The Social Impact of a Robot Co-Worker in Industrial Settings

Allison Sauppé and Bilge Mutlu
Department of Computer Sciences, University of Wisconsin–Madison
1210 West Dayton Street, Madison, WI 53706, USA
asauppe@cs.wisc.edu; bilge@cs.wisc.edu

ABSTRACT
Across history and cultures, robots have been envisioned as assistants working alongside people. Following this vision, an emerging family of products—collaborative manufacturing robots—is enabling human and robot workers to work side by side as collaborators in manufacturing tasks. Their introduction presents an opportunity to better understand people's interactions with and perceptions of a robot "co-worker" in a real-world setting to guide the design of these products. In this paper, we present findings from an ethnographic field study at three manufacturing sites and a Grounded Theory analysis of observations and interviews. Our results show that, even in this safety-critical manufacturing setting, workers relate to the robot as a social entity and rely on cues to understand the robot's actions, which we observed to be critical for workers to feel safe when near the robot. These findings contribute to our understanding of interactions with robotic products in real-world settings and offer important design implications.

Author Keywords
Computer-supported collaborative work; human-robot collaboration; collaborative robots; technology adoption; manufacturing; sociality; social cues; design guidelines

ACM Classification Keywords
H.5.3 Group and Organization Interfaces: Computer-supported collaborative work; **K.4.3 Organizational Impacts**: Computer-supported collaborative work

INTRODUCTION
While robots have long been envisioned as ubiquitous assistants that work in day-to-day human environments, the primary use of robotic technologies have been in factories and field settings for automating repetitive work or performing tasks that are inaccessible or dangerous for humans [19]. The last decade, however, has seen significant growth in the introduction of robotic products into homes and workplaces for tasks such as cleaning and delivery [6, 16]. One recent example

CHI 2015, April 18 - 23 2015, Seoul, Republic of Korea

ACM 978-1-4503-3145-6/15/04$15.00
http://dx.doi.org/10.1145/2702123.2702181

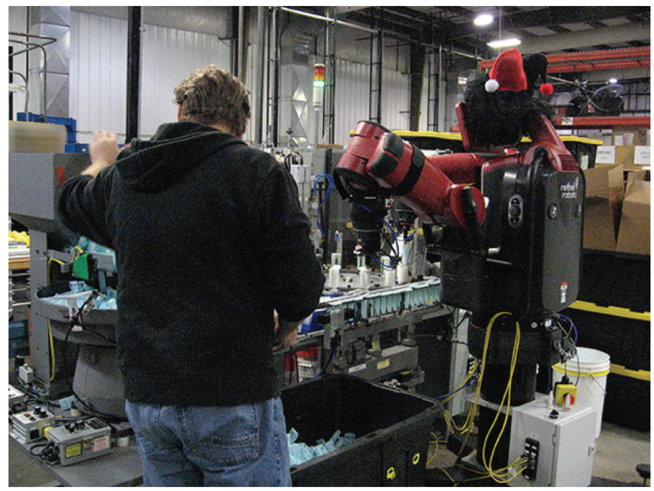

Figure 1. A collaborative manufacturing robot (right) working alongside a human operator (left) on a manufacturing task.

is the emerging use of *collaborative manufacturing robots* in industrial settings, which is poised to drastically change how work is done in small- and medium-sized manufacturing facilities. Figure 1 shows such a robot working collaboratively with a human worker on a manufacturing task.

Unlike robots designed for automation and unsafe work, collaborative robots are designed to work alongside humans and to interact and collaborate with their users, potentially changing how people perceive and interact with robotic technologies. Research in HCI has proposed different roles that computer technologies play, including "tools," "media," and "social actors," that accordingly shape people's perceptions of and responses to these technologies [4]. Computer technologies that display aspects of human language, offer interactivity, and play roles that have traditionally been filled by humans elicit attributions of sociality and social responses [18]. We expect collaborative robots that play a "co-worker" role to also be perceived as social entities, although little is known about the potential social impact of the introduction of these technologies to industrial settings on individuals and organizations.

Previous research on the impact of the introduction of robotic technology into other types of human environments, such as hospitals [13, 16, 20] and the home [5, 6, 21, 22, 23] has shown that robots significantly change people's perceptions regarding their social relationships and trigger a process of sense-making that results in the application of specific schemas, such as "collaborator," "social entity," or merely "novelty." While we expect similarities in how the introduction of robots affects people's perceptions of work across different domains, a better understanding of these effects in the manufacturing domain is necessary to draw guidelines to inform the design of robots for these settings. Furthermore, among the different robotic technologies that have been introduced into human environments, collaborative manufacturing robots uniquely play a role that has traditionally been played by humans—that of a "co-worker"—making people's interactions with them a relevant and important topic of study for HCI and CSCW research.

