrupters with the ability to revolutionize the way we live.

AR is a prime candidate for a cutting-edge technology that is now at the crossroads of being a novel technological proof-of-concept to actually being a life changing innovation. AR, which first appeared in the form of a head-mounted display in 1968, has largely been used in laboratory settings and for technological demonstrations for several decades and has only reached the commercial market in the last decade (Poetker, 2019). As augmented reality has now reached a point where the technology is usable for many applications, it is still struggling to find mass adoption and disrupt the market. Design thinking is a logical choice for an approach to propel the optimization of this technology for human use.

Pundits of the viability that mixed and extended reality offer as market disruptors have cited human-centered issues such as privacy, user psychology, ethics, and user experience as barriers for mass adoption (Mauro, 2022). These barriers have been confirmed by recent reports that some early adaptors of this technology are failing to find practical and sustainable use for it (Harding, 2022; Linebaugh & Knutson, n.d.), indicating a need for a more human-centered product development approach to enable a change in the way we think about digital interfaces. "Researchers in fields such as VR and augmented reality (AR), human-computer interaction, computer graphics, and human-factors engineering have all wrestled with difficult questions about the design, evaluation, and application of 3D UIs" (Bowman et al., 2008, p. 20). These questions include determining which input techniques work best for different types of interactions and how 3D input modalities should be designed (Bowman et al., 2009). As input modalities such as hand-tracking, speech input, eye tracking, and even brain control continue to rapidly advance taking full advantage of our human senses, it is of utmost importance to consider the advantages and disadvantages for each of these input modalities from a user perspective for different product solutions.

The selection of input modalities utilized for a given application is generally left to the discretion of software developers and is often constrained by hardware capabilities. Some manufacturers of AR/VR hardware have opted not to include a handheld controller with their head mounted display (HMD) packages, instead focusing on developing hand-tracking interactions (Sharman, 2020) while controllers are still “largely considered to be an integral part of almost every virtual reality system and its experience” (Gajsek, 2022). Each potential user scenario for AR introduces a unique set of user needs, product requirements, and constraints, resulting in certain input modalities being more appropriate for certain use cases than others. Given the variety of potential applications for enterprise AR systems, emphasizing the need for a comprehensive understanding of user needs for different AR enterprise use cases is of utmost importance as “understanding users is critical for developing a product intended for multiple applications in a global market” (Jeelani, 2022, p. 38).

While many research studies have been conducted to analyze user performance when using various input modalities with AR HMDs, little has been written about methods for identifying input needs for different user scenarios, specifically those in the manufacturing industry. Designing AR hardware and software without this understanding of user input needs often results in faulty assumptions made by AR hardware and software developers, potentially impacting product success. Given the user centered focus of design thinking along with its emphasis on business goals and technical feasibility, design thinking is uniquely positioned to help drive adoption of this technology in the enterprise space including the design and selection of input modalities. When utilizing design thinking methods to elicit details of use cases,

> The objective is not to simply understand the requirements and constraints of the problem – but to really discover the emotions, motivations and context that are all part of the design challenge, and identify the most important nuances that gives an advantage when designing. (Sharma et al., 2015, “Abstract” section).

Design thinking processes can be used to help us better define product use conditions leading to a more comfortable and pleasurable user experience (Jeelani, 2022).

1.1 Problem Statement

Augmented reality (AR) technology is gaining significant momentum across various industries, holding the promise of transforming how people in manufacturing environments work. AR systems, however, have yet to achieve full optimization for human use, resulting in suboptimal user experiences and slow market adoption. This study aims to address this challenge by investigation how design thinking methodologies can guide the design and selection of input modalities for AR technology in manufacturing environments.

1.2 Significance

This study not only establishes a comprehensive framework for leveraging design thinking methodologies to guide the design and selection of input modalities for augmented reality systems in manufacturing environments but also serves as a model of how design thinking can be applied to reveal user needs for emerging technologies. This approach is expected to have the potential to fundamentally transform technological advancements into life-changing innovations.

In contrast to the conventional product-centered approach commonly adopted during the development and maturation of emerging technologies, which primarily prioritizes technical capabilities and production requirements for new product introduction, design thinking is uniquely positioned to help optimize technologies such as AR for use by their intended users. The emphasis on user-centric design is pivotal not only for driving market adoption but also for ensuring sustained use, ultimately reshaping the landscape of AR technology to better serve its intended users.

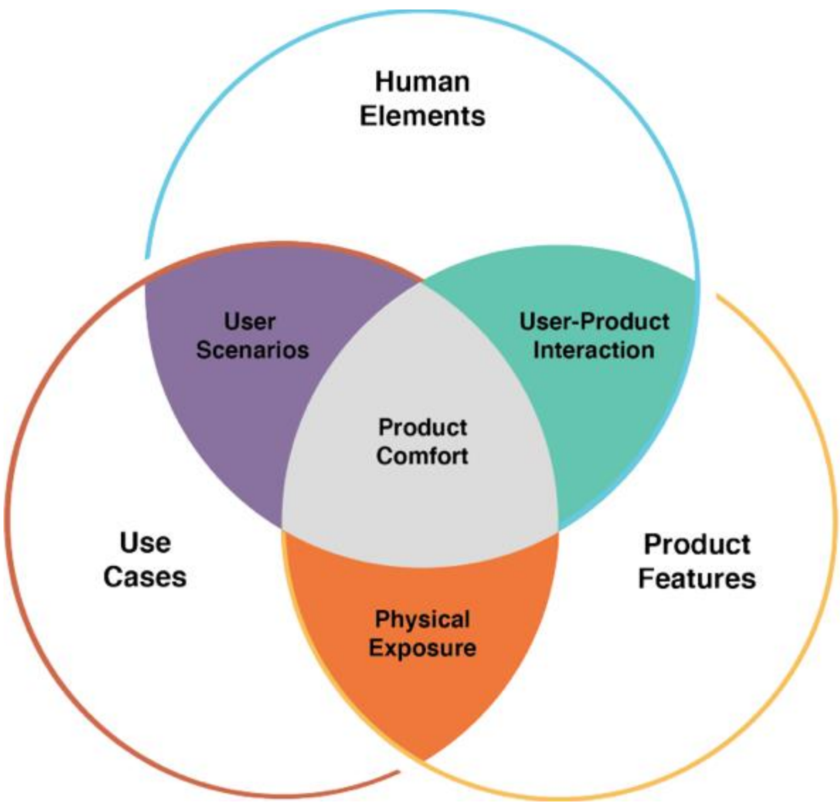
CHAPTER TWO:
LITERATURE REVIEW

A review was performed on the available literature to establish an understanding of the current body of knowledge for the content areas related to this study. This included surveying literature related to the different design processes used for new product development, augmented reality use cases, human sensory processes, and user performance for different extended reality input modalities. This literature search encompassed writings from the fields of industrial design, technology, sensory design, human-computer interaction, and design thinking and included literature in the form of peer reviewed academic research articles, trade journal articles, websites, and blog posts. The findings from this literature review are summarized and presented in the following sections: the importance of understanding users during product development; enterprise use cases for augmented reality; human senses and user interfaces; and performance and usability of different input modalities and design processes.

2.1 The Importance of Understanding Users During Product Development

The consideration of user needs for different user scenarios during product design and development, or the lack thereof, can determine the success or failure of a product since “understanding expected use cases is essential when designing a product that provides a comfortable and pleasurable experience” (Jeelani, 2022, p. 38). Understanding users, including their physical characteristics, abilities, behaviors, motivations, and past experiences, as well as understanding how they will use the product and the environmental conditions during expected use, is critical for successful product design (Jeelani, 2022, p. 37). Product comfort, for example, is entirely dependent on designing with the user as a primary design consideration and can be the determinant for whether or not a product is adopted and used by the market. In the model shown in Figure 1, Jeelani (2022) illustrated how human elements, use cases, and product features interact to influence product comfort:

Figure 1
Product Comfort Model



Note. Jeelani, 2022, p. 36

Hasdoğan (1996) explained how designers usually begin the design process by relying on their own presumptions regarding potential users and their expectations. As Hasdoğan (1996) discussed, these presumptions often do not match actual users resulting in accidents, human error, product-induced health problems, and underuse or non-use of the product. Liedtka (2015) referred to this tendency of decision makers to overestimate the similarities before their own values to the values of others as an “egocentric empathy gap” and suggests conducting research on the values of others as a remedy for this type of bias. Hasdoğan (1996) suggested incorporating product usage models in order to meet the demands of developing industries.

2.2 Enterprise Use Cases for Augmented Reality

Developers of augmented reality hardware and software often face difficulties predicting product usage due to the wide range of possible applications that can take advantage of augmented digital content. An understanding of use cases is critical when delivering products that are usable and meet user expectations since product performance and user satisfaction can vary significantly based on use conditions. When developing usage models such as those emphasized by Hasdoğan (1996), it is important to understand the context of product usage, which can be made manageable by categorizing product use cases.

The Augmented Reality for Enterprise Alliance (AREA) has identified 12 main use case categories that “help organizations better understand business problems that can be solved using AR” (*AREA*, 2020). This alliance is comprised of several member organizations including hardware developers, software solution developers, and research institutions and aims to provide data and information to help its member organizations assess, plan, and manage their augmented reality projects. As augmented reality technology continues to develop and becomes more affordable, the adoption of AR is likely to sporadically grow in the consumer market and augmented reality will become more commonplace in consumer facing environments including airports, stores, hospitals, and schools. Agrawal (2019) described 25 disruptive augmented reality use cases categorized among 10 categories. These use cases are important to consider as these applications will become more prominent as the consumer market grows as augmented reality is likely to transform their respective industries. The augmented reality use cases defined by AREA (n.d.) and Agrawal (2019) are summarized below in Table 1.

Table 1
Augmented Reality Use Cases

AREA (n.d.). cross industry AR use cases	Agrawal (2019) disruptive AR use case categories
• Navigation • Remote Assistance • Situational Awareness • Simulation • Virtual User Interface • Visualization • Maintenance • Guidance • Collaboration • Inspection • Training • Assembly	• Transportation • Mobile Commerce • Manufacturing, Engineering and Warehousing • Healthcare • Education • In-store Experience • Home Décor • Retail • Gaming • Marketing

2.2.1 Enterprise Investment in Augmented Reality

Worldwide spending on AR and VR exceeded $13.8 billion in 2022 and is expected to grow to $50.6 billion in 2026 (International Data Corporation [IDC], 2022). According to IDC (2022), the largest AR/VR investments in the enterprise space will come from discrete manufacturing, healthcare providers, professional services, education, and retail, with industrial maintenance and training expected to account for one-third of all enterprise investment into AR (IDC, 2022). Mainelli (2023) discussed how the latest IDC report shows that worldwide spending on AR software is expected to grow from $210 million in 2022 to $716 million by 2026 and identifies challenges around aging and retiring workforce, talent acquisition and retention, and difficulty training workers as key motivators for embracing this technology.

2.2.2 AR Opportunities in Manufacturing Environments

Manufacturing industries are constantly seeking innovative technologies to enhance productivity, efficiency, and safety. Augmented reality technology has emerged as a promising solution. AR can be applied in various ways in manufacturing environments including assembly guidance, maintenance, training, and remote assistance (Billinghurst & Duenser, 2012). AREA (2020) described how AR can be used to provide real-time assembly instructions and to highlight potential manufacturing errors, providing the example of Boeing using AR glasses for manufacturing tasks that resulted in reduced error rates. AREA (2020) also described how AR can be used to provide maintenance workers with information and guidance for performing maintenance tasks, including an example of how Siemens was able to use AR to improve the efficiency of maintenance processes. AREA (2020) also described how AR can be used for training and onboarding employees for performing complex tasks and provides an example of how Lockheed Martin was able to use AR to reduce the learning curve for new employees.

Finally, AREA (2020) highlighted the AR opportunities for remote assistance where remote peers can provide live guidance to remote technicians and provides an example of how PTC was able to leverage AR for remote assistance.

2.3 Human Senses and User Interfaces

In addition to understanding users and product usage, it is also critical to understand the role that human senses play in the virtual environment when designing and selecting input modalities for augmented reality applications. An input modality is merely a conduit between the user's intentions and an action being performed in the digital environment and human sensory processes are central to this interaction. "Today, audio, motion, and even our thoughts, are the basis for the most innovative computer-user interaction models powered by advanced sensor technology" (Murphy, 2017). Murphy (2017) identified five main senses that are relevant for computer user interfaces: sight, touch, hearing, smell, and taste. According to Murphy, the sight sense is used when using a graphical user interface, touch is used when operating a touchscreen device, and hearing is used by voice recognition systems. Murphy explained that as VR and AR systems aim to produce more immersive experiences, the senses of smell and taste will come into play.

Although the consensus has been that there are five senses, as historically identified by Aristotle in his work *De Anima*, most neurologists agree that there are at least nine senses (Francis, 2020). Francis (2020) described that these additional senses include thermoception (sense of heat), nocioception (the perception of pain), equilibrioception (the perception of balance), and proprioception (the perception of body awareness). According to Francis, some neurologists consider 21 or even 53 senses, which include a number of radiation senses (senses related to color/temperature and associated moods), feeling senses (sensitivity to gravity, air, and motion), chemical senses (hormonal senses), and mental senses. As AR and VR systems approach a fully immersive experience, it is prudent to understand the full array of human senses at work when interacting with these technologies as it relates to different input modalities and product use conditions.

2.4 Performance and Usability of Different Input Modalities

Each input modality has advantages and disadvantages, each of which is more or less significant depending on user and usage characteristics with regards to the sensory-experience during the user-product interaction. An understanding of how user performance is affected by different input modalities for key interactions required for a given product user scenario can help to guide the design and selection of input modalities for that application. For example, despite the growing popularity of gesture-based controls in virtual environments, effective selection with pointing gestures remains a problem (Sanz & Andujar, 2013). Sanz and Andujar (2013) discussed how natural gestures provide more of an immersive experience by permitting direct interaction with digital content, but are more physically demanding and increase the required user dexterity. Sanz and Andujar explained (2015) some of the limitations of gesture-based control:

> Although 3D interaction techniques for target selection have been used for many years, they still exhibit major limitations regarding effective, accurate selection of targets in real-world applications. Some of these limitations are concerned with visual feedback issues (occlusion, visibility mismatch, depth perception in stereoscopic displays) and the inherent features of the human motor system (instability when interacting in free space, speed/accuracy trade-off, neuromotor noise). (p. 15)

Sharman (2020) explained that while controllers are still preferred over hand tracking for creative tools and applications that require a high degree of precision, hand tracking provides much promise for simulation and training where using actual hands better simulates a real working environment. “When you are able to look down and see your hands, reacting and moving in real time, your brain tells you it’s real” (Sharman, 2020). This would indicate that hand tracking would be preferred over controller-based input for an application falling within the training use case category, where a realistic experience is prioritized over precision control.

3D pens are also appearing on the market as an alternative to controllers while providing many of the same benefits. While handheld controllers remain to be the popular input modality for applications requiring high precision control, 3D pens may be an even better option. Pham and Steurzlinger (2019) conducted a study where they found 3D pens held with a pinch grip to be lighter, more accurate, and easier to controller than a standard controller held with a power grip.

Eye-tracking, historically considered to be a research tool allowing for the analysis of eye movement, is now widely used as an input modality with the use of built in cameras in extended reality hardware, which “allow for fast and accurate monitoring of eye movements, delivering a considerable amount of data” (Clay et al., 2019). The authors explained that eye tracking possesses much potential as an input modality due to the close relationship between eye movements and cognition. Clay et al. (2019) found some disadvantages to using eye tracking as an input modality for extended reality applications include the need to calibrate and validate the eye tracker, failure of the eye tracking system if the head mounted display moves or slips, and difficulty tracking movement for darker colored eyes.

According to XR Today (“What is speech recognition?” 2022), speech recognition can play a major role in virtual reality by helping to simulate conversations with AI entities, by allowing one to navigate the virtual world without handheld controllers, and by simplifying the handheld controller user experience. As XR Today (“What is speech recognition?,” 2022) explained, speech recognition systems still lack 100% accuracy due to individual accents and ambient noise. These inaccuracies may require users to have to repeat themselves, negatively affecting task performance when using voice as an input modality and emphasizing the need to understand which user scenarios could benefit from speech recognition and how well it works in those applications.

2.5 Design Frameworks

Innovation is generally spurred by one of four incentives: an institutionalized search to leverage known performance trajectories; market opportunities to address customer requirements; technological and scientific advances; and as a response to problems (Taalbi, 2017). The motivation for bringing a new product to market, along with the values and philosophies held by key stakeholders, usually results in the adoption of one or more design processes during new product development (NPD). This includes product-centered design (PCD), user-centered design (UCD), human-centered design (HCD), and design thinking (DT).

A PCD process focuses first on technological development, emphasizing product and production requirements, followed by user functionality (Bix et al., 2009). For emerging technologies such as augmented reality, which have historically been driven by technological advancements rather than a specific user need, a PCD approach is often employed until the market begins to adopt and demand the technology. Human-centered design (HCD), in contrast to PCD, focuses primarily on human needs. HCD is defined by Norman (2013) as “the process that ensures that the designs match the needs and capabilities of the people for whom they are intended" (p. 9). User-centered design (UCD) considers user needs and wants to be the primary design considerations through all phases of the design process (Bix et al., 2009; Browne, 2021; Conrick, 2020). HCD and UCD are often been considered to be interchangeable, however, "HCD is about the empathetic and psychological side, while UCD is about the physiological and tangible side. To put it simply, one of them is about humans and the other is about users" (Mitsiakina, 2023). Bix et al. (2009) explained that a combination of PCD and UCD is necessary for optimal product design.

Design thinking as a scientific methodology and as a cognitive style is a more recent trend, with Herbert A. Simon making first mention of design as a way of thinking in 1969 and with IDEO framing DT as a mainstream process (Browne, 2021; Siang & Dam, 2022). Tim Browne, Executive Chair of IDEO, defined design thinking as "a human-centered approach to innovation that draws from the designer's toolkit to integrate the needs of people, the possibilities of technology, and the requirements for business success" ("Design thinking defined," n.d.). While UCD and DT both place an emphasis on empathy, problem solving, iteration, and collaboration, the central focus of UCD is creating solutions with user needs and feedback at the forefront of all design decisions. The central focus of DT is to utilize abductive reasoning to solve complex problems, which requires not only considering user needs but also technological feasibility and business goals (Browne, 2021).

DT presents a novel opportunity for understanding input needs from a user perspective for various product use cases. According to IDEO ("Design thinking defined," n.d.), DT lives at the intersection of desirability, viability, and feasibility. These three factors are also prime considerations for input needs for augmented reality applications, making DT a promising candidate for an approach for analyzing input modalities for augmented reality applications from a user-centered perspective.

Sharma et al. (2015) demonstrated how utilizing DT methodologies can be used help elicit details about product use cases. The use of DT methodologies to help stakeholders in "understanding the problem/use case from all perspectives, predicting potential hidden solutions, and finding opportunities to leverage on existing problems" (Sharma et al., 2015, "Introduction" section). Sharma et al. (2015) found this method to be the most appropriate during either in the initial research stage or in the synthesis stage of product development.

2.6 Summary

Successful product development relies on understanding users (Hasdoğan, 1996; Jeelani, 2022). For augmented reality applications, this can be challenging due to the variety of use cases, which includes everything from visualization to simulation (AREA, 2022) and can even include areas of opportunity in fields such as education and retail (Agrawal, 2019). Of the potential uses for AR technology, use in manufacturing environments shows a lot of promise.

When interacting with augmented and virtual worlds, all of our senses are in use (Murphy, 2017). The various input modalities, which act as a conduit between the user's intentions and the resulting action, each come with their own advantages and disadvantages (Clay et al., 2019; Pham & Stuerzlinger, 2019; Sanz & Andujar, 2013; Sharman, 2020; "What is speech recognition?," 2022). Sharma et al. (2015) demonstrated how design thinking can be used to elicit details of product use cases.

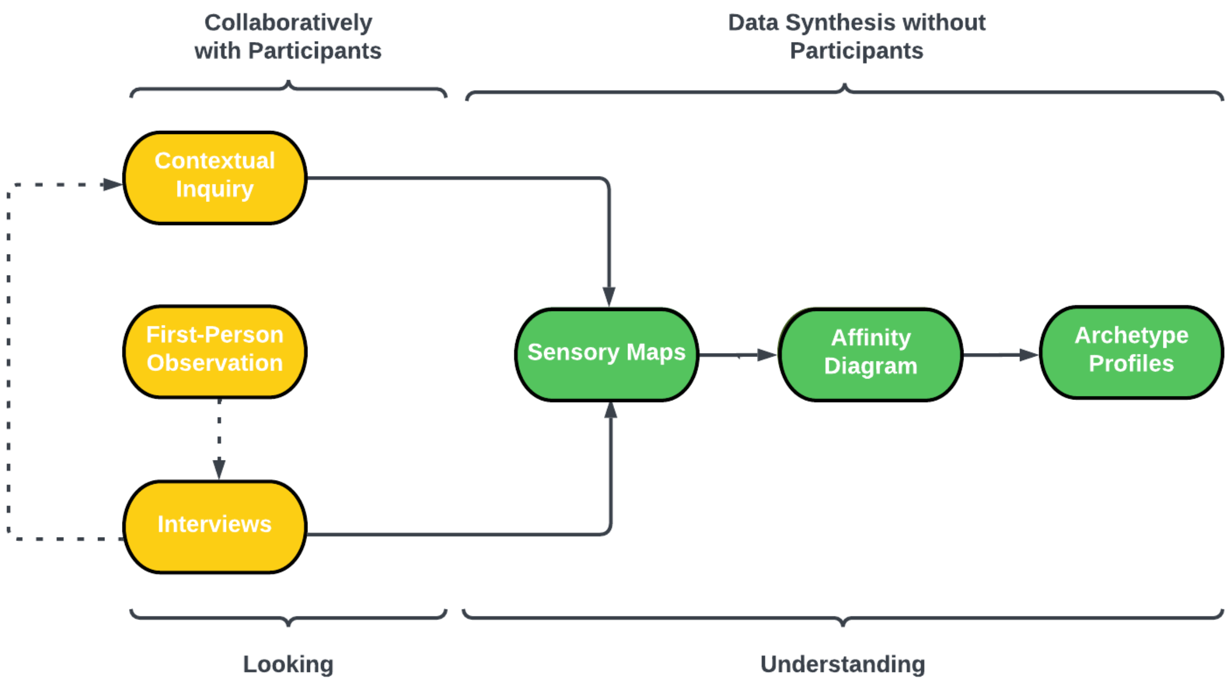
Utilizing DT methods is hypothesized to help to define user input needs for enterprise use and create a better understanding of when certain input modalities are more appropriate than others from both a user and business perspective. Currently very little in the literature exists that describes how DT methodologies can be used to guide the development and selection of input modalities for augmented reality applications. This study will address the identified gap in the literature and will expand the body of knowledge relating to using design thinking methods to analyze input modalities for augmented reality applications

CHAPTER THREE: METHODOLOGY

The goal of this study was to develop a process for uncovering user input needs for different user scenarios when using AR in manufacturing settings. In order to elicit and synthesize this information, a series of design thinking methods was used in two distinct phases. The first phase (looking) involved data collection through the use of ethnographic research methods with direct collaboration with manufacturing workers. The design thinking methods for this phase included a contextual inquiry, first-person observations, and interviews. The second phase (understanding) involved analyzing and synthesizing the data using design thinking methods to identify patterns and priorities using sensory maps, affinity clustering, and archetype profiles to build a deeper understanding of the people involved and to generate a design rationale based on the findings. A detailed explanation of the methods and procedures for each stage can be found in the following sections.

Figure 2 illustrates the methodology process flow for this study, which is also the proposed methodology to be used by companies involved with NPD when using ethnographic research to elicit user needs for the purpose of establishing product requirements. As shown in this figure, the process can start with either a contextual inquiry, first-person observation, or an interview. The starting point for the process is highly dependent on access to participants.

Figure 2
Methodology Process Flow



3.1 Sample

The sampling method for this study involved first approaching a set of known users of AR in two light assembly facilities producing electronic devices who were currently undergoing proof-of-concept trials with the technology. This convenience and purposive sample was selected due to the researcher having direct access to these participants as well as the unique context that these participants had from participating in the proof-of-concept (POC) trials. Following the collaboration with these manufacturing workers, a larger sample of frontline workers from various manufacturing industries was recruited in order to add coverage for the different types of manufacturing settings.

The first-person observations were conducted using video footage collected using the AR HMD cameras with two manufacturing engineers at one of the light assembly facilities during a 3-week POC trial for using AR to support remote assistance. These same manufacturing engineers were then interviewed at the conclusion of the POC trial. In addition to the interviews with the manufacturing engineers, five frontline workers in various manufacturing industries were interviewed in order to provide additional insight. Contextual inquiries were then performed with an experienced assembly operator/trainer as well as one of the manufacturing engineers who participated in the first-person observation and interview. Table 2 summarizes which methodologies each participant was involved with:

Table 2
Participant Breakdown

Participant	**Role**	**Industry**	**First-Person Observation**	**Contextual Inquiry**	**Interview**
P1	Principal Manufacturing Test Engineer	Consumer Electronics	X	X	X
P2	Manufacturing Test Engineer	Consumer Electronics	X		X
P3	Assembly Operator/Trainer	Consumer Electronics		X	
P4	Material Handler	Automotive			X
P5	Press Operator	Metal Manufacturing			X
P6	Picker/Order Selector	Automotive			X
P7	Skilled Tool and Die Team Member	Automotive			X
P8	Warehouse Worker	Metal Manufacturing			X

3.2 First-Person Observation

The method of a first-person observation was developed and utilized in order to provide insights related to what the user sees and experiences from their perspective. This method has not been commonly used by DT practitioners but is now possible due to world-view recording features provided by HMDs. In theory, this method is very similar to a fly-on-the wall observation, which is “an approach to conducting field research; in an unobtrusive manner” (LUMA, 2012, p. 6). Fly-on-the wall observations allow for observations to take place without interrupting the flow of activities and can be conducted in situations where you cannot speak directly with people (LUMA, 2012, p. 6). First-person observations follow a similar premise; however, the researcher has a unique opportunity to see exactly what the subject sees rather than receiving a third-person view and is able to be completely removed from the location while the tasks of interest are being performed reducing interruptions.

First-person observations were performed with two manufacturing engineers in the form of reviewing video footage recorded using the augmented reality device’s world cameras. The video footage was used to provide a first-person view of what the engineers see when they use augmented reality for remote assistance. This footage was used to reveal where the worker’s hands are relative to the headset’s world cameras, which is critical for hand-tracking interactions due to the necessity to track hand key-points. The footage also showed how workers use their hands while working, which can affect the suitability of input modalities that require the use of hands such as gestures, controllers, and other peripheral devices. The video footage was also used to build a better understanding of how frontline workers interact with the system and what types of input interactions they are most likely to use. A template for capturing key observations from the video footage reviews is found in Appendix B1.

3.3 Interviewing

Interviewing is an ethnographic research method and is a “technique for gathering information through direct dialogue” (LUMA, 2012, p. 4). As LUMA (2012) stated, interviewing allows us to “gain a better sense of people and their views of the world by subtly eliciting their true feelings, desires, struggles through a few carefully crafted questions" (p. 4). When conducting interviews, LUMA (2012) emphasized that the "unplanned and unscripted aspects of an interview can allow for equally illuminating discoveries" (p. 4).

Virtual interviews were conducted with the two manufacturing engineers from the first-person observation as well as with frontline workers from different manufacturing industries in order to reveal details about different manufacturing user scenarios and input needs for AR technology when used for remote assistance. These findings serve as direct feedback to inform input modality requirements for different manufacturing processes. The questions asked during the interview (see Appendix B2) were designed to elicit the input needs for each user scenario. This includes gaining an understanding of how users in different manufacturing environments are likely to use the technology, the types interactions they will rely on the most, as well as task and environmental constraints that may affect the suitability of different input modalities. Although the interviews were conducted using prepared questions, the interview proctor asked follow-up questions based on the responses received from participants.

The interviews were facilitated by a primary interview proctor with one to three other researchers present. In addition to capturing interview responses on text-based interview question forms, an Interview Collaboration Board template (see Appendix B3) in Lucidspark was used to capture participant responses. The Interview Collaboration Board was screen shared with participants and also served as a tool to enrich the conversations. In order to allow the primary interview proctor to focus on the conversation with participants, the other researchers present during the interviews populated the responses on the question forms and on the Interview Collaboration Boards. The other researchers were also permitted to ask follow-up questions as necessary.

3.2 Contextual Inquiry

A contextual inquiry is “an approach to interviewing and observing people in their own environment” (LUMA, 2012, p. 8). According to LUMA (2012), a contextual inquiry allows you to inquire about someone’s experiences in the context as they are happening while receiving direct input from them rather than making your own assumptions. LUMA (2012) recommended that when conducting a contextual inquiry, observations are made in an unobtrusive manner and that questions are asked at opportune moments.

Two contextual inquiries were performed. The first contextual inquiry was performed with an assembly operator/trainer who works on the same consumer electronic product as the two manufacturing engineers but at another facility. The second contextual inquiry was performed with one of the manufacturing engineers. For the contextual inquiries, the participants wore the HMD while interacting with objects in their work environment and AR features related to remote assistance such as initiating a remote assistance session, placing digital markers on real-world objects, and entering text annotations. The focus of the contextual inquiries was on understanding task requirements, work environments, and how users use their senses. Template forms for capturing user sensory interactions are found in Appendix B3. Compared to other methods for observation and ethnographic research, contextual inquiry provides the opportunity to directly observe and interact with frontline workers as they work in their real work environments.

3.5 Sensory Map

Sensory maps were produced for the contextual inquiry subject as well as for each of the interview participants. A sensory map is a modified version of an empathy map, which focuses more on the human senses rather than an individual’s thoughts and feelings. While empathy maps traditionally capture what the user says, thinks, does, and feels (Gibbons, 2018), the sensory map template created for this study focuses on three of the five widely referenced senses (sight, vision, and touch), as well as the five additional senses described by Francis (2020), including thermoception, nocioception, equilibrioception, and proprioception. The template for the sensory map can be found in Appendix C1.

3.6 Affinity Clustering

Affinity clustering was used to qualitatively synthesize interview findings. Affinity clustering is a method for establishing patterns and priorities and is "a graphic technique for sorting items according to similarity" (LUMA, 2012, p. 40). As LUMA (2012) explained, this method results in "being able to draw insights and new ideas out of otherwise disparate pieces of information" (p. 40). LUMA stated that affinity clustering "helps you identify issues and insights, reveals thematic patterns, facilitates productive discussion and builds a shared understanding" (p. 41).

In order to conduct the affinity clustering method, the researcher clustered key findings based on common themes and needs for each user scenario. As Braun and Clarke (2006) explained, thematic analysis can be used to minimally organize qualitative data while eliciting rich detail. Common input needs, task requirements, and environmental constraints from the interviews will be clustered by analyzing notes and recordings from the previous methodologies. The template for the affinity cluster can be found in Appendix C2.

3.7 Archetype Profiles

Archetypes were identified based on the results from the previous methodologies and an archetype profile was developed for each identified archetype in the manufacturing industry. An archetype profile is a novel approach to understanding different types of users and stakeholders.

An archetype profile is similar to a persona profile, which is a method for understanding people and systems and is “an informed summary of the mindset, needs and goals typically held by key stakeholders” (LUMA, 2012, p. 34). Psychologist Carl Jung is credited with introducing the concepts, describing a persona as a social identity that an individual presents to the world while describing archetypes as patterns that represent fundamental human experiences, emotions motivations (Mcleod, 2023). Unlike a persona profile, which typically focuses on an individual fictitious character with unique demographics and personal experiences, the archetype profiles focus more on groups of potential end users who perform similar work and share common user needs. The template for the archetype profiles can be found in Appendix C3.

3.8 Summary

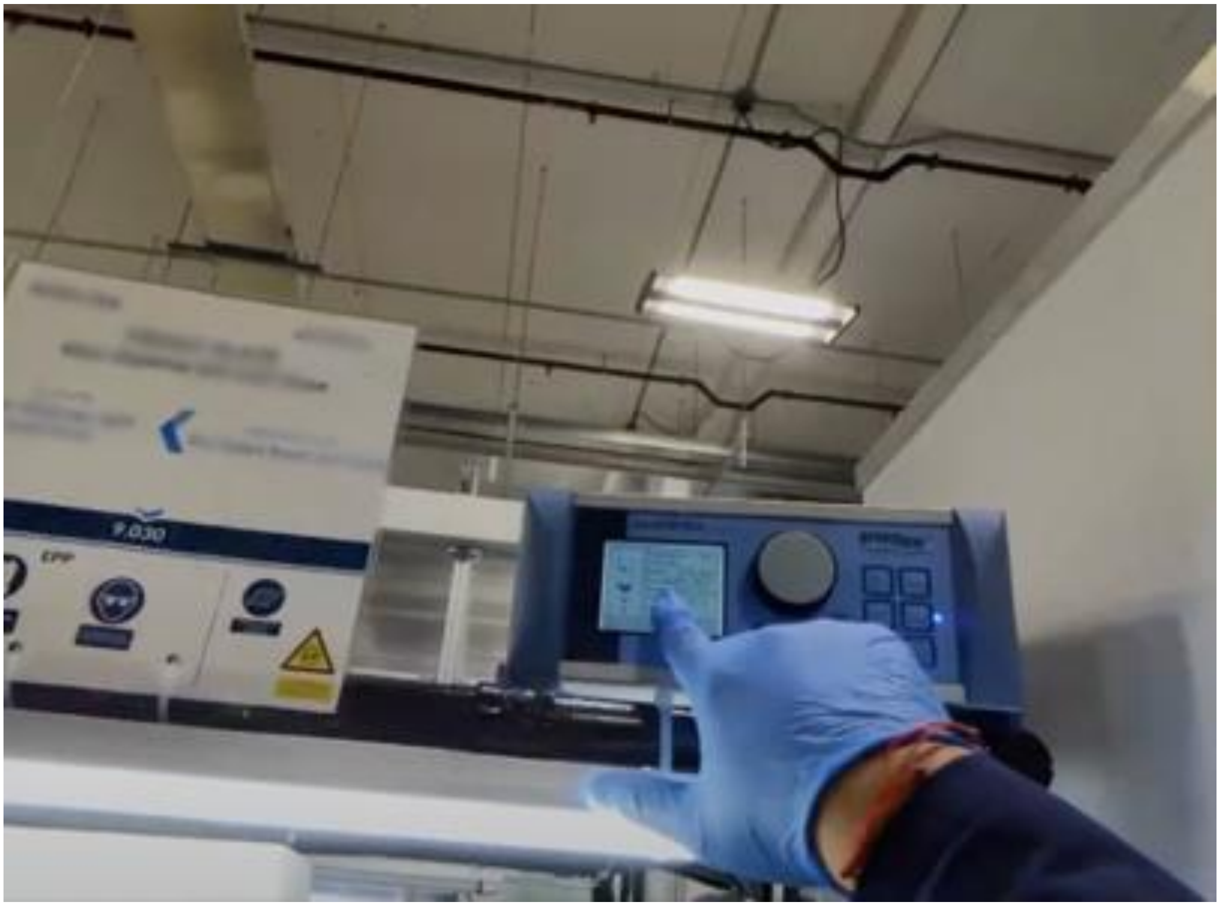
The utilized design thinking methods were selected to help uncover user input needs for using AR in manufacturing settings. Ethnographic research in the form of contextual inquiries, first-person observations, and interviews were used to elicit details related to user goals, motivations, and needs. This data was be analyzed qualitatively using sensory maps and affinity clustering leading to the development of archetype profiles for identified key user archetypes. The archetype profiles can be used by design, engineering, and product teams when developing product requirements.

CHAPTER FOUR: RESULTS

4.1 First-Person Observation

The first-person observation proved to be an effective method for understanding what the end user experiences from their perspective. Unlike a traditional fly-on-the-wall observation, the first-person observation allowed the research team to see where participants focused their attention as well as what they could see through the frame of the AR HMD, both which are critical to understand when determining user input needs. Of particular interest was how users handled the controller when performing their normal work. It was observed that participants would switch hands when holding the controller if they need to perform a one-handed task with their dominant hand. When performing a two-handed task, they would place the controller on a nearby surface such as a table surface or on the edge of a piece of machinery. It was also observed that the hands of the participants would often leave the field-of-view of the AR HMD's world cameras, which could affect the performance of hand-tracking, which requires the hands to be visible to the cameras that track hand-key points. The sensory analysis data from the first-person observations can be found in Appendix D.

Figure 3
Sample footage from first-person observation



4.2 Interviewing

The interviews provided an opportunity for the research team to ask directed questions to manufacturing subject matter experts (SMEs) in order to gain insights on their work and their work environments. The interviews with the set of participants (P1 and P2) who participated in the AR POC trial and first-person observations facilitated a deeper conversation due to the participants having a context for use of AR to support remote assistance and also due to the research team having a context for the work these participants perform. Although the remaining interview participants (P4-P8) did not have much familiarity with AR technology, the insights they were able to provide regarding their work and work environment were helpful for establishing an understanding of the possible user scenarios where this technology could be deployed, resulting in a more robust identification of user needs. The responses to the interview questions can be found in Appendix E. The Interview Collaboration Boards that were populated during the interview sessions can be found in Appendix F.

4.3 Contextual Inquiry

The contextual inquiry with the Principal Manufacturing Test Engineer (P1) in the electronics assembly facility revealed a few insights related to input needs when using an AR HMD to support remote assistance. It was observed that this participant had difficulty when using the controller for distant marker placement, specifically related to depth perception when placing the marker, which would indicate the probability of even more difficulty when performing this task using hand-tracking. The participant also had some difficulty with controller text entry, which would indicate the need for voice-based text entry, which could be restrictive in certain manufacturing environments. The sensory analysis data for the contextual inquiry with P1 can be found in Appendix G2.

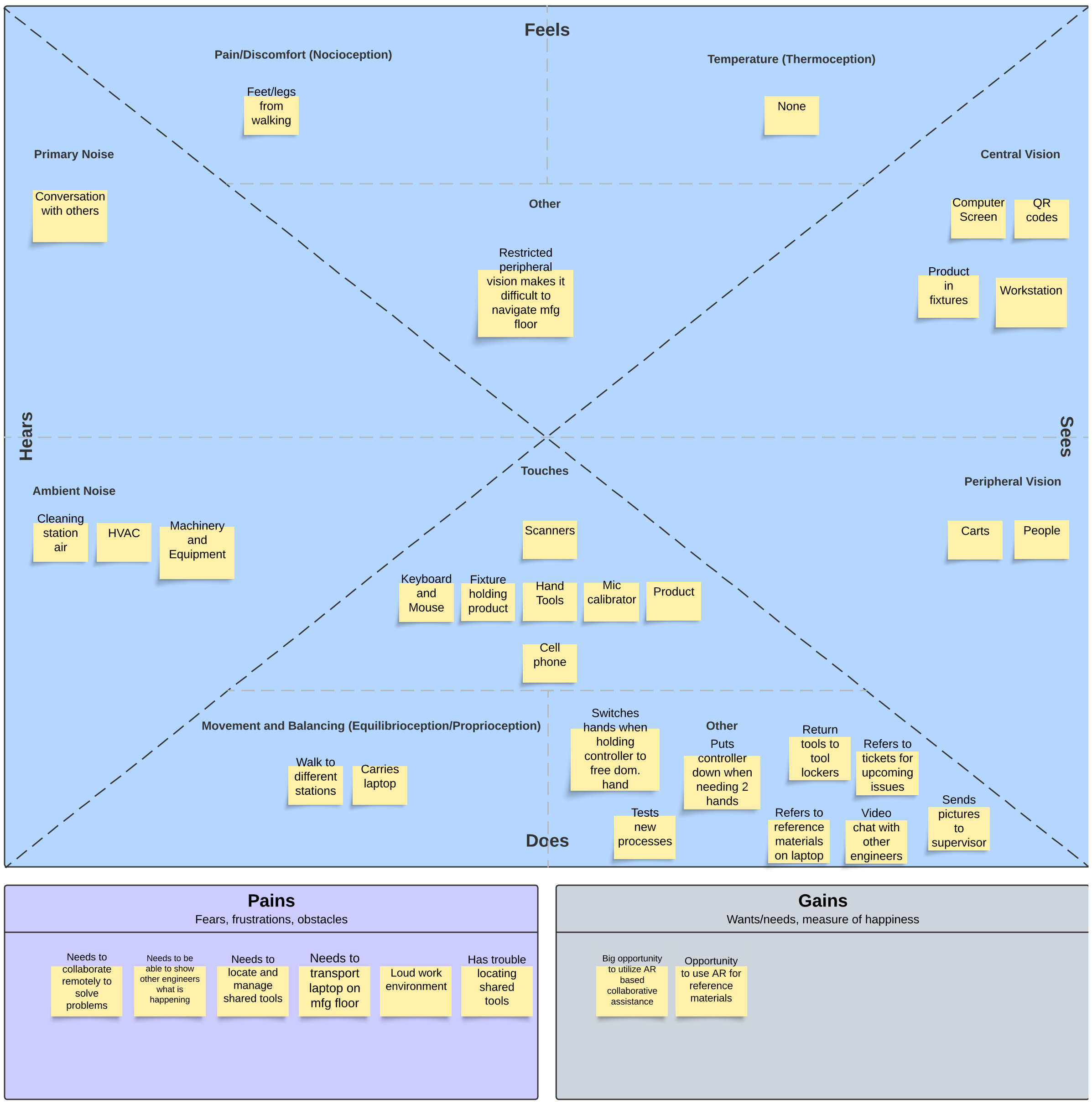
The contextual inquiry with the Assembly Operator/Trainer (P2) in the separate electronics assembly facility revealed several pain points when the operator was using the HMD while performing assembly tasks, mainly related to having to put the controller down while performing assembly tasks and having to transport the controller between work cells. There were several instances where the operator had to return to the previous work cell to retrieve the controller. Maintaining battery life was also an issue as the device was not pre-charged, resulting in the operator having to not only transport the HMD and controller between work cells but also the charger in addition to continuously having to find available power outlets. The sensory analysis data for the contextual inquiry for P2 can be found in Appendix G1.