In this paper, we present findings from an ethnographic study of the integration of one particular collaborative robot at three manufacturing facilities, focusing on worker perceptions of the robot and their work together. At each site, we conducted fly-on-the-wall observations of the robot, its environment, and those around it as well as interviews with multiple stakeholders. We analyzed data from these observations and interviews using Grounded Theory. Among the many themes that emerged from this analysis, we report on findings and propose design guidelines regarding the *sociality* of the robot. In the remainder of the paper, we introduce prior work on the social impact of technologies as well as the shift robotic technologies are currently undergoing. Next, we present the details of our study, including the robotic platform we focused on, details about study sites we visited, and the methods we used for data collection and analysis. We conclude the paper by outlining our findings and discussing their implications for the design of future technologies that may function as social agents in manufacturing settings.

BACKGROUND

Collaborative robots in manufacturing settings follow a long trend of technologies—from desktop computers to virtual agents—that are perceived by human users as having social qualities. These robots also represent a shift from the traditional use of robots in manufacturing settings for safe and efficient industrial automation. In the paragraphs below, we briefly review prior literature on the perception of prior technologies as having sociality, the introduction of robots into day-to-day human environments and their perceived sociality, and the recent shift in industrial use of robotic technology.

Perceived Sociality of Technologies

The design of computer technologies follow metaphors that shape the way their users perceive and interact with them. Fogg [4] proposed "tool," "media," and "social actor" as three such metaphors that respectively result in perceptions of computers as providing new abilities, conveying content, and playing social roles. When computers follow the metaphor of a social actor, particularly displaying aspects of human language, offering interactivity, and playing roles that humans play, their users "mindlessly" apply social rules and expectations despite explicitly acknowledging that these machines have no social qualities [18]. Even computers that minimally follow this metaphor elicit attributions of gender, ethnicity, personality, and expertise to them, displays of politeness and reciprocity toward them, and disclosure of information when they divulge information first [15, 18].

When computer technologies are designed to more closely follow the metaphor of a social actor, as speech interfaces, virtual agents, and social robots do, people's interactions with them more closely resemble human-human interactions [1, 11, 17]. Research on embodied conversational agents (ECA) has demonstrated that people employ dialogue strategies from human-human conversations, such as greetings, farewells, small talk, and insults, and display elements of a human conversational style, such as disfluencies, in their interactions with ECAs that engage in social dialogue with them [1, 11].

While the design of robotic technologies vary in how closely their designs follow the metaphor of a social actor, we expect much of these attributions and responses to be present in people's interactions with them. For example, users of robots designed with minimal cues for sociality, such as the Mars Rover, perceive the robot as a social actor, identifying with the unique qualities and abilities of the robot, as well as a social resource for the human team [24].

Robots in Day-to-Day Environments

The last decade has witnessed the widespread introduction of robotic technologies into day-to-day environments. Prior work has studied how these products changed workplace and domestic practices and how their users perceived them. Studies of the use of the robotic vacuum cleaner Roomba in domestic environments found that users attributed lifelike characteristics, such as personality, gender, intentions, and feelings, to their cleaning [5, 6, 23] and developed a sense of unique ownership and intimacy with their products that led them to promote their robots in their social networks [23].

Robotic technologies have also been introduced to organizations, most prominently to perform transportation and delivery tasks at hospitals. Prior work studying the effects of the introduction of these robots on work and social practices found differences in how different groups responded to and worked with the robot [13, 16, 20]. Hospital workers whose jobs were less demanding benefited from the help that the robot provided and perceived the robot more positively, while others who worked in a more demanding environment found the robot to be a burden and a disruption to their social environment due to the robot's inability to recognize and adapt to those demands [16]. Based on their familiarity and experience with the robot, different stakeholders applied different cognitive frames to the robot, including "alien," "machine," "worker," and "colleague" [13]. Prior work has also examined how people interact with robots integrated into organizations and the broader social processes involved in these interactions. A study of the deployment of a snack-delivery robot in a university building found that users develop social relationships with the robot and that individual interactions with the robot result in a "ripple effect" in the social environment, engaging non-users in these interactions and promoting socializing [12].