4.4 Sensory Maps

The sensory map for P1 in Figure 4 shows the sensory interactions that P1 experienced while using an AR HMD for remote assistance. P1 works in a busy environment and is exposed to all sorts of sights and sounds including workstations, carts, computer screens, people, and machinery. P1's facility is considered light assembly; therefore, there is no heavy-duty machinery such as presses that would warrant the use of hearing protection. Considering that P1 is a manufacturing engineer responsible for all processes in the facility, he finds himself moving around the facility frequently with a laptop and sometimes experiences pain in the feet and legs from walking and some restricted peripheral vision when wearing an HMD. P1 handles many objects including scanners, fixtures, shared tools, and product and refers to several reference materials usually in the form of PDF documents. When using the AR HMD for remote assistance, P1 will often switch hands when using the controller or put it down on a nearby surface due to the hand-on work required.

Figure 4

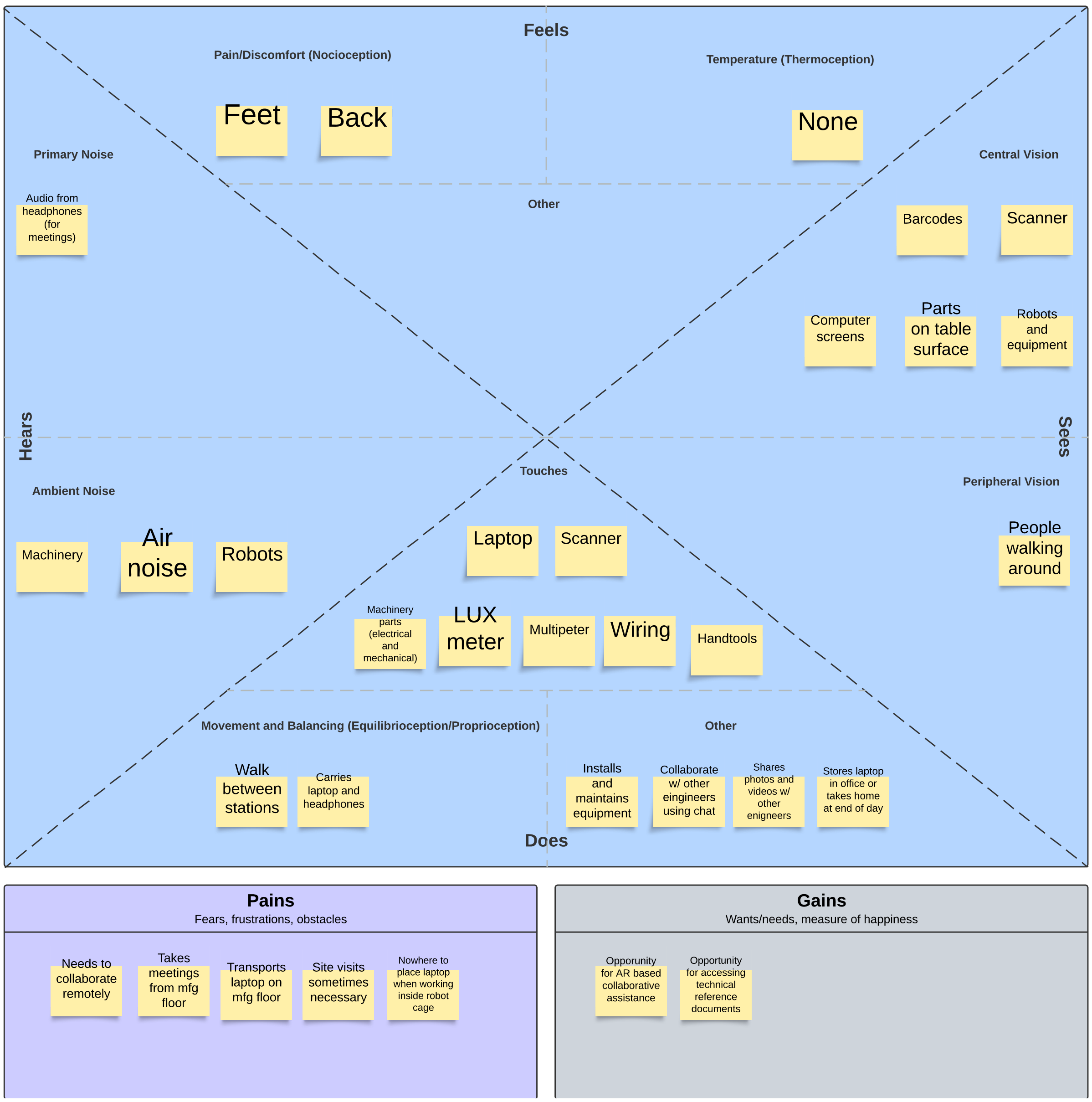
P1 Sensory Map



The sensory map for P2 in Figure 5 shows the sensory interactions that P2 experiences while using an AR HMD for remote assistance. P2 works in the same busy work environment as P1 where he is exposed to similar sights and sounds and also complains about pain in the feet and back due to frequent walking. Like P1, P2 handles many objects through the course of a workday and sometimes takes meetings from the plant floor due to already being on the floor and having his laptop and headphones with him. P2 mentioned that he struggles with finding a place to store his laptop (and other objects) when working at a work station.

Figure 5

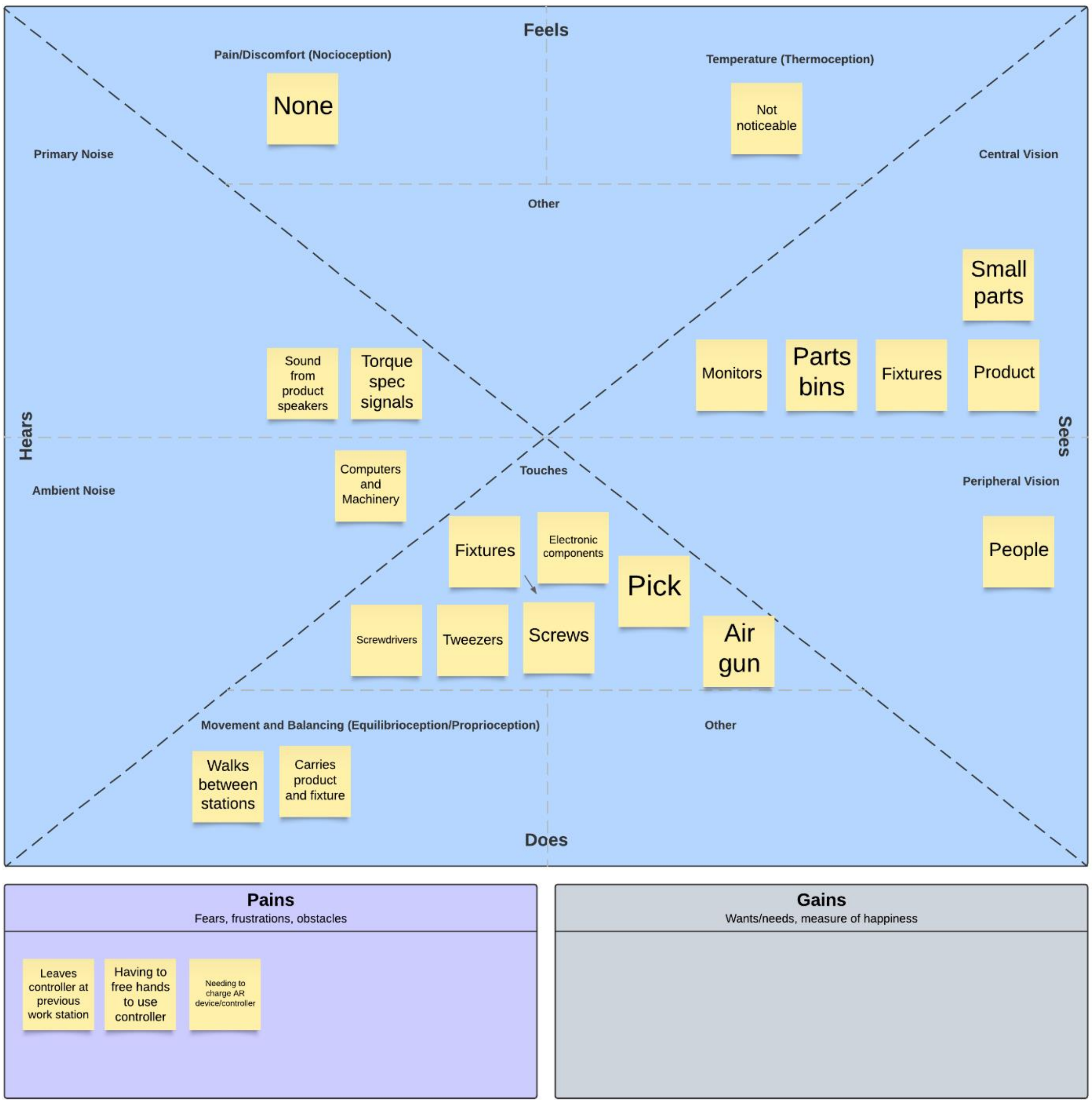
P2 Sensory Map



The sensory map for P3 in Figure 6 shows the sensory interactions that P3 experiences while using an AR HMD for remote assistance. P3 works in a relatively calm clean room environment, well-lit with some ambient noise coming from computers and light assembly machinery. P3 handles a number of different parts and small tools, and walks between work stations carrying a fixture with the product in it. For some of the test and calibration activities, P3 needs to listen to torque spec signals and also needs to test the sound coming from the product's built-in speakers.

Figure 6

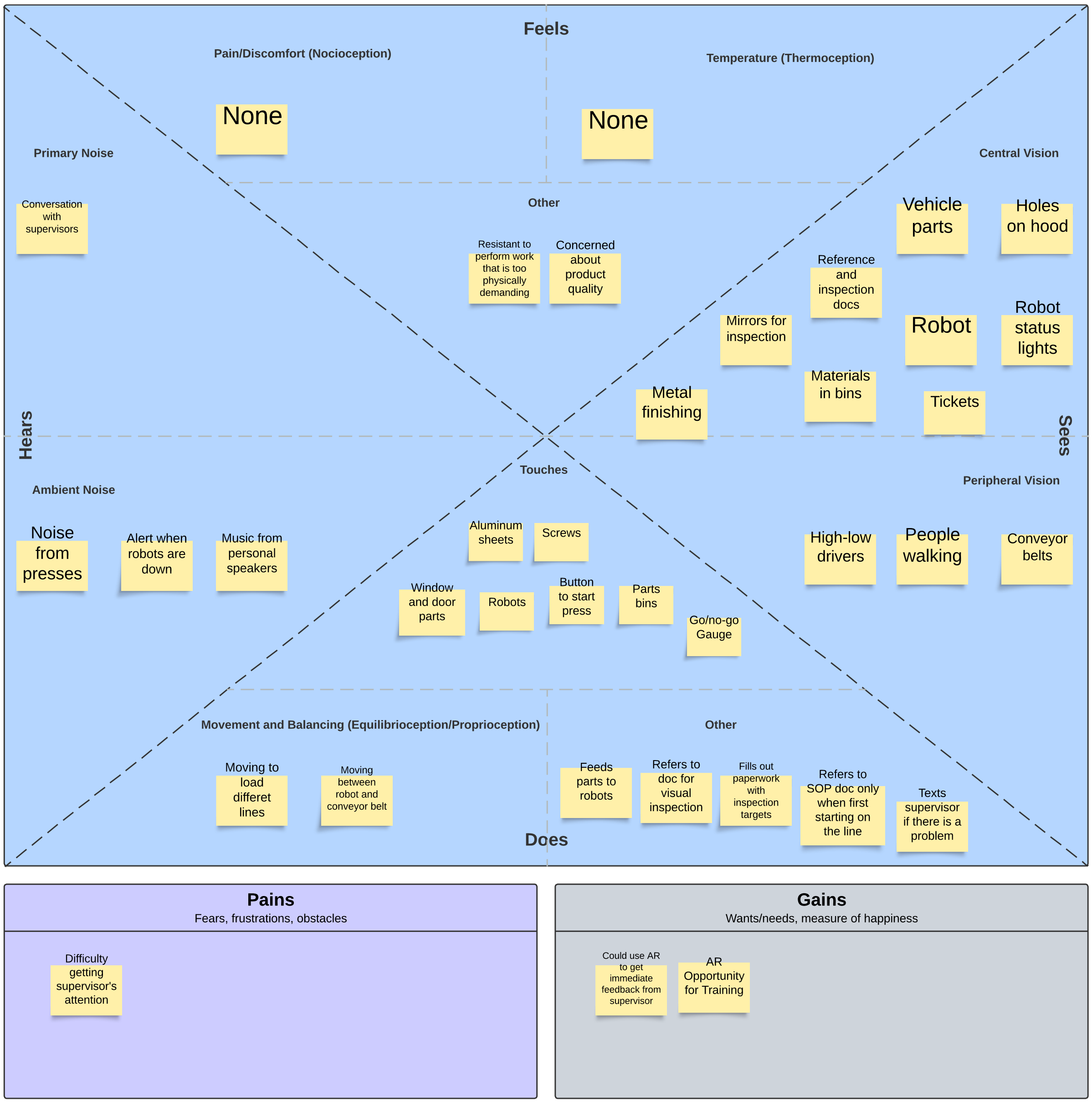
P3 Sensory Map



The sensory map for P4 in Figure 7 shows the sensory interactions that P4 experiences when performing their regular work. P4 works in a very busy and loud work environment in an automotive manufacturing facility. The noise that can be heard inside the facility includes noise from presses, robot signals, and music from personal speakers. The work that P4 performs is relatively physically demanding due to the handling of aluminum sheets and finish product. The surrounding work area is congested with high-low drivers, pedestrian traffic, and conveyor belts. P4’s work involves inspection work, both using visual inspection against referenced product specifications as well as using go-no-go gauges. P4 also moves between different production lines.

Figure 7

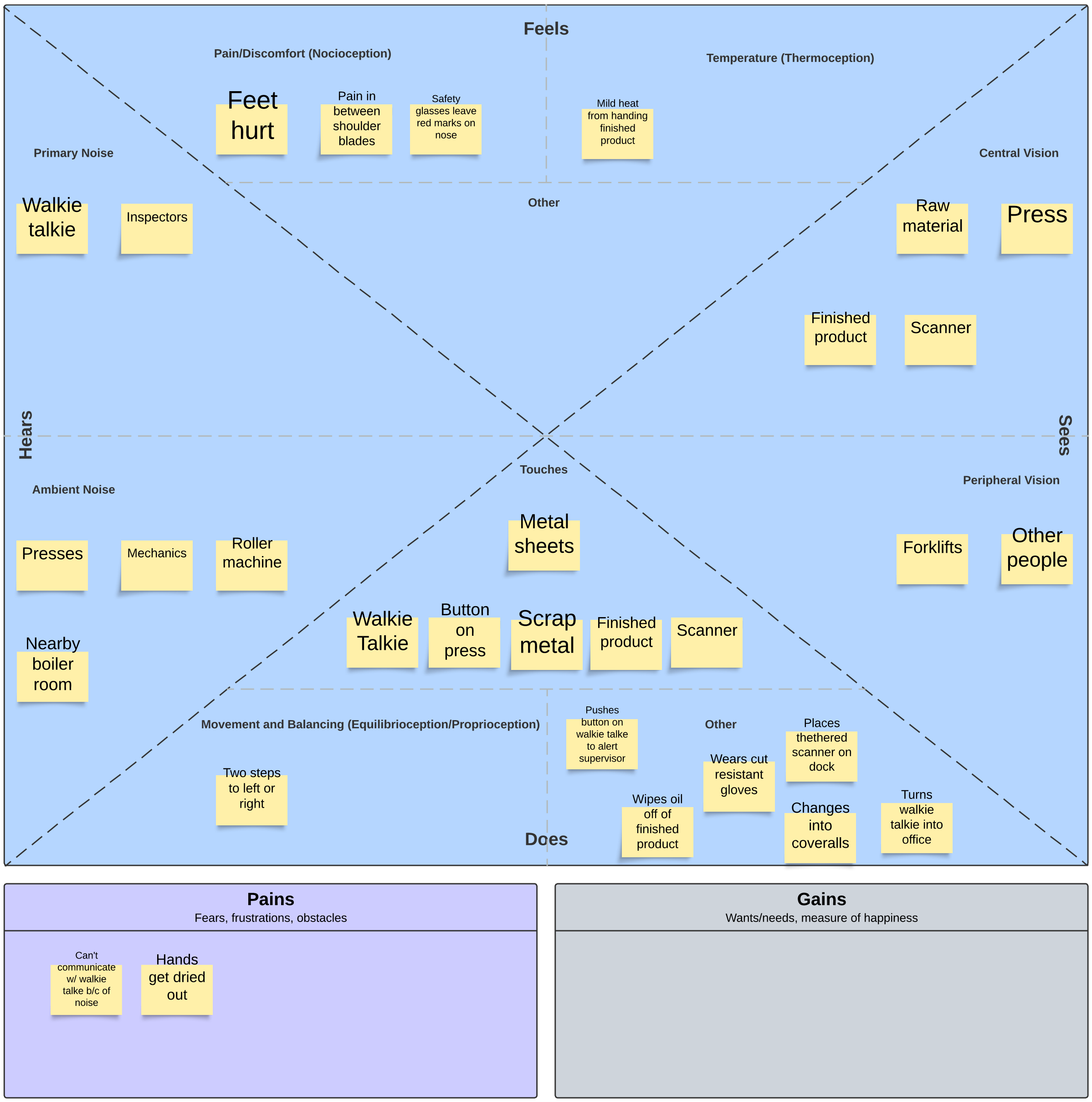
P4 Sensory Map



The sensory map for P5 in Figure 8 shows the sensory interactions that P6 experiences when performing their regular work. P5 works in a busy and loud work environment full of presses, machinery, forklifts, pedestrian traffic, and a very loud nearby boiler room. P5 attempts to have conversations with product quality inspectors, but often has difficulty because of the ambient noise. P5 also has a walkie talkie to communicate with their supervisor, but only uses the alert button due to the loud environment. P5 handles metal sheets, scrap metal, and finished metal products and presses buttons to operate the press. P5's work is mostly static, only taking two steps to the right and left to retrieve raw materials and to offload completed parts. P5 wears coveralls, cut resistant gloves, and safety glasses. P5 reports pain and discomfort in their feet, between the shoulder blades and can feel some mild heat through their gloves when handling finished products.

Figure 8

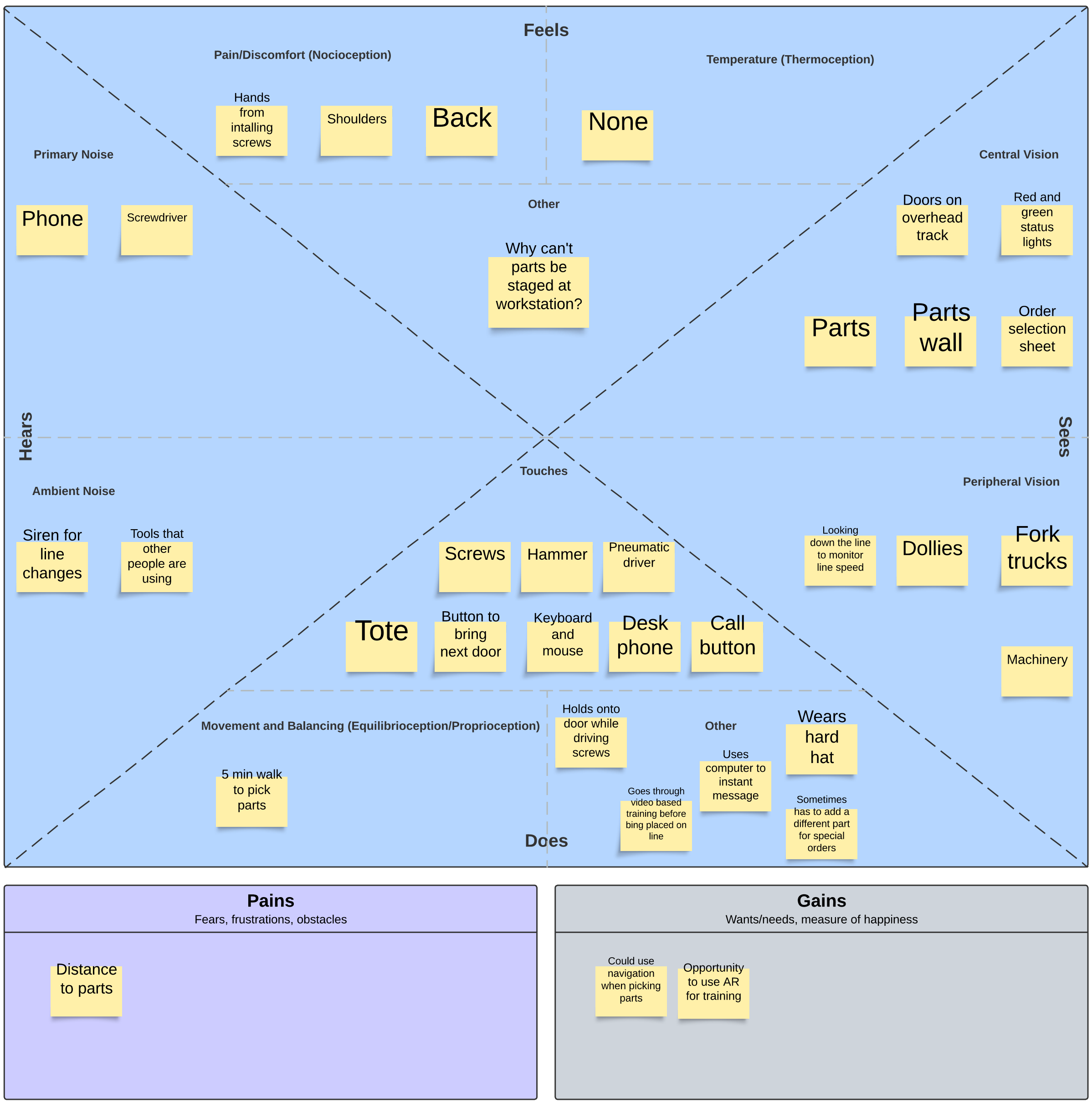
P5 Sensory Map



The sensory map for P6 in Figure 9 shows the sensory interactions that P6 experiences when performing their regular work. P6 works in a busy and loud work environment with fork truck traffic, dollies, machinery, and people walking around as well as noise from machinery, air tools, and robots. P6 picks parts from a parts wall in an area separate from the assembly line and handles hand tools, air tools, small parts, and parts totes. P6 works with both hands, holding onto the product while attaching fasteners, and refers to several different reference documents.

Figure 9

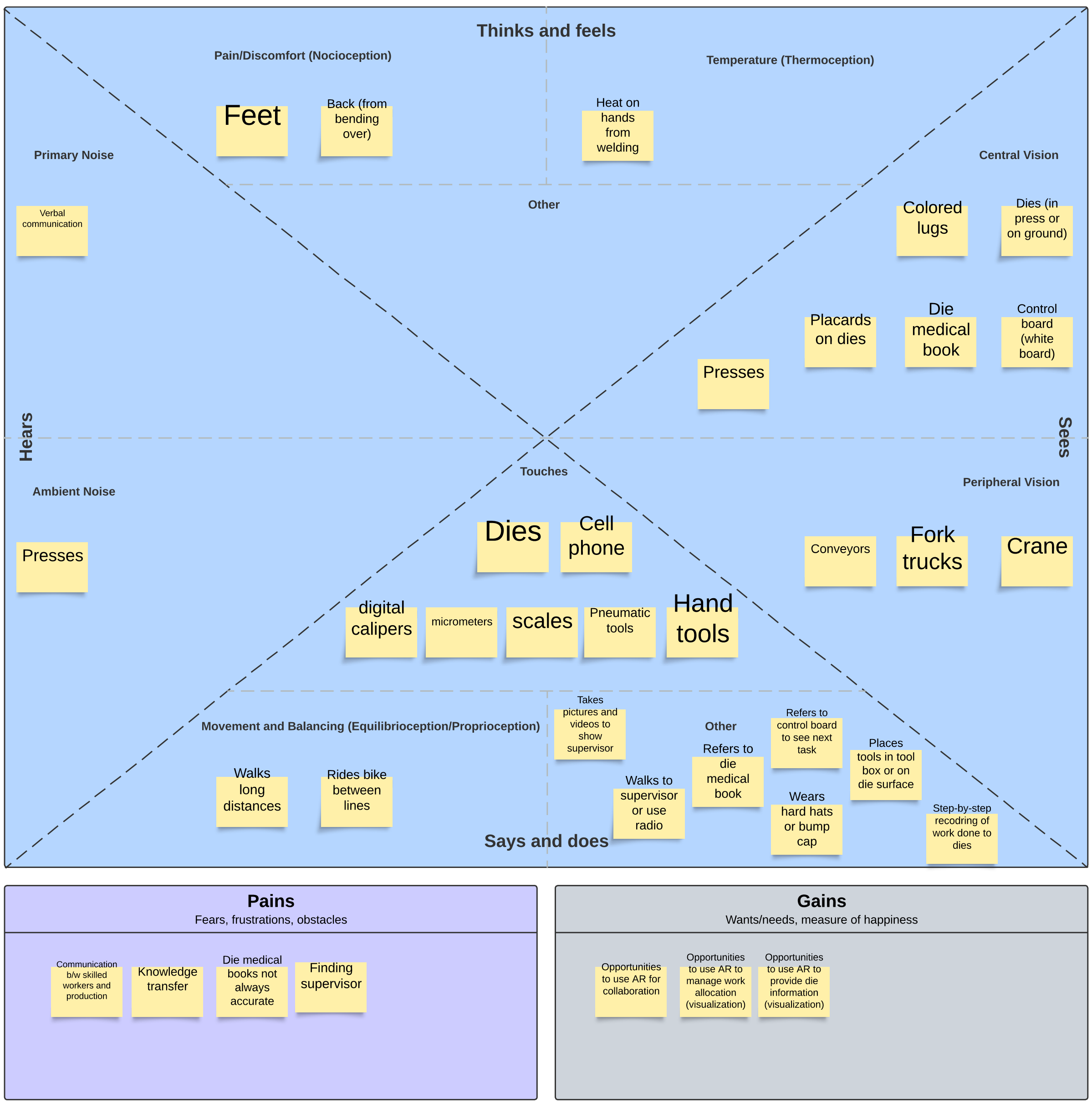
P6 Sensory Map



The sensory map for P7 in Figure 10 shows the sensory interactions that P7 experiences when performing their regular work. P7 can hear loud noises from stamping presses and can see conveyors, fork trucks, and cranes in their peripheral vision. Due to P7's responsibilities in different areas of the facility, P7 walks long distances and may even ride a bike. P7 handles many different hand tools, welding equipment, and machine dies and refers to several different reference documents. P7 complains of foot and back pain.

Figure 10

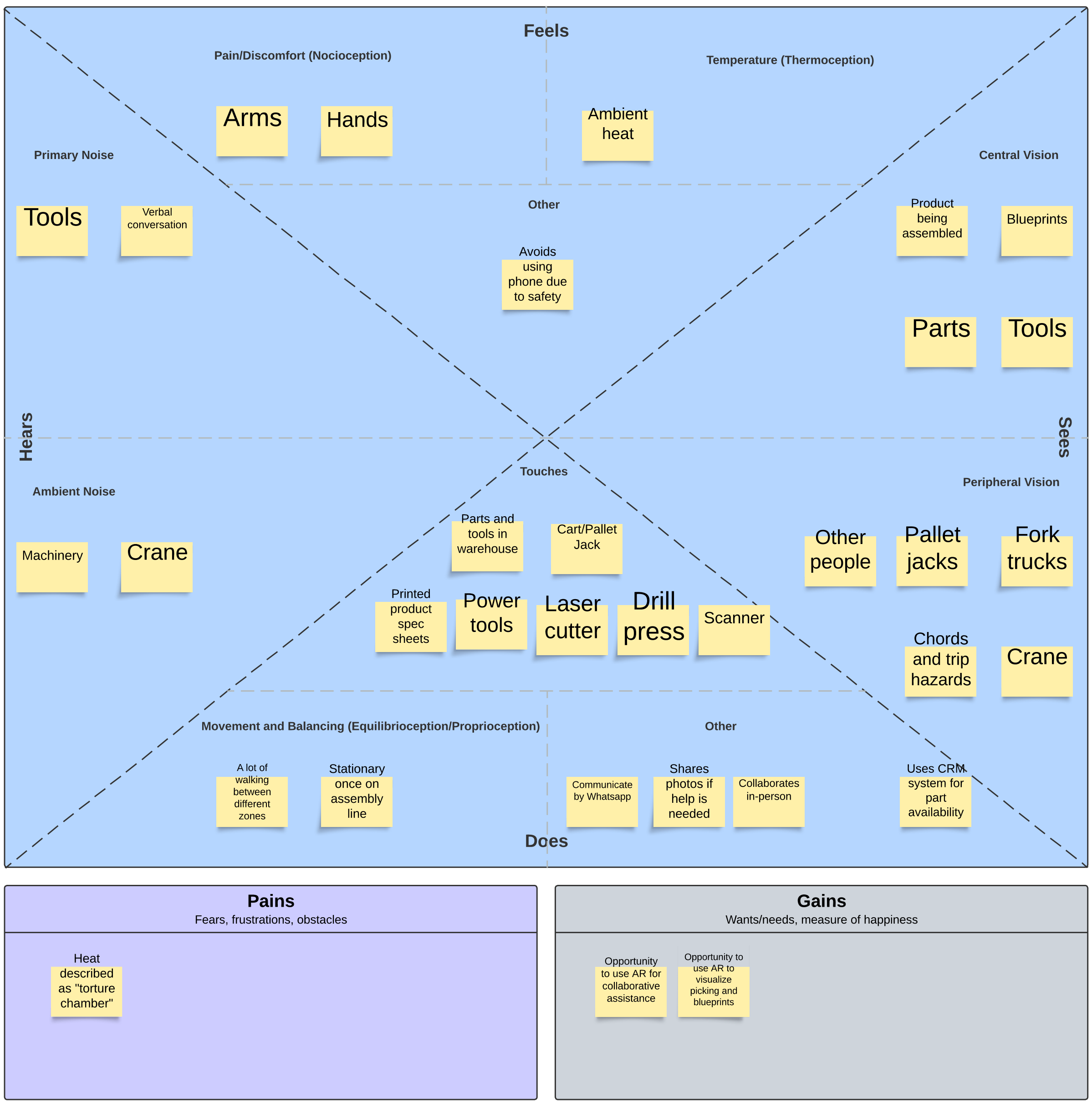
P7 Sensory Map



The sensory map for P8 in Figure 11 shows the sensory interactions that P8 experiences when performing their regular work. P8 performs very hands-on work, transporting parts and tools from a warehouse using cars and pallet jacks, and using tools and machinery including power tools, laser cutters, and drill presses. P8 can hear sound from machinery and cranes, and moves between different zones at different times in the day. P8's work environment is very hot and P7 reports arm and hand pain.

Figure 11

P8 Sensory Map



4.5 Affinity Clustering

The affinity diagram shown in Figure 12 revealed a few insights regarding how the different manufacturing roles can be grouped into archetypes. Table 3 summarizes the clusters for types of work performed while Table 4 summarizes the AR opportunities identified for each participant.

Table 3
Clustering of Types of Work

Participant	Static Work	Dynamic Work	Variable Work	Inspection	Picking
P1		X	X		
P2		X	X		
P3		X	X		
P4		X		X	
P5	X				
P6	X	X	X		X
P7		X	X	X	
P8	X	X	X		X

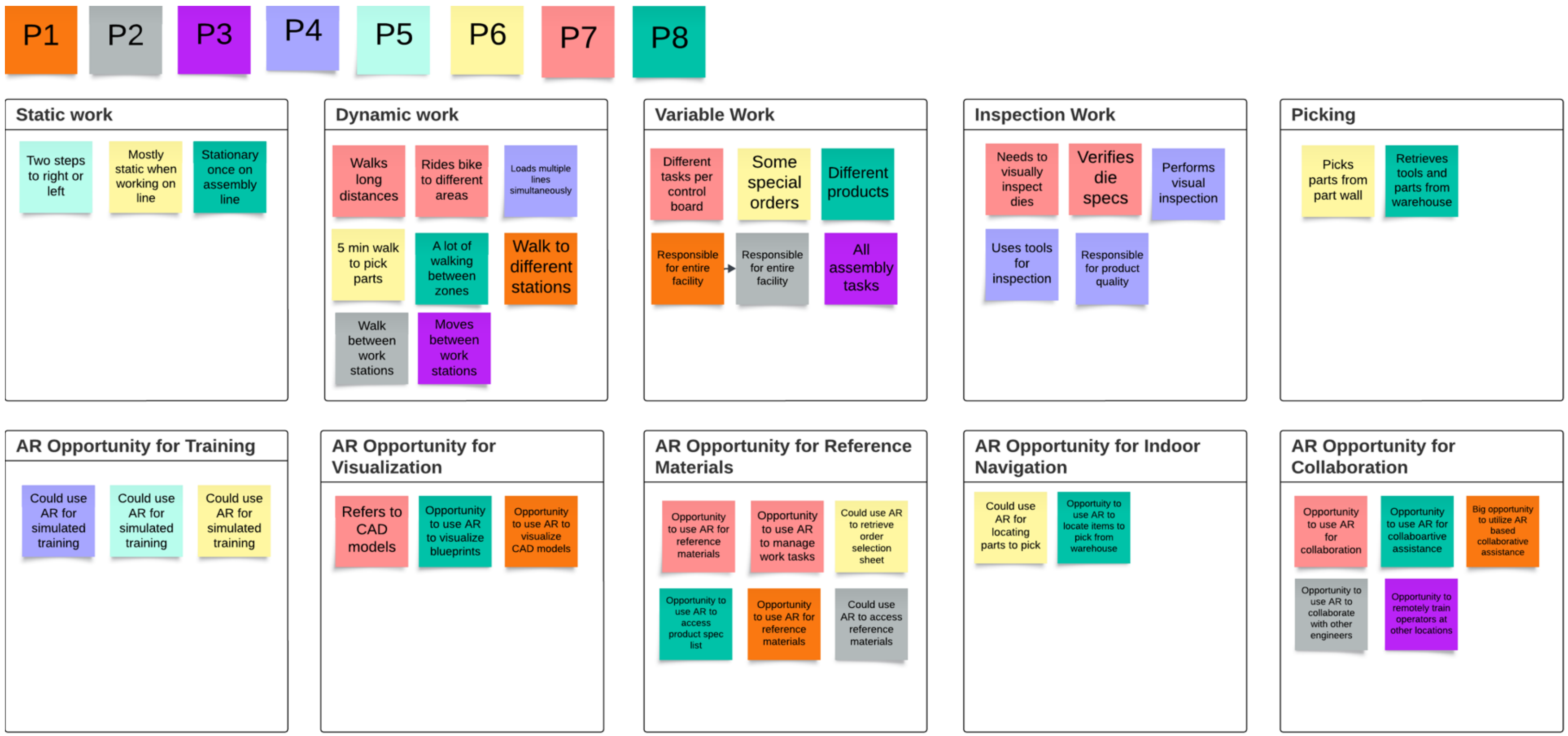
Table 4
Clustering of AR Opportunities

Participant	Training	Visualization	Reference Materials	Indoor Navigation	Collaboration
P1		X	X		X
P2			X		X
P3					X
P4	X				
P5	X				
P6	X		X	X	
P7		X	X		X
P8		X	X	X	X

The Press Operator (P5) was the only subject that performs 100% static work and does not perform any variable work, inspection work, or picking tasks. P5 also only has opportunities to use AR for training. The Assembly Operator/Trainer (P3), the Material Handler (P4), and the Picker/Order Selector (P6) all performed similar work to P5, but with more dynamic work responsibilities as well as some responsibilities for performing picking and inspection activities. The remaining participants all also performed mostly dynamic/variable work with AR opportunities beyond training. There is much overlap between P1/P2 and P6, P7, and P8 overlap; however, P1 and P2 are not directly involved with production.

Figure 12

Affinity Diagram



4.6 Archetype Profiles

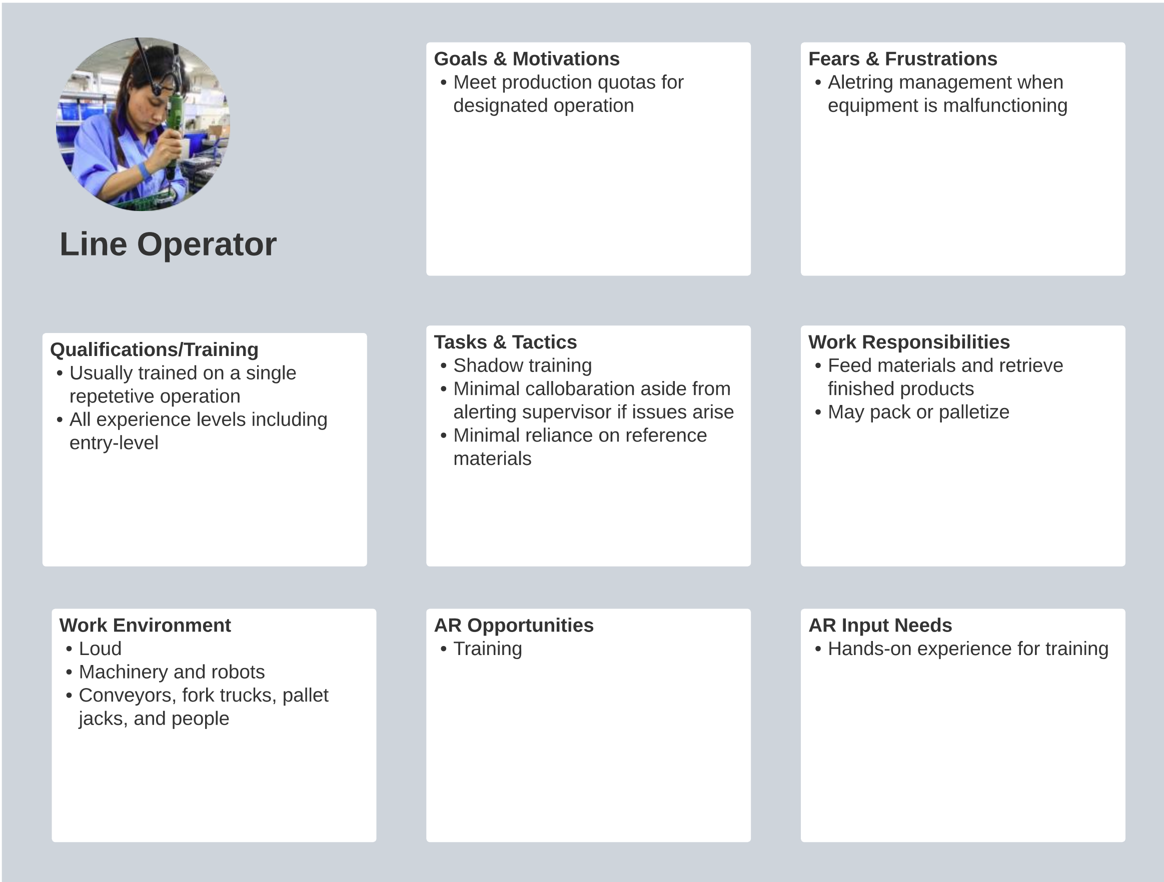
Four key user archetypes for manufacturing workers who could benefit from augmented reality were identified: the line operator, the flexible line worker, the skilled technician, and the manufacturing engineer.

4.6.1 Line Operator

The line operator archetype includes frontline workers who primarily perform very routine and standardized work. The line operator will mainly work at one work station with minimal product variations and is primarily focused on meeting production quotas. Training usually involves a review of standard operations procedures (SOPs) followed by shadow training in real time. The work tasks for the line operator include basic feed and retrieve tasks and possibly some packing and palletizing work. If an equipment or quality issue arises, the line operator will usually alert a supervisor and wait for a resolution. The line operator usually works in a busy work environment with loud noises coming from machinery and robots as well as a lot of traffic and movement including conveyors, fork trucks, pallet jacks, and other people. The AR opportunities for the line worker are usually limited to simulated training, where hands-on interaction with digital content is necessary, since the line operator usually does not need to perform complex work or collaborate with others when problems arise. The archetype profile for the line operator is shown in Figure 13.

Figure 13

Line Operator Archetype Profile



4.6.2 Flexible Line Worker

The flexible line worker usually performs similar work as the line operator, but with added job responsibilities. Unlike the line operator, the flexible line worker isn't usually confined to one work station or area. In addition to being cross-trained on multiple operations, the flexible line worker may work on mixed model lines or assembly processes with custom orders. The flexible line worker may also have some picking and inspection responsibilities. The flexible line worker may also be required to refer to reference documents, especially when monitoring product quality and production throughput. The flexible line worker usually works in a similar loud and busy environment as the line operator. Regarding AR opportunities, the flexible line worker could use AR not only for training but also for training, visualization, navigation, inspection, and assembly use cases. Similar to the line operator, the flexible line worker would prefer to not have to use an external input device and is unlikely to need the level of precision and control provided by a controller or stylus. The archetype profile for the flexible line worker is shown in Figure 14.