Robots in Manufacturing

Driven mainly by the automative industry, the use of robots in manufacturing has traditionally focused on efficient, reliable, and precise production [3], resulting in robots that are unsafe for and caged off from human workers [9]. Recent advances in technology and methods for robot control have enabled a new class of robots that are safe for human workers and flexible enough to be integrated into human-robot work-cells [10, 14]. While the growing introduction of these robots into manufacturing settings is expected to drastically change work practices, worker perceptions of the robot, and the design of the work environment in these settings, no studies to date have examined these changes. A significant gap exists in our understanding of the effects of the integration of collaborative robots into manufacturing settings and of people's interactions with and perceptions of these technologies. This paper presents a study that aims to close this gap, focusing on worker perceptions of and interactions with the robot, and draw guidelines for the design of future collaborative technologies for manufacturing.

STUDY OUTLINE

To better understand how collaborative robots are affecting the work practices and perceptions of manufacturing employees, we conducted an ethnographic study at three manufacturing plants that had acquired a particular robotic platform. Below, we describe the platform we studied, the study sites we visited, our data collection methods, and the analysis of our data.

Robotic Platform

We focused our study on companies that owned the Baxter[1] robot, developed and manufactured by Rethink Robotics, examples of which can be seen in Figure 2. Baxter was released after beta testing in October of 2012. Unlike traditional manufacturing robots that are expensive, dangerous, and highly specialized, it is designed to be affordable at a price point of $25,000 USD, safe to operate around humans, and trainable for a variety of tasks using a visual programming interface.

The robot's design follows a humanoid morphology, including two manipulator arms and a screen used as a "face" through the display of eyes, and is the standing height of a human. The robot itself is 3 ft (0.914 m) tall, but deployed robots are often mounted on a platform that raises its height to be between 5 ft 10 in (1.778 m) and 6 ft 3 in (1.905 m).

The robot's hardware and software is optimized primarily to perform *pick and place* tasks. In these tasks, Baxter acquires an object or objects using either one or both of its "hands," i.e., grippers attached to the end of its arms, from a bin or a moving conveyor belt. The object(s) are then deposited in another bin or a workbench. The robot might be integrated with nearby systems with which it can communicate. For example, the robot might pick a finished product from the moving conveyor belt of an assembly line and place it in a shipping container. After the product is appropriately placed and stacked in the container, the robot would communicate to the assembly line that it is ready to pick and place the next product.

Study Sites

We recruited three manufacturing companies, each of which owned at least one Baxter robot, to participate in our study. Below are brief descriptions of the companies.

[1]www.rethinkrobotics.com/products/baxter/

Company 1 is a small family-owned business of about 40 employees. It specializes in plastic injection molding and produces plastic parts for different clients. These parts are often components of products that the company's clients manufacture or assemble.

Company 2 is a small business of about 50 employees. It produces and sells components used for securing electrical connections and is known for its outdoor waterproof electrical components.

Company 3 is a large international company of several thousand employees spread out across multiple facilities that produce office furniture. Four of these facilities have purchased a single Baxter. We included one of these facilities with approximately 150 employees in our sites.

Each company had owned their robot for four to eight months at the time of our visit. In addition to phone and e-mail correspondence over several months, the first author spent four days at Company 1, two days at Company 2, and one day at Company 3 conducting fieldwork. All sites were located within the continental United States.

Workspace Setup

The robot was integrated into its own *work-cell*—an area defined by its resources and the equipment dedicated to a single task—at each site visited (see Figure 2). Below, we give brief descriptions of Baxter's work-cell at each site.

At *Company 1*, Baxter was assigned to move and automatically bag stacks of medical cups. In this setup, a traditional industrial robot was responsible for moving finished medical cups from the plastic injection molding machine to a conveyor belt, which moved stacks of finished medical cups toward Baxter, which then picked up a stack and placed it in the automatic bagging machine. After placing two stacks in the machine, Baxter sent a signal to the bagging machine to place the two stacks in a bag and deploy a new bag. Periodically, an operator gathered completed bags and packaged them in a larger shipping box. Operators and maintenance staff also attended to the robot when problems arose.

At *Company 2*, Baxter set up plastic tubes to be filled with a silicone material for waterproofing wires. A hopper of tubes gradually dispensed tubes into a second container and eventually onto a line that moved the tubes towards Baxter. Baxter then picked up a tube in each hand and placed them in a second machine to be processed. After processing, the second machine deposited the completed tube into a bucket. Operators were responsible for periodically filling the hopper with more tubes and replacing the filled buckets. Operators and maintenance staff attended to the robot when problems occurred.