Figure 14

Flexible Line Worker Archetype Profile

4.6.3 Skilled Technician

The skilled technician spends the majority of their time maintaining equipment and troubleshooting production and quality issues. Although the skilled technician usually shares the same loud and busy work area as the line operator and the flexible line worker, they may also spend time working in machine shops or dedicated repair areas. The skilled technician usually holds some sort of trade certification and generally works at a higher level than either the line operator or the flexible line worker. The nature of the skilled technician's work leads to several opportunities for AR, including remote assistance, visualization, maintenance, guidance, collaboration, inspection, and assembly use cases. Just like the line operator and the flexible line worker, the skilled technician would prefer to not have to carry an external input device, especially when using the AR HMD while performing hands-on work. The skilled technician may have some needs for higher precision control, specifically when viewing CAD models or when performing marker placement and annotations during remote assistance sessions, which may warrant the need to use a controller or stylus. The archetype profile for the skilled technician is shown in Figure 15.

Figure 15

Skilled Technician Archetype Profile

4.6.4 Manufacturing Engineer

The manufacturing engineer performs the most advanced and complex work out of the four identified archetypes. The manufacturing engineer generally holds a college degree with several years of professional experience. Like the skilled technician, the manufacturing engineer is also primarily concerned with limiting production disruptions and ensuring product quality and throughput; however, they are also responsible for commissioning new equipment and for optimizing manufacturing processes. The manufacturing engineer will access CAD models and reference materials more than the skilled technician. The manufacturing engineer will also perform a higher level of collaborative work. Of the identified archetypes, the manufacturing engineer has the most opportunities to use AR including for remote assistance, situational awareness, visualization, maintenance, guidance, inspection, and assembly. The manufacturing engineer would prefer not to have to charge and carry an external input device due to the large footprint in the facility and the hands-on work required. The manufacturing engineer, however, may require precision control when engaged in remote assistance or when referring to CAD models, which could require the use of a controller or stylus. The archetype profile for the manufacturing engineer is shown in Figure 16.

Figure 16

Manufacturing Engineer Archetype Profile

CHAPTER FIVE: DISCUSSION

5.1 Reflection on Selected Methodologies

This study proved that design thinking methodologies could be successfully used to build an understanding of users and user needs for emerging technologies. In particular, it was found that while one of many available ethnographic research methods can help to build an understanding of end users, a combination of methods provides the most in-depth understanding. Interviewing a frontline worker, for example, provides the opportunity to collect verbal feedback from the participant but lacks the context that can be gained by seeing or being immersed in the work environment. Conversely, being able to observe a worker in person or having access to first-person video footage collected using an HMD does not provide researchers with the opportunity to learn from speaking with participants about their work and their pain points. By combining ethnographic research methods that are more observational with those that are more conversational, we can develop a full understanding of users and their needs when interacting with the technology.

This study also confirmed how design thinking methodologies can be used for two distinct purposes when used to uncover user needs: collecting data on users (looking) and synthesizing that data into insights and findings (understanding). The methods used for collecting data on users requires collaboration with participants, either active or passive. The methods for synthesizing this data are performed without the involvement of the participants and can be either performed by the researcher individually or collaboratively in a group setting with a team of researchers.

Finally, this study served to prove how three novel design thinking techniques that were developed significantly for this study could be used to help uncover user needs. A first-person observation, which is a modified version of a fly-on-the-wall observation, allows researchers to see exactly what participants see from their vantage point with the use of the HMD's real-world cameras. This method provides a level of understanding of the participant's experience that is very difficult to achieve with a standard fly-on-the-wall observation, and is made possible by AR technology itself.

A sensory map, which is a modified empathy map, allows researchers to understand how participants use their human senses while focusing less on thoughts and emotions. When attempting to uncover user input needs when interacting with mixed-reality technologies, it is critical to understand how users rely on their senses which was significantly aided by the use of sensory maps.

Finally, the archetype profile, which is a modified version of a persona profile, allows researchers to understand different user archetypes rather than a specific fictitious individual. By focusing less on user characteristics and demographics and more on user motivations, actions, and pain points, researchers can derive conclusions about user needs for different types of people who will be using the product for similar purposes in similar environments under similar contexts of use.

5.2 User Needs When Using AR in Manufacturing Environments

One significant revelation from this study was that user input needs when using AR HMDs in manufacturing environments is highly dependent on how different archetypes will use the technology, which in turn is dependent on the complexity of the work performed by each archetype. The line worker, for example, has very little use for AR beyond simulated training, which benefits mostly from an advanced hand-tracking system. A manufacturing engineer, on the other hand, could use AR for several use cases, including remote assistance, situational awareness, visualization, maintenance, guidance, collaboration, inspection, and assembly. The manufacturing engineer would likely benefit from not needing a controller for most tasks. However, there are situations where a controller is necessary, such as when manipulating a CAD model or placing markers. One of the key findings from this study was that we cannot make a broad conclusion about which input modalities are necessary when using AR in the manufacturing environment and instead need to examine the various possible user scenarios for different user archetypes. The design thinking methodologies utilized in this study proved to be effective methods for eliciting these details.

5.3 Limitations and Future Research Opportunities

Several limitations were identified for this study. First, a small sample size of participants was utilized, providing limited coverage for the potential types of work and work environments that AR technology can be used support. For example, none of the included participants worked outdoors or solely performed quality assurance type work. Next, none of the participants had experience with a full deployment of AR technology in their work environment and were either using it for proof-of-concept purposes or had never used AR at all. This is primarily because the use of AR technology in manufacturing is still in the early stages of adoption and development.

While this limited adoption presents an opportunity for companies promoting AR technology in manufacturing, it also poses a challenge due to potential user unfamiliarity with the interface. Finally, the participants who had some experience using AR in their work environment had only used it for remote assistance and not any of the other potential use cases.

Future research includes expanding the sample size of participants in order to ensure broader coverage of the types of users and work environments being considered. Providing participants in industries beyond consumer electronics with the opportunity to use AR headsets to support their work is also likely to result in more insightful feedback during interviews. Having participants utilize the AR hardware for use cases beyond remote assistance would also help to confirm assumptions about input needs for different scenarios. Finally, the methodologies used in this study could be used after the deployment of the technology in a manufacturing facility to derive more relevant and less hypothetical insights.

5.4 Implications

This study examined the impact of applying design thinking to identify user input needs in manufacturing environments. The implications of this study extend beyond this specific application and reveal the power of understanding user needs during product development. Furthermore, the design thinking approach used in this study has the potential to influence corporate structures, particularly in breaking down silos between departments.

This study demonstrates how design thinking can serve as a catalyst for the transition from product-centered design to user-centered design. This shift encourages a more user-focused approach to innovation leading to a more integrated relationship between technology and its users. This transition represents a substantial change in how corporations approach product development. It signifies a movement away from a strict focus on technology towards a more user-centered and empathetic approach, fostering collaboration between departments such as product development and marketing. Instead of siloed approaches focusing on individual product features, this shift demands a holistic perspective, uniting different departments to collectively address and meet user needs.

CHAPTER SIX:
CONCLUSION

The design thinking methods utilized in this study effectively facilitated the identification of user archetypes and for defining user needs when using augmented reality in manufacturing environments. The eight participants in this study each participated in one or more ethnographic research methods in order to uncover user input needs, including contextual inquiries, first-person observations, and interviews. Participants who took part in multiple exercises (first-person observation + interview or first-person observation + interview + contextual inquiry) provided the most useful insights as each subsequent ethnographic research method built on the learnings from the previous method.

Several novel techniques were introduced in this study, including first-person observations, sensory maps, and archetype profiles. While these techniques are adaptations of conventional design thinking methodologies, this study demonstrated their efficacy as successful tools for uncovering user needs for this type of application. The first-person observation, in particular, expands the design thinking toolkit by providing a level of insight that is enabled by AR technology itself.

The outcomes of this study serve as an example of a paradigm shift from a product-centered design approach to a user-centered design approach. Design thinking proves to be an ideal fit for uncovering user needs for an innovation that is still seeking mass adoption. Design thinking serves as a valuable framework for tailoring a technological innovation to the specific needs of its target users, especially in an emerging market effectively improving the alignment with user needs and promoting enterprise adoption.

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APPENDIX A: IRB APPROVAL LETTERS

wcg IRB

1019 39th Ave SE / Suite 120
Puyallup, WA 98374
855-818-2289
www.wcgirb.com

December 14, 2022

Mohammad Jeelani, B. EnvD., MSIE
[redacted]

Dear Mohammad Jeelani:

SUBJECT: IRB EXEMPTION—REGULATORY OPINION
Sponsor Contact: Mohammad Jeelani, B. EnvD., MSIE
Sponsor Protocol No.: RR 139
Protocol Title: Comparative analysis of human input modalities for augmented reality applications

This is in response to your request for an exempt status determination for the above-referenced protocol. WCG IRB's IRB Affairs Department reviewed the study under the Common Rule and applicable guidance.

We believe the study is exempt under 45 CFR § 46.104(d)(3), because this research involves behavioral interventions in conjunction with the collection of information through verbal or written responses or audiovisual recording; subjects will prospectively agree to the intervention and information collection; the behavioral interventions are brief in duration, harmless, painless, not physically invasive, and not likely to have a significant adverse lasting impact on the subjects; the investigator has no reason to think the subjects will find the interventions offensive or embarrassing; any disclosure of the human subjects' responses outside the research would not reasonably place the subjects at risk or criminal or civil liability or be damaging to the subjects' financial standing, employability, educational advancement, or reputation; and the research does not involve deceiving the subjects regarding the nature or purposes of the research.

This exemption determination can apply to multiple sites, but it does not apply to any institution that has an institutional policy of requiring an entity other than WCG IRB (such as an internal IRB) to make exemption determinations. WCGIRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions. You are responsible for ensuring that each site to which this exemption applies can and will accept WCG IRB's exemption decision.

WCG IRB's determination of an Exemption only applies to US regulations; it does not apply to regulations or determinations for research conducted outside of the US. Please discuss with the local IRB authorities in the country where this activity is taking place to determine if local IRB review is required.

Please note that any future changes to the project may affect its exempt status, and you may want to contact WCG IRB about the effect these changes may have on the exemption status before implementing them. WCG IRB does not impose an expiration date on its IRB exemption determinations.

If you have any questions, or if we can be of further assistance, please contact Lindsay A. Abraham, J.D., C.I.P., at 360-252-2862, or e-mail RegulatoryAffairs@wirb.com.

LAA:hp
D3-Exemption-Jeelani (12-14-2022)
cc: WCG IRB Accounting
WCG IRB Work Order #1-1612940-1

RADFORD UNIVERSITY

Research Compliance Office

Institutional Animal Care and Use Committee / Institutional Review Board

January 30, 2023

TO:	Margaret Konkel, MFA
RE:	Radford Acknowledgment of IRB Approval
STUDY TITLE:	Comparative Analysis of Human Input Modalities for Augmented Reality Applications
IRB REFERENCE #:	RR 139

The Radford University Institutional Review Board (IRB) acknowledges the WCG IRB review and approval of the IRB submission for the above-referenced study.

The Radford University IRB would like to thank you for your hard work and for keeping us informed.

Good luck with this project!

Radford University Institutional Review Board
Irb-iacuc@radford.edu
https://www.radford.edu/content/research-compliance/home.html

Cc: Mohammad Jeelani, B. EnvD., MSIE

RADFORD UNIVERSITY

Institutional Review Board (IRB) Institutional Authorization Agreement

Name of Institution or Organization Providing IRB Review (Institution/Organization A):
WCG IRB
IRB Registration # IRB00000533 Federalwide Assurance (FWA) # N/A

Name of Institution Relying on the Designated IRB (Institution B):
Radford University
IRB Registration # IRB00001142 Federalwide Assurance (FWA) # FWA00004850

The officials signing below agree that Radford University may rely on the designated IRB for review and confirming oversight of its human subjects research described below: (*check one*):

(__) This agreement applies to all human subjects research covered by Institution B's FWA.

(X) This agreement is limited to the specific protocol(s):
Name of Research Project: Comparative analysis of human input modalities for augmented reality applications
Name of Principal Investigator: Mohammad Jeelani, B. EnvD., MSIE
Sponsor or Funding Agency (*if any*): N/A

(__) Other (*please describe*): ____________________

The review conducted by the designated IRB will meet the human subjects protection requirements of Institution B's OHRP-approved FWA. The IRB at Institution/Organization A will follow written procedures for reporting its findings and actions to appropriate officials at Institution B. Relevant minutes from IRB meetings will be made available to Institution B upon request. Institution B remains responsible for ensuring compliance with the IRB's determinations and with the terms of its OHRP-approved FWA. This document must be kept on file by both parties and provided to OHRP upon request.

Signature of Signatory Official (Institution/Organization A):

____________________ Date: 19-Dec-2022 | 12:27 PM PST

Print Full Name: R Bert Wilkins JD MHA CIP Institutional Title: Regulatory Chair Director

NOTE: The IRB of Institution A may need to be designated on the OHRP-approved FWA for Institution B.

Signature of Signatory Official (Institution B):

____________________ Date: ____________________

Print Full Name: Dr. Jeanne Mekolichick Institutional Title: Institutional Official and

APPENDIX B: DATA COLLECTION FORMS

Appendix B1: First-Person Observation Data Collection Form

First Person Observation	
User	
Performed Tasks	
Successes	
Failures	
Notes	

Appendix B2: Interview Questions

User Profile:

1. What is the title of your position?
2. What are your responsibilities at work?

3. Did you need a degree, certification or safety qualifications for the position?
4. Demographics:
a. Age:
b. Gender:
c.

User Tasks:
5. Please walk us through the work you do. Specific steps are welcome.

Environment:
6. Please describe your work environment.

7. How big is your work space?
a. Ceiling height?

8. What is the temperature in your work environment?

9. Please describe the lighting in your work environment.
a. Are there any reflective surfaces in your workspace?
b. Are there any windows around your workspace?

10. What sounds are present in your work environment?

11. Do you know if Wi-Fi is available in your work environment?
12. Do you know if you have cell service in your work environment?

13. Are there any Bluetooth connected devices you use?

14. Do you primarily work stationary or do you walk and move to other areas?
a. Do you sit or stand?
b. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?
a. Where are those items relative to eye level? Are you looking up, down?
b. How close are you to the object you are focusing on?
c. Are things color coded?
d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don't focus on)

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)

18. What do you wear when you work?
a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)
a. Which hazards are you protecting from?

20. Do you wear corrective lenses?
a. If they wear safety glasses and corrective lenses, how do those integrate?

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

22. What types of assistance or collaboration do you require from your manager or supervisor?

Reference Materials / Databases / Computer station or Portable devices

23. Are there standard operating procedures documented for the tasks you perform?

24. What is the format of these SOP's and where are they stored?

25. How often do you refer to these SOP's?

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

a. What sw do you use? What do you use it for?
b. Do you type on a keyboard for any of your tasks?

Training

27. Please describe how you were trained to do your job?

28. What types of practice opportunities did you have before being allowed to work in full production?

29. What training materials were utilized during your training (videos, documents, etc.)?

Tools

30. What types of tools and equipment do you use while you work?

31. Are you required to carry any weight? If so, how much max?

32. What are all of the things you need to touch while you work?

33. How do you transport and/or temporarily store these items while you work?

34. Where are these items stored at the end of your work shift?

Variability of Work

35. Are there product variations that you have to manage?

36. If so, how are product variations communicated to you?

Pain and Discomfort

37. What body parts do you experience pain or discomfort with at the end of your work shift?

38. How would you rate the severity of the pain and discomfort you experience?

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?

Appendix B3: Interview Collaboration Board Template

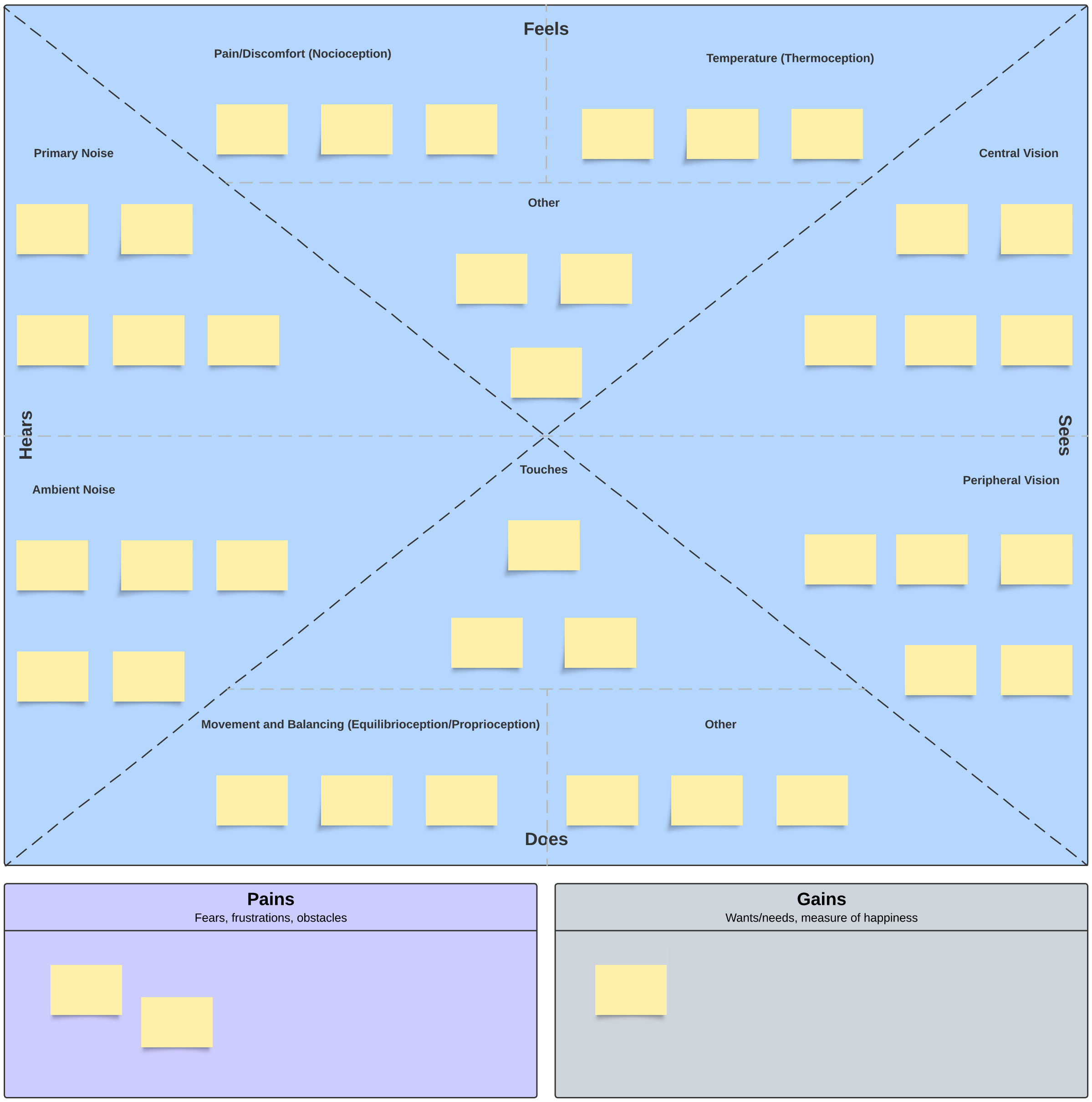
1. Who are you?
2. What do you do?
3. Where do you do it?
4. If you need help...
5. Reference materials
6. Training
7. Tools
8. Variability
9. How do you feel?