At *Company 3*, Baxter was set up in a separate area for maintenance workers to retrain it for a new task. During our visit, the robot was being trained to package hardware for furniture, such as brackets, into a box. The maintenance worker arranged the hardware to be boxed to the right of Baxter in a particular configuration, flat pieces of cardboard to stack between hardware to the left of Baxter, and the box to package the hardware in front of Baxter. When activated, Baxter picked up each

Figure 2. Examples of a collaborative robot at work packaging medicine cups at Company 1 (top) and moving plastic tubes at Company 2 (bottom).

piece of hardware individually and placed it in the box. At predefined points, Baxter used its left hand to acquire a piece of cardboard and place it on top of the hardware currently in the box. Then, additional hardware was added. In the targeted workflow, the box and hardware would be delivered to Baxter via a conveyor belt, and the completed box would continue down the conveyor belt. An operator would be responsible for periodically giving Baxter additional flat pieces of cardboard.

Method

During the course of the study, we collected data on a number of different facets of the integration of the robot into the manufacturing environment, including motivations for purchasing a collaborative robot, the process of integrating it to the existing manufacturing workflow, organizational changes to accommodate the use of the robot, and worker perceptions of and interactions with the robot. In this paper, we focus on the design elements and factors that shaped worker perceptions of and interactions with the robot, including the robot's appearance, its social behavior, and its introduction into the work environment.

Fly-on-the-Wall Observations

We conducted fly-on-the-wall observations of activities around and involving the robot at both Company 1 and Company 2. While Company 3 had a collaborative robot that had previously been deployed at an assembly line, they had decided to re-train the robot in a separate area for a new task. While we did observe that the robot was located in a separate area for retraining at Company 3, we did not have the opportunity to see the robot being trained. Experiences about the retraining process were instead gathered from interviews. We also observed nearby human-operated work-cells to better understand what made the robot's work-cell unique. At Company 3, data collection also included observations of the setup of the human-operated work-cells and interviews about how the robot was or would be integrated into these tasks.

At each site, observations focused on the robot and its surrounding environment, including how the robot was completing its task, the robot's interactions with nearby equipment, how the robot reacted to unexpected situations, and how workers interacted with the robot. Observations also included understanding the more general environment of the company, including how workers interacted with one another and the organizational structure of the company.

Interviews

In addition to the fly-on-the-wall observations, we conducted semi-structured interviews with key stakeholders at each site, including *management*, *maintenance*, and *operators*. While there were differences in the task Baxter was assigned at each site, the roles and experiences of the stakeholders was uniform, allowing us to consider the same organizational roles across all three sites. Below, we describe the organizational roles of these stakeholders and their involvement with the robot.

Management staff included employees who were responsible for decisions regarding obtaining the robot, for setting and overseeing company goals, or for high-level human-resource issues. These employees had varying degrees of interaction with the robot, including helping with troubleshooting work-cell problems or contacting technical support, depending on the company's size. However, management relied on maintenance staff for the integration of and troubleshooting with the robot. Management staff were asked questions concerning the size, organization, and mission of the company; the demographics of their workforce; the decision-making process behind purchasing the robot; and the effect of the robot on various metrics, such as productivity and profit.

Maintenance staff included employees who handled the upkeep and troubleshooting of machines in the manufacturing environment. Additionally, these employees were responsible for the integration of the robot, programming the robot, training other employees on using the robot, and troubleshooting the robot as necessary. These employees were often the first to handle day-to-day issues with the robot and its work-cell. Maintenance staff were asked questions concerning their roles and responsibilities at the site; how they prioritized their work; their involvement with the integration of the robot; what skills they acquired during integration; their interaction with the robot; and troubleshooting the robot.

Operators included employees who worked at one or more workstations at the manufacturing facility. Although different operators might be assigned to a particular workstation at different times, each operator was solely responsible for meeting the quota at their workstation, and often developed a unique workflow for that particular workstation. Operators typically resolved minor troubleshooting tasks, but would contact maintenance staff when additional help or expertise was necessary. One operator was always assigned to work alongside and monitor the robot. These employees were not trained on how to program the robot, but they knew how to handle common mistakes in the work-cell and how to reset the robot if necessary. Some operators were assigned to work alongside the robot every day, while others only worked with the robot every other day. Operators were asked questions concerning their previous manufacturing experience; whether they had prior experience completing the robot's task manually; their perceptions and interactions with the robot; and their process for troubleshooting problems that the robot encountered.

Across the three sites, we interviewed a total of 17 informants, including six managers, eight maintenance employees, and three operators. The interviewees were identified from among employees suggested by the authors' contacts at each site, workers observed during fly-on-the-wall observations, and employees mentioned during previous interviews. The interviews started with the researcher seeking and obtaining informed consent and proceeded with a semi-structured interview involving an initial set of questions at Company 1 and growing sets of questions at Company 2 and Company 3 that built upon knowledge from previous site visits. The interviews were captured as written field notes and audio recordings. Each interview was approximately 30 min in length ($M = 27$ min, 22 sec; $SD = 5$ min, 33 sec), and employees received a $5 USD gift-card to a local coffee shop as compensation.

Analysis

A Grounded Theory approach [7] was used to analyze textual data obtained from field notes and interview transcriptions. We first conducted an open coding process in which codes were assigned to significant events or references. Open coding was completed for all field notes and transcriptions. To establish inter-rater reliability, a second researcher then used provided codes to code 10% of the data. The inter-rater reliability showed substantial agreement between the primary and secondary coders (82% agreement, Cohen's $\kappa = .79$). Next, axial coding was used to identify phenomena, such as repeated events or interactions, among the codes. In total, 11 axial codes were developed that relate to worker perceptions of and interactions with the robot. Finally, we used a selective-coding process to understand the relationships among axial codes.

FINDINGS

In this section, we present the main findings from our analysis that provide insight into the experiences of various stakeholders with the robot. Figure 3 provides a visual summary of the four themes that emerged from our analysis. We support each theme with observations or quotes from interviews where applicable, indicate stakeholder perspectives with labels "MG" for "Management," "MT" for "Maintenance," and "OP" for "Operator," and indicate company affiliation with "C" followed by the number corresponding to our earlier descriptions.

Summary of Results

Operator-Robot Relationship
Operators view their relationship with the robot as humanlike, while maintenance and management view the robot as equipment.

Attribution of Human Characteristics
Operators believed the robot has personality and intent. The robot also inspired a range of emotional responses in operators.

Social Interactions with the Robot
Operators engaged in a number of social interactions with the robot. All staff desired a speech channel for social and troubleshooting purposes.

Responses to the Robot's Design
The robot's physical appearance helped nearby workers feel safe. The robot's eyes provided insights into the robot's status and next action.

Figure 3. An overview of our analysis of the resulting themes and how those themes manifested in our data. The collaborative robot's integration at three manufacturing plants yielded four main themes for employee-robot sociality.

Operator-Robot Relationship

A prominent theme that emerged from our analysis was the differential perceptions of the robot by operators and by maintenance and managerial staff. Operators who worked directly with the robot regularly characterized their relationship with the robot in collegial or personal terms, referring to the robot as their "work partner" (OP2C2) or "friend" (OP1C2). Even other operators who worked at nearby work-cells perceived these relationships as unique, one operator noting that her co-worker at a nearby station often referred to the robot as her "son" due to their ability to communicate and work well with each other.

> **OP1C2:** People call him my son. They don't like [the name] "Baxter" and think it's funny how much I like working with him, that I understand him.

Although operator-robot relationships were usually cordial, operators also characterized their relationships with the robot in negative, yet familial or relational, terms.

> **OP3C3:** He [the robot] just has a hard time doing work a lot. Especially when he goes down, I'm like "What's up?" ... Feels like babysitting my grandkids.

> **OP1C2:** Sometimes I write down on my [time] sheet "Baxter was not a team player today."

Operators also noted that they talked about the robot as a "friend" outside of work with their acquaintances. Some operators reported that their friends sometimes asked "how the robot was doing" (OP2C2).

While operators characterized their relationship with the robot in collegial and personal terms, maintenance and management staff viewed working with the robot to be similar to working with other industrial equipment. These employees often referred to the robot as "monotonous" and "error prone," describing their interactions with the robot as involving "fixing it" when problems arose.

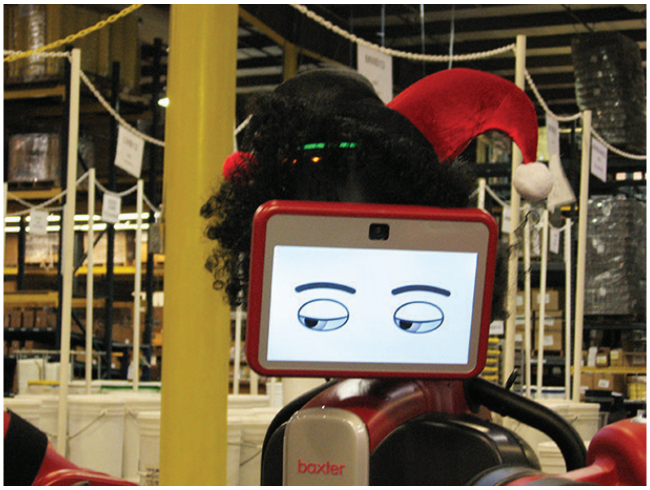

Figure 4. The robot from Company 2, dressed up in a wig and jester hat. Previously, the robot was adorned with a rainbow clown wig.