Appendix B4: Sensory Analysis Data Collection Form – Contextual Inquiry

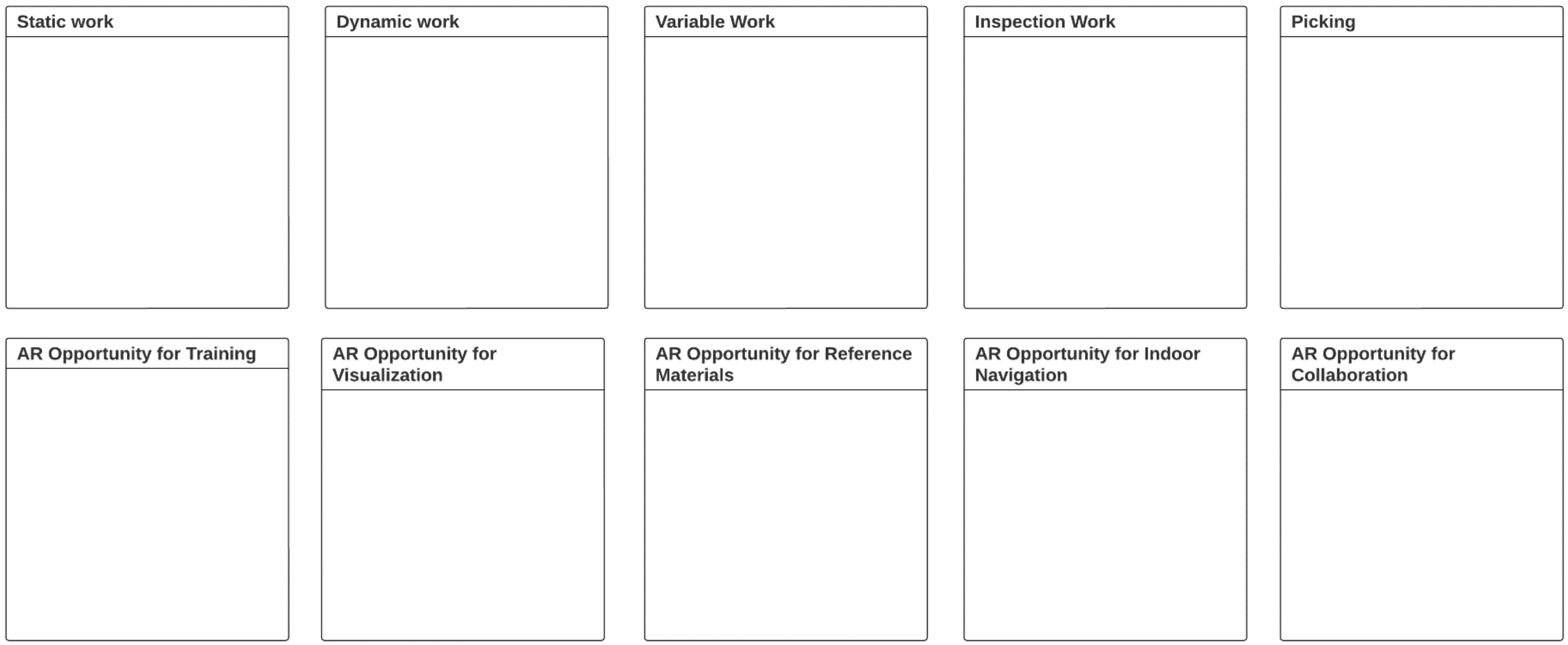
Sensory Analysis		
	Task 1	Task 2
Sight		
Touch		
Hearing		
Smell		
Taste		
Thermoception		
Nocioception		
Equilibrioception		
Proprioception		
Notes:		

APPENDIX C: ARTIFACT TEMPLATES

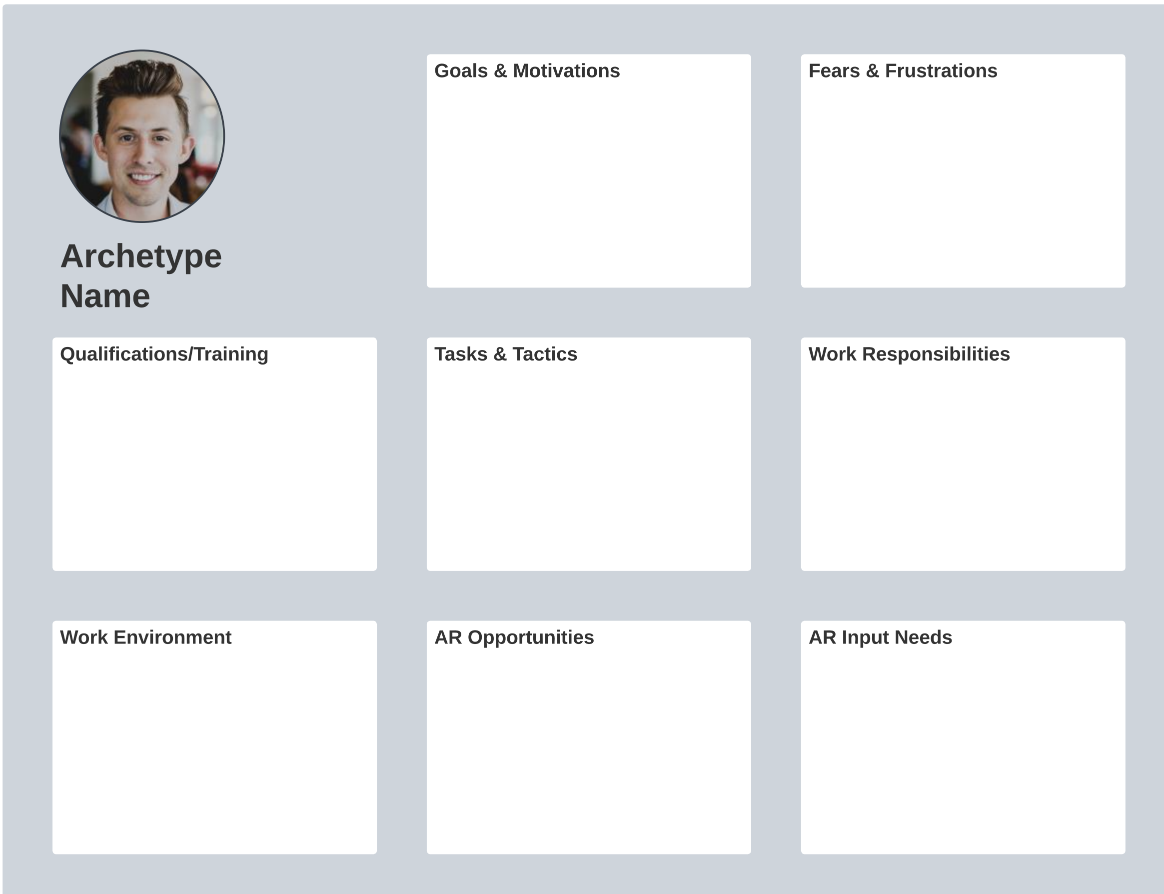
Appendix C1: Sensory Map Template



Appendix C2: Affinity Diagram Template



Appendix C3: Archetype Profile Template



APPENDIX D: FIRST-PERSON OBSERVATION DATA

Appendix D1: P1 First-Person Observation Data

First Person Observation	
User	P1
Performed Tasks	• Review of workstation changes • Troubleshooting product technical issue
Successes	• Walkthrough was effective for showing the rest of the org recent changes made to workstations • “See what I see” feature helpful for troubleshooting issue with remote desktop user
Failures	• Text input slow with controller • Some WIFI issues encountered • Having to put controller down when needing to use hands
Notes	

Appendix D2: P2 First-Person Observation Data

First Person Observation	
User	P2
Performed Tasks	Facility walkthrough
Successes	• Providing remote desktop user with facility tour • Pointing to objects with controller ray • Placing markers on different pieces of equipment and product features • Entering annotation text
Failures	• Observed switching hands when holding controller and needing to use dominant hand
Notes	

APPENDIX E: INTERVIEW RESPONSES

Appendix E1: P1 Interview Responses

User Profile:

1. What is the title of your position?
   Principal mfg. test engineer

2. What are your responsibilities at work?
   Cover different grounds
   Cover all aspects of wearable
   Does not do calibration portion
   Work with fixtures for subassembly
   HQ ships items and replicate setups and Gauge R&R
   Not deviating from the process, work with the local teams for maintenance and tools
   Run the station
   Sometimes code related, see if sensors are working
   Update

3. Did you need a degree, certification or safety qualifications for the position?
   Bachelors in computer software
   Intro knowledge Six sigma
   There is some training but different as test engineers working for ML.
   Only a couple of things to sign
   Insurance
   Layout of the floor, safety exits, ESD training, ISO training

4. Demographics:

a. Age: 38

b. Gender:

User Tasks:

5. Please walk us through the work you do. Specific steps are welcome.

Environment:

6. Please describe your work environment.
    - SW related and can remote in, in a small office steps away from the mfg. floor. Crucible space for 11
    - On the floor

7. How big is your work space?
    - Office space in meters = 5 x 8
    - 3 or 4 basketball courts

8. What is the temperature in your work environment?
- OS: 22-28C
- 20-22C
    - We need to have a controlled environment in terms of humidity and temperature
- 30% humidity

9. Please describe the lighting in your work environment.
   Artificial white light on mfg. floor
   In mfg. you we have a lot of light above the head of the operator

a. Are there any reflective surfaces in your workspace?
    i. Sometimes there may be a lot of screens for calibrators to check and station to be running
    ii. Translucent white boards (1.5)
        1. At the end of the aisles
    iii. Glass to split cubicles in office

b. Are there any windows around your workspace?
    .none

c. Dark rooms or environments

10. What sounds are present in your work environment?
   Really loud, due to cleaning station which cleans the devices. Air gun around 70dbs.
   The quiet days 60dB
      AC running, humming of the machines, and equipment that is on
   Everyone working 80dB
   Office is quite around 40dB
      No machines or AC
   Quiet area around the audio area. Signage is posted to keep volume at a minimum

11. Do you know if WIFI is available in your work environment?
    Yes - most part its ok
    ~40 access points
    There is a corner which has a lot of machinery which may cause the dropping.
    4 access points and cellular

12. Do you know if you have cell service in your work environment?
    Yes - good

13. Are there any Bluetooth connected devices you use?
    Yes - can walk about 10 meters away with mobile headset

14. Do you primarily work stationary or do you walk and move to other areas?
    a. Do you sit or stand?
       i. Usually Walk around. Different process running so checking sub assembly to sub assembly
    b. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?
    a. Where are those items relative to eye level? Are you looking up, down?
    b. How close are you to the object you are focusing on?
    c. Are things color coded?
    d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don't focus on)
    - Hard to move around due to lack of peripheral vision

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)
    - mostly people walking around
    - Moving tarps and items on trays
    - Environment could be crowded with carts and people

18. What do you wear when you work?
    a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)

a. Which hazards are you protecting from?

20. Do you wear corrective lenses?

a. If they wear safety glasses and corrective lenses, how do those integrate?

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

22. What types of assistance or collaboration do you require from your manager or supervisor?

- Sends picture
-

Reference Materials / Databases / Computer station or Portable devices

23. Are there standard operating procedures documented for the tasks you perform?

- Some slides and documents on Google Drive for setup on how to calibrate and start equipment
- List of commands
- How do you access: usually have laptop close to the station.

24. What is the format of these SOP's and where are they stored?

25. How often do you refer to these SOP's?

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

a. What sw do you use? What do you use it for?

b. Do you type on a keyboard for any of your tasks?

Training

27. Please describe how you were trained to do your job?

28. What types of practice opportunities did you have before being allowed to work in full production?

29. What training materials were utilized during your training (videos, documents, etc.)?

Tools

30. What types of tools and equipment do you use while you work?
   - Laptop
   - Borrow tooling
     - Stored in lockers in the area
     - Hard to find because the mfg. space always changes
     - Not the only user
   - How do you know what tool you need?
     - A lot of times things aren't labels and then its trial and error
   - QR code scanner to transmit text to comp
   - Cell phone for video call

31. Are you required to carry any weight? If so, how much max?
    Just when setting up the stations and moving fixtures
    10-60lbs

32. What are all of the things you need to touch while you work?
    Calibrators, computer, fully assembled units,
fixtures.

33. How do you transport and/or temporarily store these items while you work?

34. Where are these items stored at the end of your work shift?

Variability of Work

35. Are there product variations that you have to manage?

36. If so, how are product variations communicated to you?

Pain and Discomfort

37. What body parts do you experience pain or discomfort with at the end of your work shift?
    Legs from walking around. Could walk 20km
    Concrete flooring

38. How would you rate the severity of the pain and discomfort you experience?

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?

Appendix E2: P2 Interview Responses

User Profile:

1. What is the title of your position?
   Mfg. test engineer
2. What are your responsibilities at work?
   - NPI engineer (new product intro)
     - When tests arrive mechanical and electrical
   - 2 years to do all installation
   - Calibration
   - Maintenance
     - Equipment delivered from production
     - More expertise
       - Ex robot crashes. Very long
   - Goal = good numbers for yield and on time equipment
   - Yield is the pressure

3. Did you need a degree, certification or safety qualifications for the position?
   - EE, main role is mechatronic

4. Demographics:

a. Age: 54

b. Gender:

c.

User Tasks:

5. Please walk us through the work you do. Specific steps are welcome.

Environment:

6. Please describe your work environment.
   - Mfg. floor (90% or more)
   - Small office outside the plant
   - Similar role but focuses on device flashing at the end of the line which

7. How big is your work space?
   Approx. 100 x 80 meters
   15-meter ceiling

8. What is the temperature in your work environment?

21C

9. Please describe the lighting in your work environment.
A lot of fluorescent lights on ceiling (500 - 600 lux)
Assembly line they have task lighting at the bays
Inside the test cell there are targets (big light screen) underneath black drapes
Testing totem for CV accuracy

a. Are there any reflective surfaces in your workspace?
Tables are black and have some sort of plastic that reflects

b. Are there any windows around your workspace?
none

10. What sounds are present in your work environment?
Some noise but not that bad
Robot makes noises
Air pressure
Not bad, usually we don't have problems with headphones

11. Do you know if WIFI is available in your work environment?
Different complaints, IT install many Access points in high position
IT had to rectify poor signal recently

12. Do you know if you have cell service in your work environment?
Not that good. If you walk to the center of the plant, cell signal is very poor.
5G just started getting implemented but most people have 4G.

13. Are there any Bluetooth connected devices you use?
Currently wearing Bluetooth
Totems are Bluetooth so it has to work

14. Do you primarily work stationary or do you walk and move to other areas?

a. Work where the problems are, works in different stations

b. Do you sit or stand?

i. When I am executing at a station I am standing

c. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?

a. Where are those items relative to eye level? Are you looking up, down?

b. How close are you to the object you are focusing on?

c. Are things color coded?

i. Robot is orange

ii. Yes, most things are black, but labels are colored yellow, orange,

iii.

d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)

Not necessarily, bar codes and scanner

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don't focus on)

Focus on one thing, not really tracking peripherals

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)

In the factory there is a lot of activity

People walking around with wearables, tables,

18. What do you wear when you work?

a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)

Inside you need ESD coat

Shoe strips for ESD

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)

a. Which hazards are you protecting from?

20. Do you wear corrective lenses?

a. If they wear safety glasses and corrective lenses, how do those integrate?

i. Safety glasses and

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

Usually work close to HQ

Google chat

Check model A6

22. What types of assistance or collaboration do you require from your manager or supervisor?

How to fix and verify a constructed mechanical component

Reference Materials / Databases / Computer station or Portable devices

23. Are there standard operating procedures documented for the tasks you perform?

- All mfg. ISO 9000 has to pass operation procedures

24. What is the format of these SOP's and where are they stored?

- ME or Test engineers describe the procedure in chat etc.

25. How often do you refer to these SOP's?

- SOP are for operators not engineers
- ML owns the procedures which he abides to

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

a. What sw do you use? What do you use it for?

b. Do you type on a keyboard for any of your tasks?

Training

27. Please describe how you were trained to do your job?

- Communicate with colleagues in plantation
- Use to go to Covid
- Apprenticeship
- For operating a robot, it takes a while to train.

28. What types of practice opportunities did you have before being allowed to work in full production?

29. What training materials were utilized during your training (videos, documents, etc.)?

- Data base for test referencing. Link copied to LSboard google sheets with links to slides

Tools

30. What types of tools and equipment do you use while you work?

31. Are you required to carry any weight? If so, how much max?

32. What are all of the things you need to touch while you work?
Wiring, screwdrivers, measuring tape

33. How do you transport and/or temporarily store these items while you work?

34. Where are these items stored at the end of your work shift?

Variability of Work

35. Are there product variations that you have to manage?

36. If so, how are product variations communicated to you?

Pain and Discomfort

37. What body parts do you experience pain or discomfort with at the end of your work shift?
    - Legs due to standing and walking around
    - Back hurt a little when they do assembly

38. How would you rate the severity of the pain and discomfort you experience?

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?

Appendix E3: P4 Interview Responses

User Profile:

1. What is the title of your position?

Product manufacturer / press operator

Material handler

2. What are your responsibilities at work?

Feed materials to robots - stamping
Aluminum sheets, screws, parts for doors and windows
Parts stored on racks and bins
Clean and maintain robots

3. Did you need a degree, certification or safety qualifications for the position?

Safety training for new lines

4. Demographics:
a. Age: 43
b. Gender:
c.

User Tasks:
5. Please walk us through the work you do. Specific steps are welcome.

Door line:
Pick up materials from bins
Feed them into robots
Hit button
Green and white lights tell when more parts are needed

Environment:
6. Please describe your work environment.
Stamping on one side, assembly on the other
Bins staged by other workers

Conveyor belts moving parts

7. How big is your work space?
   1300-1400 employees
   Open assembly area

8. What is the temperature in your work environment?
   No AC
   Dock doors open
   Cold in winter
   15 to 20 degrees hotter in summer than outside

9. Please describe the lighting in your work environment.
   a. Are there any reflective surfaces in your workspace?
      Mirrors in inspection area
   b. Are there any windows around your workspace?
      Some natural light
      LED lights
      Motion lights
      Task lighting for inspection

10. What sounds are present in your work environment?
    Very loud (hearing protection)
    Presses (20) can be heard in assembly area
    Robots send auditory signal - ice cream truck sound when line is down
    Personal radios

11. Do you know if WIFI is available in your work environment?

    Good WIFI signal

12. Do you know if you have cell service in your work environment?

    Good cell signal except for Verizon

13. Are there any Bluetooth connected devices you use?

    People use Bluetooth headphones and speakers
    Scanners used to be used

14. Do you primarily work stationary or do you walk and move to other areas?
Walk to different

a. Do you sit or stand?

Stand

b. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?
Front: Robot
Side: parts bin

a. Where are those items relative to eye level? Are you looking up, down?
All

b. How close are you to the object you are focusing on?
Near and far

c. Are things color coded?
Red/orange light - loading too slow
White/green light - Safe to load

d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)
Read tickets on racks

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don't focus on)
Fork truck traffic
Parts quantities

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)
Busy - people, fork trucks, parts bins, conveyors

18. What do you wear when you work?

a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)
No leggings (jeans)
Leather shoes
Not required to tuck in or tie hair

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)

Safety glasses w/ side shields
Sleeves
Gloves
Ear plugs/muffs

a. Which hazards are you protecting from?

Lacerations

20. Do you wear corrective lenses?

a. If they wear safety glasses and corrective lenses, how do those integrate?

Prescription safety glasses

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

Yell or text

22. What types of assistance or collaboration do you require from your manager or supervisor?

Running out of ticket paper, materials not delivered by tugger drive, fan broken
Defects

Reference Materials / Databases / Computer station or Portable devices

23. Are there standard operating procedures documented for the tasks you perform?

SOP at every station

24. What is the format of these SOP's and where are they stored?

Binder with plastic covering

25. How often do you refer to these SOP's?

Mainly when first starting on a line
When making workplace improvement suggestions

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

Paperwork that needs to be filled out when performing inspections - diagram of the part with all of the things to look for
Log glue expiration dates

a. What sw do you use? What do you use it for?
None

b. Do you type on a keyboard for any of your tasks?
None

Training

27. Please describe how you were trained to do your job?
Review SOP
Team lead demonstrate
New line - documents, videos, test (in conference room)

28. What types of practice opportunities did you have before being allowed to work in full production?
Live practice

29. What training materials were utilized during your training (videos, documents, etc.)?
Videos, documents, SOP

Tools

30. What types of tools and equipment do you use while you work?
Tool to check hole finishes
Go-no-go gauge

31. Are you required to carry any weight? If so, how much max?
Parts being loaded - light aluminum parts

32. What are all of the things you need to touch while you work?
Parts
Button to start robot (one hand)
Bins

33. How do you transport and/or temporarily store these items while you work?
Tools tethered to station so they are not lost

34. Where are these items stored at the end of your work shift?
Stored at workstation

Variability of Work

35. Are there product variations that you have to manage?
    Yes, but tooling change by technician is required

36. If so, how are product variations communicated to you?

Pain and Discomfort

37. What body parts do you experience pain or discomfort with at the end of your work shift?
    None

38. How would you rate the severity of the pain and discomfort you experience?

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?
    No

Appendix E4: P5 Interview Responses

User Profile:

1. What is the title of your position?

Press operator

2. What are your responsibilities at work?

Operate presses

3. Did you need a degree, certification or safety qualifications for the position?

No

4. Demographics:
a. Age: 35

b. Gender:

User Tasks:
5. Please walk us through the work you do. Specific steps are welcome.

Retrieve material from part to the right
Pull press down
Retrieve part
Break off extra metal
Put finished product into crate

Environment:
6. Please describe your work environment.

Large open factory
Three rows of presses, seven feet apart

7. How big is your work space?

Size of a pole barn

8. What is the temperature in your work environment?

Big industrial fan at each press

9. Please describe the lighting in your work environment.

Ceiling lights 18 feet in the air, well lit

a. Are there any reflective surfaces in your workspace?

Shiny concrete floors

b. Are there any windows around your workspace?

No.

10. What sounds are present in your work environment?

Extremely loud. Boiler room, presses, forklifts.