We believe that these differences result from different formative experiences with the robot. Maintenance and management staff indicated that the initial demonstrations of the robot during its acquisition had set high expectations that were challenged during the integration process due to difficulties with enabling the robot to quickly and reliably sense its environment. Addressing these difficulties required these employees to iteratively create a static and predictable work environment for the robot and the intelligent sensing features of the robot to be underutilized. This gradual shift away from the initially-envisioned use-cases may have disillusioned these employees and resulted in perceptions that were similar to those of other equipment. While some operators had worked with the robot during this transition period, they had little knowledge of why the robot was transitioned into a more static environment, potentially maintaining their initial frames of the robot.

> **MT1C1:** It [Baxter] is easy to program, it's the precision of everything else [around Baxter] that's difficult.

> **MT2C1:** Our biggest thing is to tie Baxter into the bagger, tie Baxter into the conveyer, and tie Baxter there; and again it comes down to inputs, outputs, and there's not a lot of versatility. ... Right now, I have to sit here meticulously and program every little spec of dust where vision would be boom, boom, boom.

Even operators showed awareness of the differences in how they perceived their relationship to the robot compared to how maintenance and management staff did, as expressed in the following excerpt:

> **OP1C2:** He [MT3C2] likes to come tinker around. It's like his little toy. I'm like "Don't touch anything! You'll screw him up."

Attribution of Humanlike Characteristics

Our analysis revealed a second theme that centered around the operators attributing humanlike characteristics, such as personality and intent, to the robot. Operators frequently described Baxter as having personality traits, such as "cheerful" (OP1C2), "happy" (OP1C2, OP2C2), "fun" (OP2C2, OP3C3), and "perky" (OP1C2), as illustrated in the following excerpt:

> **OP2C2:** Yeah, he's a lot of fun to be around. He can improve my day.

At Company 2, the robot's physical appearance had been altered to include a wig and jester hat (see Figure 4). Operators at this site felt that the robot's new appearance fit well with its perceived personality, as described below:

> **OP1C2:** To me, it totally fits him. ... So if he's in a good mood, it fits him. Or sometimes he has an attitude, "Whatever," you know? That look is just him.

Operators also described the robot and its actions as triggering a range of feelings, reporting feeling happy or pleased while working with the robot—sometimes more so than with a human co-worker—as illustrated in the excerpt below.

> **OP3C3:** Yeah, it can be nice to work by him when I just want a quiet day and he's working well. Lot less hassle then trying to tell someone you don't want to talk.

Other times, operators reported feeling upset or angry with the robot for its actions and expressing resent towards the robot for its mistakes. An operator expresses stress and frustration in the following excerpt:

> **OP1C2:** If he's [the robot is] having a bad day, that...is...very frustrating. Cuz there's no numbers getting out on my job or his job, he's just a mess. ... It's a little stressful.

Some operators believed that the robot expressed intent in its actions, most commonly when the work-cell or the robot malfunctioned, particularly when the operator had just left the work-cell moments before. For example:

> **OP1C2:** I know that [the robot makes mistakes] and I understand that, so certain things don't bother me. Now sometimes, if I have 8 hours of that, and I'm like, that's when I think he knows what he's doing on purpose, or he's beeping, and as soon as I turn my back to look at him, he stops, I turn around again he beeps, and I'm like, "Really Baxter? Are you doing that on purpose? Cuz you're driving me nuts!"

As a result, these operators expressed the need for someone to watch or supervise the robot in their absence. They felt that supervision might help prevent the robot from making a mistake as well as allow mistakes to be corrected promptly. This feeling is illustrated in the excerpt below:

> **OP1C2:** I'm going to use the bathroom. If something weird happens, I'm only going to be gone 30 seconds. Sometimes I want to get someone to watch him, like he's a kid.

Finally, regardless of the type of emotions the robot regularly elicited, all operators reported that the robot inspired interest. Even if some operators were initially reluctant to work with the robot, they eventually became engaged with the robot. Operators reported asking maintenance staff questions and suggesting improvements in Baxter's programming, how the

Figure 5. Two operators working near the robot. The vantage point of the operators makes it difficult to monitor the robot's status. Additionally, the tasks the operators are completing requires their visual attention.

work-cell should be organized, and how to optimize the way operators interacted with the robot. For example:

> **OP3C3:** I noticed it didn't search so good sometimes, ... so I told them [maintenance] to see if they could make it better.

Social Interactions with the Robot

Another prominent finding from our analysis was that operators reported having a wide range of social interactions with the robot. The most pertinent day-to-day interaction for operators was listening to the sound of the robot's work to monitor the robot's activities. Many work-cells are not designed in such a way that nearby operators can visually monitor the robot, as illustrated in Figure 5. Even when the the design of the work-cell allowed visual monitoring, directing attention toward the robot would mean taking attention away from their own work. Thus, operators learned to interpret the sound and rhythm of the robot's work in order to identify patterns of mistakes that demanded their attention. For example, no sound may indicate that the work-cell had shut down, the sound of objects being incorrectly placed may suggest that a part of the cell had shut down and the robot continued to operate, and the sound of the robot acquiring new missing objects may indicate that the objects that the robot would later acquire were not being reliably moved toward the robot. The excerpts below provide examples of the practices that operators developed to interpret the sound of the robot's work.

> **OP1C2:** Now I don't look, I mostly listen. He's like a child, if he's been quiet for too long, I know something's wrong. ... We've developed an understanding.

> **OP2C2:** I mean maybe just because I'm accustomed to working with him everyday, maybe now I can anticipate the problems a little bit more. I know what's going on.

Operators also reported sometimes finding themselves talking to the robot. These expressions were often musings while trying to understand why the robot had stopped working. At other times, operators were upset with the robot and were admonishing it or yelling at it out of anger or frustration, as illustrated in the excerpts below.

> **OP1C2:** I find myself just wondering aloud sometimes when something is wrong, hoping he'll give me an answer.

> **OP3C3:** Sometimes he really tees me off, and I let him know it.

While operators reported already engaging in social interactions with the robot, they and some maintenance staff expressed a desire for the robot to display more social behavior. These employees appreciated the robot's use of its eyes to convey sociality (discussed in the next theme), but felt that the robot could be more socially interactive, for example, by making small talk. Operators explained that although their work required them to focus on their workspace, they frequently engaged in small talk with one another during shifts to help pass the time and establish and maintain relationships. They wished that the robot could similarly engage in basic small talk, mimicking the sociality of working with other nearby operators during shifts where operators are assigned work with the robot and no other operators are nearby, as shown in the excerpts below.

> **OP3C3:** They're [humans are] quicker and I need somebody to talk to. I couldn't teach him to talk. ... I tried to teach him to deal cards but that didn't work either.

> **OP2C2:** It would be nice if he could just shoot the breeze.

> **OP1C2:** I want it to say "Good morning, [informant's name], my favorite co-worker" and display a little bouquet of flowers.

Maintenance staff agreed with operators that the addition of speech to the robot would be beneficial, but for other reasons. The robot's work-cell can stop for a variety of reasons, including equipment malfunction, the lack of a necessary material or object, or a problem with the robot. Unsure of how to remedy the situation, operators often turn to a nearby maintenance worker for help. In such situations, neither operators nor maintenance workers usually have sufficient context for diagnosing the problem, requiring them to check many different components of the environment. Maintenance staff believed that the addition of speech capabilities to the robot may enable verbal troubleshooting, such as providing specifics on the problem (MT2C1) or giving step-by-step instructions on how to correct the problem (MT3C2, MT6C3).

> **MT3C2:** It would be nice if Baxter could fix his own problems, but I would settle for him telling us how to do it.

> **MT5C3:** I started working here long after he [the robot] got here, and sometimes I have no clue what to do [to fix him]. Him helping would be good.

Workers also suggested that the robot's face, which doubles as a screen, could provide more information. Employees felt that the screen could offer redundant information in addition to the speech content. Manufacturing plants often contain background noise that might at times grow progressively louder. While employees believed that speech would be the easiest way to communicate with the robot, the addition of using the screen as an information display would provide employees with an alternative channel of communication should speech be impaired by the environment.

Responses to the Robot's Design

The last theme that emerged from our analysis was worker responses to the robot's appearance, focusing on two features: the robot's overall form and its eyes. Both elements of the robot's design were considered important for staff to feel comfortable working near the robot. Workers described the humanlike design of the robot as "familiar," giving them a sense of security and comfort when working in close proximity to the robot. This familiar design was in stark contrast with many industrial robots that are distinctly non-human and dangerous to be around. In the excerpt below, a maintenance worker highlights that this familiar design provides the robot with predictability.

> **MT4C2:** I like that it looks kinda like a human. ... It's familiar, ya know? I feel like I know what to expect.

Two other employees described the robot not as humanlike, but still as bearing a resemblance to other lifelike forms, specifically to a "praying mantis" due to the way it arms rotate. These employees still felt that this appearance induced feelings of safety when compared to other industrial robots, as illustrated in the excerpt below.