11. Do you know if WIFI is available in your work environment?
Hasn’t tried

12. Do you know if you have cell service in your work environment?
Certain spots near outer walls

13. Are there any Bluetooth connected devices you use?
No

14. Do you primarily work stationary or do you walk and move to other areas?
Mostly stationary, 6ft x 6ft work area. Moves two feet to left and right.

a. Do you sit or stand?
Stand

b. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?
Press
Can see other presses to left and right
Parts bin to right

a. Where are those items relative to eye level? Are you looking up, down?
Looks down (stomach level) when feeding

b. How close are you to the object you are focusing on?
Directly in front

c. Are things color coded?
Red button (emergency stop) and green button (start press)

d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)
No

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don't focus on)

Forklift traffic

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)
People behind. Other presses to the side. Forklift traffic.

18. What do you wear when you work?
a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)
Coveralls, pocket on back and at breast
Tie hair
No loose jewelry

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)
Hearing protection

Safety glasses
Steel toe boots
Gloves - thick woven material

a. Which hazards are you protecting from?
Noise, metal shards

20. Do you wear corrective lenses?
No
a. If they wear safety glasses and corrective lenses, how do those integrate?

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

Button on walkie talkie so alert supervisor (too loud to talk over walkie talkie)

22. What types of assistance or collaboration do you require from your manager or supervisor?

Machine malfunctioning

Injury

Reference Materials / Databases / Computer station or Portable devices
23. Are there standard operating procedures documented for the tasks you perform?

Yes

24. What is the format of these SOP's and where are they stored?

Printed documents in binders on wall in office for each press (numbered by press)

25. How often do you refer to these SOP's?

Rarely, only when first starting

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

No

a. What sw do you use? What do you use it for?
b. Do you type on a keyboard for any of your tasks?

Training

27. Please describe how you were trained to do your job?

Watch videos. Sit down with trainer and go through SOP for all presses. Observe trainer. Practice opportunities. Trainer works alongside for a month.

28. What types of practice opportunities did you have before being allowed to work in full production?

Full production, slower production speed

29. What training materials were utilized during your training (videos, documents, etc.)?

Videos and SOP documents

Tools

30. What types of tools and equipment do you use while you work?

Scanners
Walkie talkie

31. Are you required to carry any weight? If so, how much max?

Scrap metal box that moves,

32. What are all of the things you need to touch while you work?

Raw material, press, button on press, finished product, scanner, walkie talkie

33. How do you transport and/or temporarily store these items while you work?

Walkie talkie in back pocket

Scanner sits on flat surface on the press. Dock available. Disconnect and reconnect to scan at the end of batch.

34. Where are these items stored at the end of your work shift?

Turn walkie talkie into office. Scanner on dock at press.

Variability of Work

35. Are there product variations that you have to manage?

Same part for several days.

36. If so, how are product variations communicated to you?

Move to another press.

Pain and Discomfort

37. What body parts do you experience pain or discomfort with at the end of your work shift?

Feet

Some pain between shoulder blade (probably from bending down)

38. How would you rate the severity of the pain and discomfort you experience?

Slight

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?

Mild (finished part is hot)

Appendix E5: P6 Interview Responses

User Profile:

1. What is the title of your position?

   Picker/order selector

2. What are your responsibilities at work?

   90% - installing screws into the door
   10% - retrieving parts

3. Did you need a degree, certification or safety qualifications for the position?
   None

4. Demographics:

a. Age: 40
b. Gender:
c.

User Tasks:

5. Please walk us through the work you do. Specific steps are welcome.

Order selection sheet - given to her every morning
Go to wall with part numbers - open bin
Put parts into a tote
Bring back to station
Install on door - pneumatic driver to install

10 min process

Environment:

6. Please describe your work environment.

Assembly line
Metal desk with computer to the right
Concrete flooring
High ceiling

7. How big is your work space?
Small work space - 6x6
Entire floor - football field
a. Ceiling height?

8. What is the temperature in your work environment?
Always cold - central AC

9. Please describe the lighting in your work environment.

Fluorescent lighting on ceiling
Task lighting

a. Are there any reflective surfaces in your workspace?
Desk is reflective
Mirror on desk

b. Are there any windows around your workspace?
No

10. What sounds are present in your work environment?
Noisy environment - Line itself, tools, siren, collision

11. Do you know if WIFI is available in your work environment?
Only in break area

12. Do you know if you have cell service in your work environment?
Cell signal bad on floor

13. Are there any Bluetooth connected devices you use?
Unaware

14. Do you primarily work stationary or do you walk and move to other areas?

Stationary except for parts retrieval

a. Do you sit or stand?

Stand

b. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?

Line with overhead conveyor transporting door

a. Where are those items relative to eye level? Are you looking up, down?

All

b. How close are you to the object you are focusing on?

Arm’s length

c. Are things color coded?

No

d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)

Order sheet

Part number on bins

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don’t focus on)

Line to left to see line progress

Clock

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)

Conveyor in front

Moving machinery behind

18. What do you wear when you work?

Jeans, work shoes, shirt

a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)

Tuck in

Hair tied

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)

Vest, helmet, glasses

a. Which hazards are you protecting from?

Fork trucks

Overhead parts

20. Do you wear corrective lenses?

Contacts

a. If they wear safety glasses and corrective lenses, how do those integrate?

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

Phone on desk

Call button

22. What types of assistance or collaboration do you require from your manager or supervisor?

If line is stuck

If tools aren't working

Figure out why part isn't fitting

Reference Materials / Databases / Computer station or Portable devices

23. Are there standard operating procedures documented for the tasks you perform?

Yes

24. What is the format of these SOP's and where are they stored?

Binder on the desk at station

25. How often do you refer to these SOP's?

Rarely

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

Order sheet
Computer there, doesn't really use
Sometimes uses to request part replenishment
Report line issues

a. What sw do you use? What do you use it for?
Ping - skype

b. Do you type on a keyboard for any of your tasks?
Yes, for sending messages

Training
27. Please describe how you were trained to do your job?
1 week - video based general training including task specific videos and some demonstration
1 week - shadow a trainer

28. What types of practice opportunities did you have before being allowed to work in full production?
Full production

29. What training materials were utilized during your training (videos, documents, etc.)?
Videos

Tools
30. What types of tools and equipment do you use while you work?
Air guns
Hammer, screwdrivers, air gun attachments

31. Are you required to carry any weight? If so, how much max?
Part tote (light)

32. What are all of the things you need to touch while you work?

Air gun, screws, door, button to advance line

33. How do you transport and/or temporarily store these items while you work?

Air gun suspended, other items in bin

34. Where are these items stored at the end of your work shift?
Stay on line

Variability of Work

35. Are there product variations that you have to manage?

Yes

36. If so, how are product variations communicated to you?

Line change

Pain and Discomfort

37. What body parts do you experience pain or discomfort with at the end of your work shift?

Hands from repetitive motion
Back
Some shoulder aching

38. How would you rate the severity of the pain and discomfort you experience?
Minor

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?
Air gun can get warm

Appendix E6: P7 Interview Responses

User Profile:

1. What is the title of your position?

Skilled tool and dye team member

2. What are your responsibilities at work?

Managing 500 dyes
Repairing dyes
Engineering changes
Build dyes
Take care of new start-ups

3. Did you need a degree, certification or safety qualifications for the position?

Tool and dye journeyman's card
8 years tool and dye experience
Testing - welding, machining, hand working
Computer based test - electrical, dye components

4. Demographics:
a. Age: 27
b. Gender:
c.

User Tasks:
5. Please walk us through the work you do. Specific steps are welcome.
Preventative maintenance on dyes
-Tear down and rebuild dyes
-Check KPI's on dyes

Line support
-Opening machine
-Removing
-Inspecting
-Take dye back to shop
-Repair dye

Repair dye
-Disassemble tool
-Diagnose issue
-Record breakdown step by step
-Record repair spots
-Weld damaged areas
-Coordinate with dye manufacturing for scan data
-Final tuning and hand finish

Environment:

6. Please describe your work environment.

   Designated machining area
   Two bays side by side
   Dye store behind every line
   Tool boxes
   Tool cages
   5S everywhere
   Steel tower - 80ft tall with shelves designated for each dye
   Welding room

7. How big is your work space?
   100 yards long

a. Ceiling height?
   Very high

8. What is the temperature in your work environment?
   Cold in winter, hot in summer (90 degrees)
   Fans and portable air conditioners

9. Please describe the lighting in your work environment.

a. Are there any reflective surfaces in your workspace?
   No

b. Are there any windows around your workspace?
   No (skylight on roof)

10. What sounds are present in your work environment?
    13 press lines

11. Do you know if WIFI is available in your work environment?
    WIFI available - sometimes slow due to congestion

12. Do you know if you have cell service in your work environment?
    Good cell signal (certain providers don't get good service)

13. Are there any Bluetooth connected devices you use?
    No

14. Do you primarily work stationary or do you walk and move to other areas?
    Very mobile, going out to lines (riding bikes), retrieving tools

a. Do you sit or stand?
    Stand
  b. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?
    Shop - Dye either on ground or on work horses
    Line - Looking at dyes inside of press

a. Where are those items relative to eye level? Are you looking up, down?
    Looking down when working on dye in shop
    Dyes at eye level inside of press
  b. How close are you to the object you are focusing on?
    Very close in shop
    Looking through safety glass on line
  c. Are things color coded?
    Lugs on dyes to connect crane
    - yellow for picking up and moving
    - red for opening dye

    Green walkway (no ppe)

    Control board - diagram of line and dyes (color coded by part number)

    Color coded magnets on chart (red or green) to signify if dye is in shop

  d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)

Control board
Work order paper
Placards on dyes
Gas monitors on dyes
Binders with dye information
Caliper measurements
Micrometers

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don't focus on)

Fork truck traffic
Crane

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)

Shop is not busy aside from other tool makers and crane

Line:
Fork trucks
Blanks into press
Crane
People on line
Conveyors
Robots

18. What do you wear when you work?

Work pants, t shirt

a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)

No tuck in

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)

Welding jacket
Safety boots
Ear plugs
Glasses
Sleeves
Hard hats when running crane or on production line

a. Which hazards are you protecting from?

Laceration

Heavy parts
Welding hazards

20. Do you wear corrective lenses?

Glasses

a. If they wear safety glasses and corrective lenses, how do those integrate?

Prescription safety glasses - company provides

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

Physically find them
Use team leader's radio to call supervisor to shop or line
Send pictures and videos

22. What types of assistance or collaboration do you require from your manager or supervisor?

Get maintenance to help look at a problem
Collaborate with quality and have them check
Collaborative trouble shooting

Reference Materials / Databases / Computer station or Portable devices

23. Are there standard operating procedures documented for the tasks you perform?

Yes

24. What is the format of these SOP's and where are they stored?

Laminated printed sheets in office

25. How often do you refer to these SOP's?

Rarely, tool and dye work is not standardized

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

Control board
Dye medical book for each dye

a. What sw do you use? What do you use it for?
b. Do you type on a keyboard for any of your tasks?

Training

27. Please describe how you were trained to do your job?

4-month training
Hands-on training
Observe and practice

28. What types of practice opportunities did you have before being allowed to work in full production?
Guided practice opportunity after demonstration

29. What training materials were utilized during your training (videos, documents, etc.)?
No, only safety videos

Tools

30. What types of tools and equipment do you use while you work?
    Welders
    Grinders
    Hand tools - hammers and wrenches
    Files
    Batter powered impacts

31. Are you required to carry any weight? If so, how much max?
    Tools
    Crane for heavy steel

32. What are all of the things you need to touch while you work?
    Tools
    Dyes

33. How do you transport and/or temporarily store these items while you work?
    Top of tool box or on the outer surface of the dye

34. Where are these items stored at the end of your work shift?
    Own tool box - specific parking spot in shop
    Community tools - specific 5s location in tool crib

Variability of Work

35. Are there product variations that you have to manage?
    Yes

36. If so, how are product variations communicated to you?
    Team lead assigns work
    Retrieve ticket from control board

Pain and Discomfort

37. What body parts do you experience pain or discomfort with at the end of your work shift?
    Feet
    Back from bending over

38. How would you rate the severity of the pain and discomfort you experience?
    Minor

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?
    Yes - welding

Appendix E7: P8 Interview Responses

User Profile:

1. What is the title of your position?

   Warehouse worker

2. What are your responsibilities at work?

   Product Assembly
   Picking
   Packing

3. Did you need a degree, certification or safety qualifications for the position?

   MIL STD 248 certified

4. Demographics:

a. Age: 38, 36, 38
b. Gender:
c.

User Tasks:

5. Please walk us through the work you do. Specific steps are welcome.

   Picking
   Read sheet and find materials/tools - given at huddle
   Products scanned with handheld device and put in appropriate zone using a cart of pallet jack or forklift

   Product Assembly
   Cart manufacturing - drilling, sanding, washing

   Packing
   Taking product over to packing area
   Inspect

Environment:

6. Please describe your work environment.

   Large warehouse
   Office area
   Assembly lines
   Welding areas
   Quality centers
   Packing area

7. How big is your work space?
   200,00sq ft

a. Ceiling height?
   About 40ft

8. What is the temperature in your work environment?
   Cold air coming from dock - as low as 45F
   Very hot in summer - as high 80F
   Large industrial fans on ceiling

9. Please describe the lighting in your work environment.
   Overhead led lighting, all not on
   Task lighting for welders
   Good lighting, natural light from dock
   More high intensity lighting in assembly area

a. Are there any reflective surfaces in your workspace?
   Area by loading dock - reflective wall

   b. Are there any windows around your workspace?
      Windows

10. What sounds are present in your work environment?
    Overhead crane
    Machinery - presses and saws
    Not too loud to hold a conversation

11. Do you know if WIFI is available in your work environment?
    Yes - strong

12. Do you know if you have cell service in your work environment?
    Yes - strong

13. Are there any Bluetooth connected devices you use?
Yes - strong

14. Do you primarily work stationary or do you walk and move to other areas?
Walking when picking, walking product to packing, stationary at assembly line

a. Do you sit or stand?

Stand

b. If sit, on what? (stool, chair w/arms, chair w/o arms)

15. What do you see directly in front of you while you work?
Parts, products, tables, rollers, floor, other people
Blueprint on table

a. Where are those items relative to eye level? Are you looking up, down?
Looking down about 45 degrees

b. How close are you to the object you are focusing on?
Mostly within 5 feet

c. Are things color coded?
Warning signs
Tools - green/blue

d. Is there any text you need to read? (labels, text on parts, serial numbers, part numbers)
Picking sheet
Serial numbers on machinery
CRM on PC

16. What do you need to see around you or in peripherals? (i.e. - something you keep track of but don't focus on)
Other people on the same assembly line
People walking
Pallet jacks
Trip hazards (chords)

17. How busy is the environment around you? (people around you, conveyors, moving parts or machines)

People and machinery everywhere

18. What do you wear when you work?
a. Is there a dress code? (i.e. - Tuck in shirt, handling of long hair)
No clothing that is too dark (safety visibility)

19. What are the PPE requirements in your work environment? (gloves, hardhats, safety goggles)
Hearing protection optional in some areas, mandatory in others
Steel toe boots (optional)
Safety glasses

a. Which hazards are you protecting from?
Loud noises
Machinery
Heavy parts

20. Do you wear corrective lenses?
a. If they wear safety glasses and corrective lenses, how do those integrate?
No

Assistance

21. If you need assistance from someone else (coworker, manager, supervisor, etc.) what do you do?

In-person conversation (nearby or in office)
Email
What's app
Sharing pictures
Mostly in-person collaboration

22. What types of assistance or collaboration do you require from your manager or supervisor?

Assembly nuances for different parts (verifying assembly process)

Reference Materials / Databases / Computer station or Portable devices
23. Are there standard operating procedures documented for the tasks you perform?

Spec sheet

24. What is the format of these SOP's and where are they stored?

Printed in a binder at the station

25. How often do you refer to these SOP's?

Refer to it regularly

26. Are there any reference materials you refer to while you work (written documents, information on computer screens, etc.?)

CRM system
Blue prints (printed and digital)

a. What sw do you use? What do you use it for?

CRM software
Vizio for blueprints

b. Do you type on a keyboard for any of your tasks?

Keyboard and mouse

Training

27. Please describe how you were trained to do your job?

Trainer
Learning modules

28. What types of practice opportunities did you have before being allowed to work in full production?

29. What training materials were utilized during your training (videos, documents, etc.)?

Computer based training with videos

Tools

30. What types of tools and equipment do you use while you work?

Saws, presses, handheld scanners

31. Are you required to carry any weight? If so, how much max?

Pallet jack used for heavy objects

32. What are all of the things you need to touch while you work?

Parts, tools

33. How do you transport and/or temporarily store these items while you work?
At workstation

34. Where are these items stored at the end of your work shift?
Mostly stays at work station
Portable device stored at dock

Variability of Work

35. Are there product variations that you have to manage?

36. If so, how are product variations communicated to you?

Pain and Discomfort

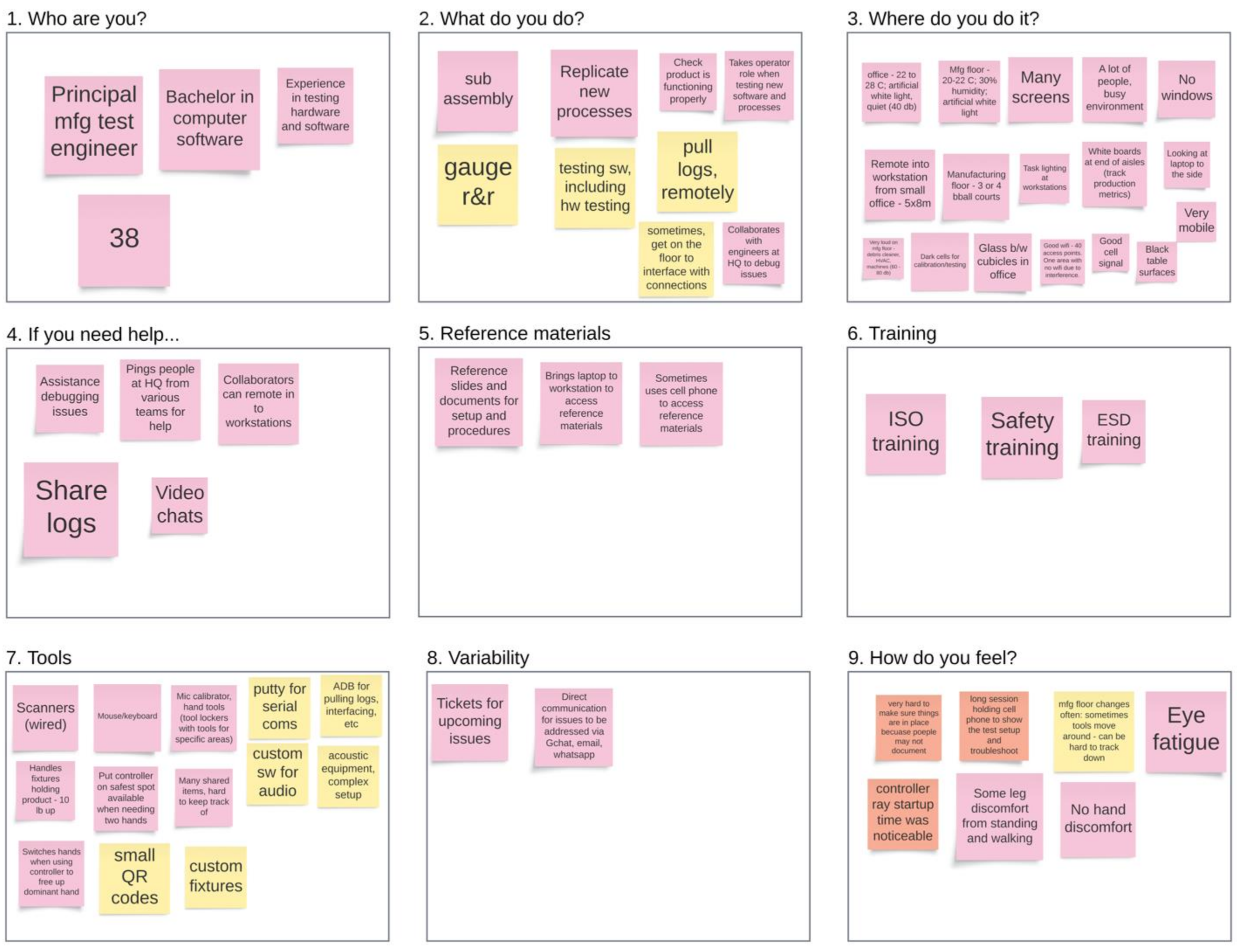
37. What body parts do you experience pain or discomfort with at the end of your work shift?
Hands and arms

38. How would you rate the severity of the pain and discomfort you experience?
Significant

39. Do you ever feel heat on your hands from the tools, equipment or parts you touch?
Not much (gloves help)

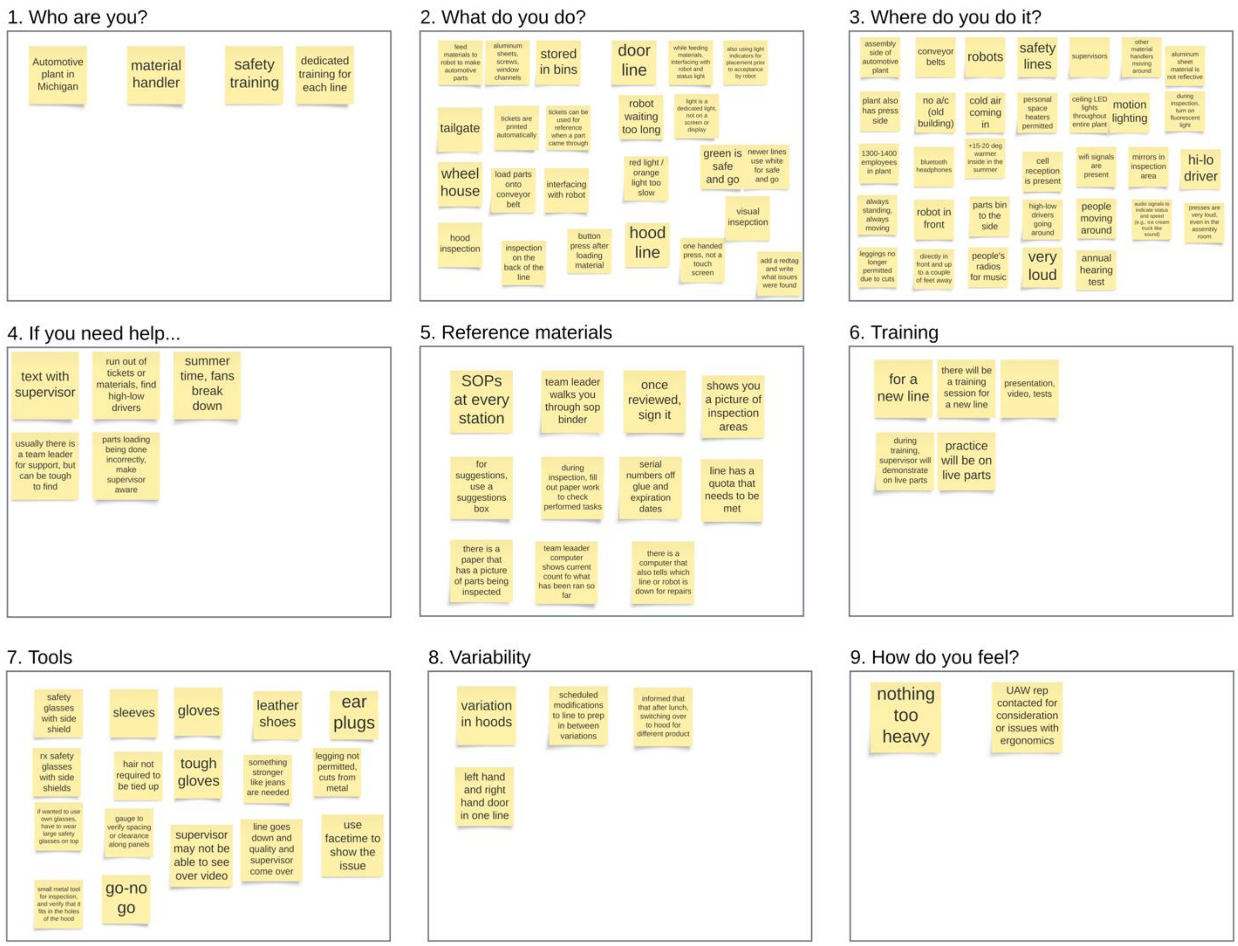
APPENDIX F: INTERVIEW COLLABORATION BOARDS

Appendix F1: P1 Interview Collaboration Board

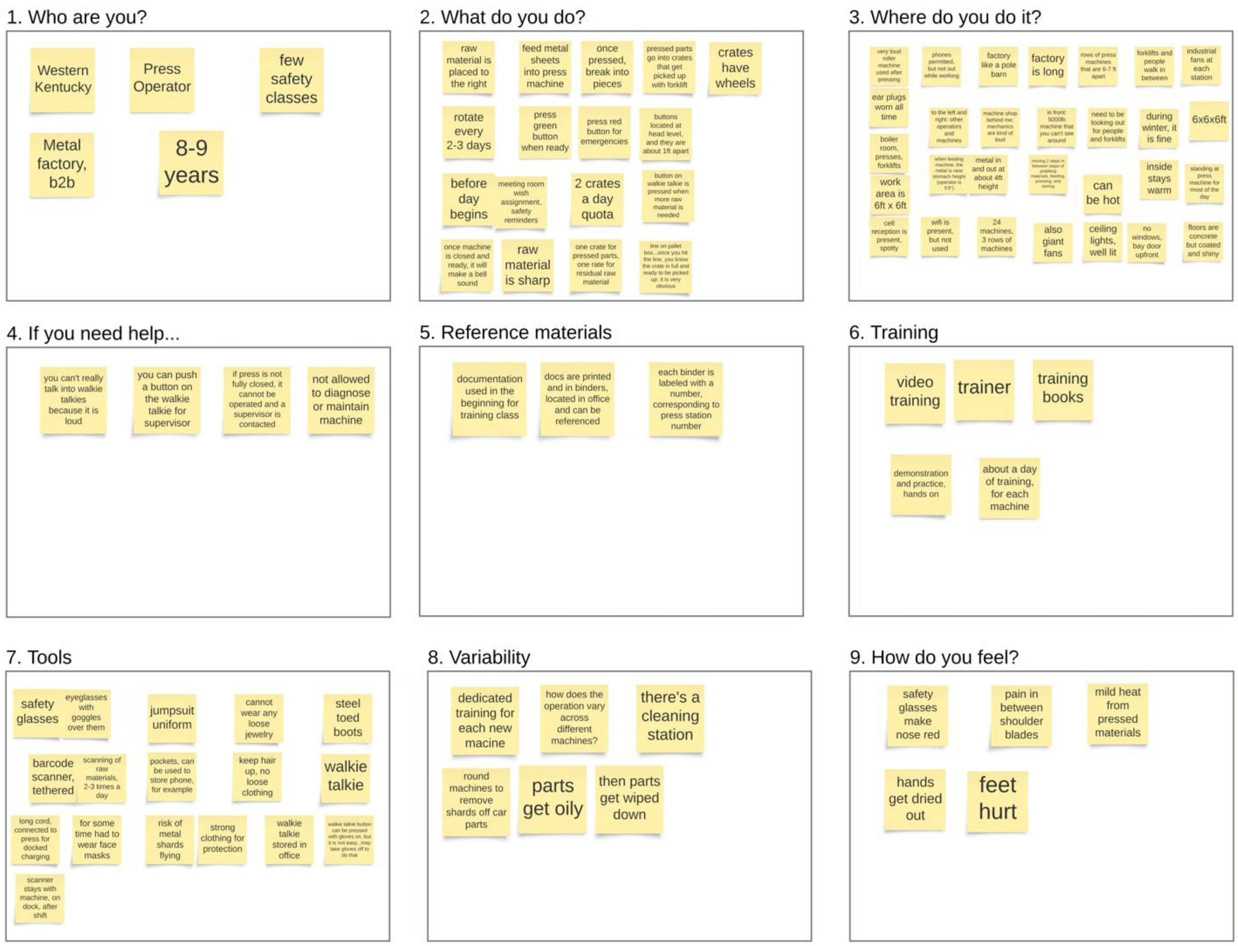


Appendix F2: P2 Interview Collaboration Board

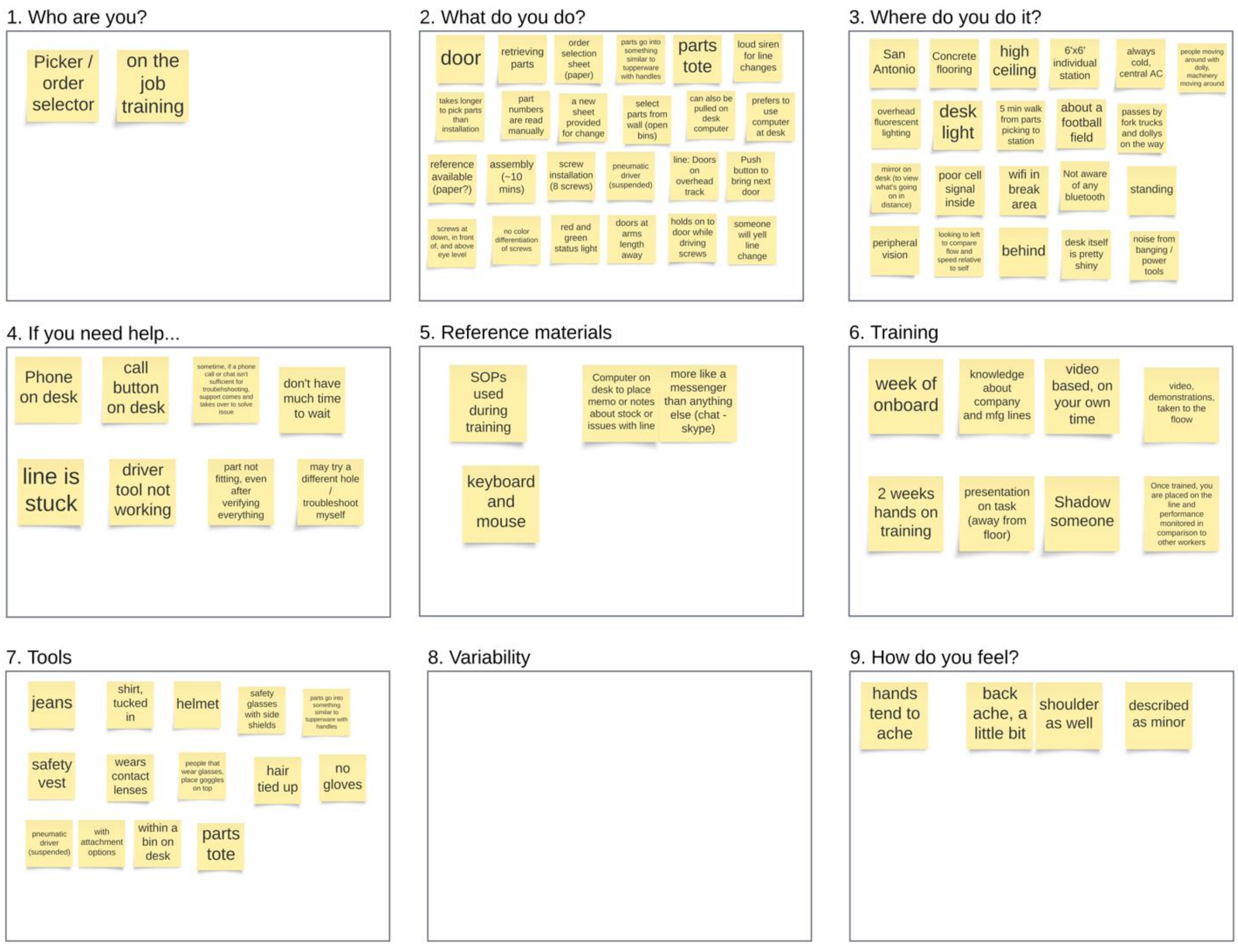
Appendix F3: P4 Interview Collaboration Board



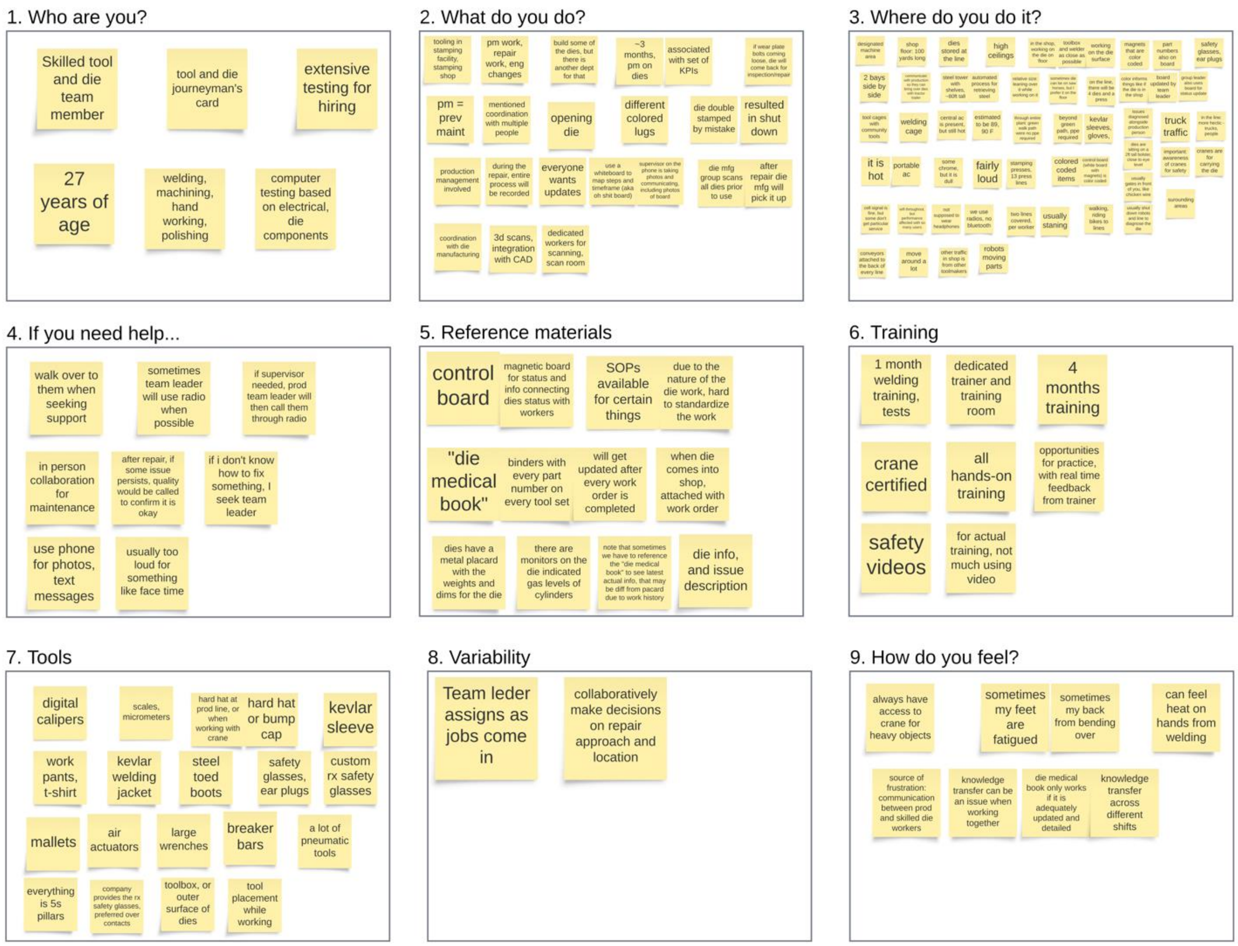
Appendix F4: P5 Interview Collaboration Board



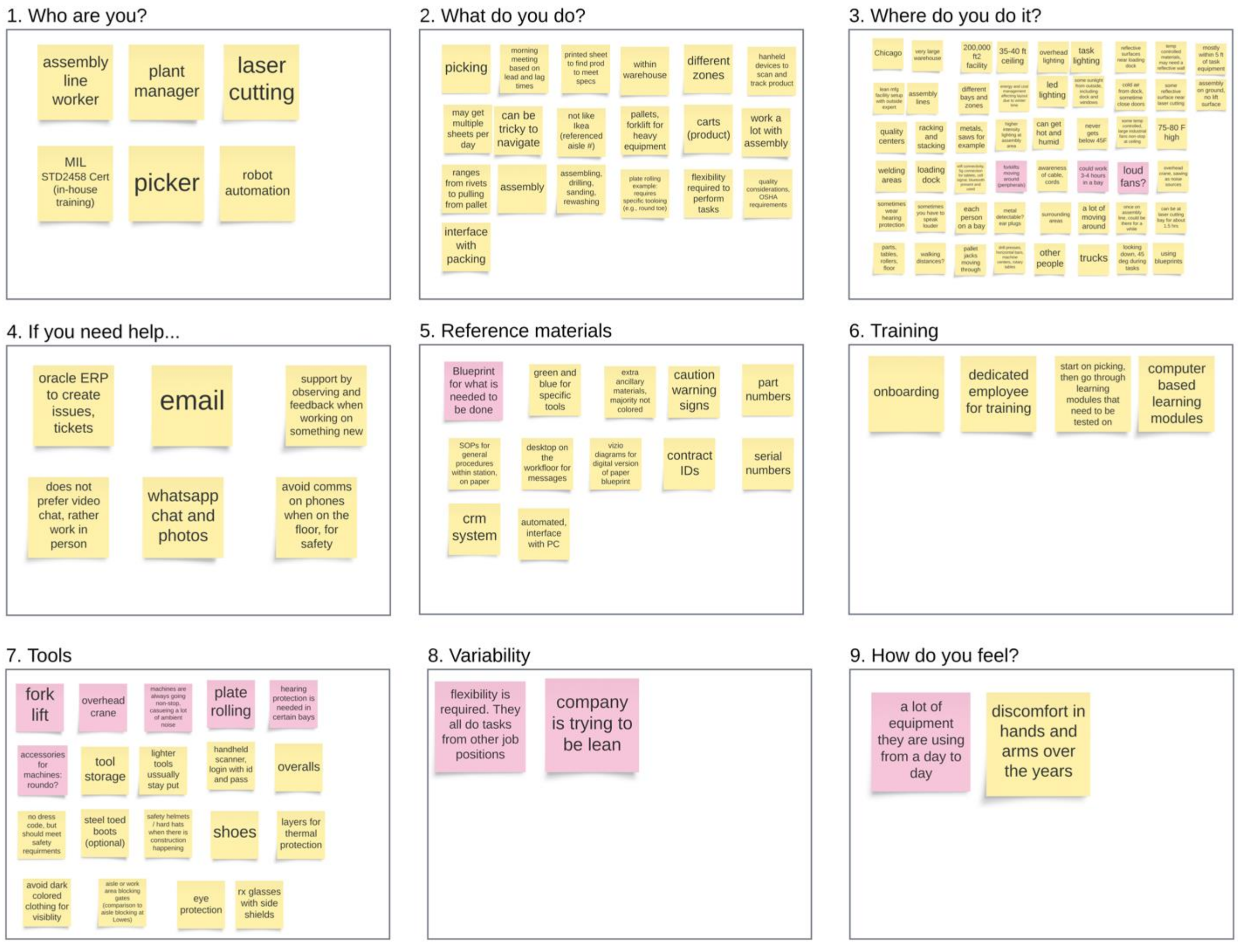
Appendix F5: P6 Interview Collaboration Board



Appendix F6: P7 Interview Collaboration Board



Appendix F7: P8 Interview Collaboration Board



APPENDIX G: SENSORY ANALYSIS DATA – CONTEXTUAL INQUIRY

Appendix G1: P3 Sensory Analysis Data – Contextual Inquiry

Sensory Analysis	
	Product Assembly
Sight	• Looking at assembly process (less than a foot away) • Fluorescent task lighting • Parts bins in background • Looks at monitor while testing • A lot of visual inspection (quality checks, screw placement, etc.) • Needs to see placement of small parts
Touch	• Small screwdrivers (similar to eyeglass screwdrivers) • Small tweezers • Fixture holding product • Handling parts • Tiny screws • Pick • Air gun
Hearing	• Light computer/machinery noise • No hearing protection • Auditory signals for torque spec • Need to listen to tones from product speakers during inspection
Smell	• N/A
Taste	• N/A
Thermoception	• No noticeable heat from tools
Nocioception	• No pain or discomfort reported • Repetitive shoulder movement observed
Equilibrioception	• Walks between stations with product/fixture while also transporting AR system
Proprioception	• Needs to move between neighboring stations
Notes	• Operator left controller at original station after moving down line • Operator reported some difficulty seeing screw colors while wearing device • Charger for device and controller needed to be moved every time operator moved between stations • When using controller, operator paused normal work to free hands

Appendix G2: P1 Sensory Analysis Data – Contextual Inquiry

Sensory Analysis	
	Mfg. Engr Troubleshooting using Remote Assistance
Sight	• Robots • Product in fixture • Parts • Monitors • Co-workers • Black backgrounds in robot stalls • Work cell faming on floor (trip hazard)
Touch	• Product • Fixtures • Hand tools
Hearing	• Machinery • HVAC
Smell	N/A
Taste	N/A
Thermoception	No noticeable heat from tools
Nocioception	No pain or discomfort reported
Equilibrioception	• Walks between workstations • Walk to and from office area
Proprioception	• Navigating manufacturing area with limited real-world visibility when wearing HMD • Need to step over work cell framing at ground
Notes	