> **MT3C2:** Those arms, they remind me of a, what is it? Praying mantis? Yeah. Still, looks very calm, deliberate.

Employees also expressed a preference toward the dark-gray-and-red color and the industrial design of the robot. Compared to traditional industrial robots, employees felt that the robot's design suggested a friendly and non-threatening, even a "playful," interaction, as indicated below.

> **OP1C2:** Yeah, I'm like [to my friends], "He's like a Rock 'em, Sock 'em robot!" That red, it's so playful.

At Company 2, the addition of the wig and jester hat shown in Figure 4 further emphasized the humanlike appearance of the robot, adding to its "personality."

One particularly well-liked design element was the robot's eyes. The robot was equipped with a screen for a face, which displayed a pair of graphical "eyes." The face or the eyes served no sensing purpose (i.e., vision capabilities) but instead provided a way for nearby workers to understand the robot's current status in a "natural" way that did not require additional training, as expressed by a managerial employee below.

> **MG5C3:** I like them [the eyes]. ... Because, I love that, I mean, it, because it's the nonverbal communication. ... I think that it's just natural.

These eyes were pre-programmed to follow the trajectory of its arms, allowing employees to better anticipate where the robot's hands were likely to move next. As illustrated in the excerpt below, this feature was considered particularly useful for new employees who might still be learning about the task.

> **MG1C1:** They [new employees] don't usually understand what the robot will do next, where it will go... This [the eyes], this helps them get it.

The robot also had a set of pre-programmed facial expressions: "confused" for when it is has trouble completing a task, "sad" for when the robot has given up on a task, and "surprised" for when a human had entered the workspace of the robot.

> **MG1C1:** They [the operators] know what the "surprise" look is, they know what the "sad" look is, they...they know it.

Employees noted that the robot's eyes and facial expressions were particularly useful when glancing at the robot from farther away. At a distance, the robot's eyes and facial expressions provided some context as to its otherwise indiscernible task status.

Additionally, employees felt that the robot's eyes conveyed intelligence. This perceived intelligence gave employees who worked in or around the robot's work-cell confidence in the robot's actions and intentions, as expressed by the maintenance worker below.

> **MT4C2:** The eyes make him seem smart. Like he knows what he's doing.

DISCUSSION AND DESIGN IMPLICATIONS

The themes that emerged from our analysis suggest two key implications for the design of collaborative robots: the importance of designing for sociality and the need to support a diverse set of relationships between the robot and different stakeholders. Additionally, these implications can be extended to other types of agentic technologies, including speech-based and embodied virtual assistants, such as a speech-based task guidance system building on its prior relationship with its user. Below, we discuss the implications of our work, the limitations of our study, and our plans for expanding this research.

Designing for Sociality

Many of our results highlight the importance of sociality in a robot playing the role of a co-worker. We did not expect the social elements of the robot's design or social relationships people established with it to be important factors in its integration into a manufacturing environment, due to our naive presumption that there is little need for sociality in completing manufacturing tasks. Workers across three organizations in our study repeatedly brought up sociality in characterizing their relationship with the robot, in discussing the characteristics of the robot, and in suggesting improvements for the robot. Our observations suggest that this desire for increased sociality stems from current social practices operators engage in amongst one another during their own work, such as two operators at adjacent workstations engaging in small talk.

The design of future collaborative robots for manufacturing settings must take into account the benefits of supporting worker expectations of sociality to improve work practices as well as the social environment in these settings. Although they offer the same safety and flexibility benefits as Baxter does, many collaborative robots are designed only as single robotic arms with little or no elements to support sociality. Our results indicate that social features that are already included in Baxter's design, such as its overall humanlike morphology and the behaviors displayed by its eyes and face, not only provide workers with a positive experience by eliciting feelings of safety and comfort but also improve manufacturing work by communicating cues that are necessary for successful coordination. However, increased sociality has the potential to create false expectations that may risk worker safety. Although collaborative robots are becoming increasingly safe for nearby workers, designers must strive to match the perceived safety of the robot with its actual safety. Future designs of collaborative robots must build on the success of these features and further expand their use of design elements that support sociality while understanding and balancing this increased sociality against the expectations and the needs of its users.

Based on our findings, we believe that future designs could improve the robot's sociality to achieve two design goals. First, collaborative robots must be designed to support and enrich the social environment in the organizations to which they are introduced. We found that social interactions and relationships are key elements of collaborative work even in task-oriented, safety-critical settings such as manufacturing. Supporting expectations for basic conversational skills, such as greeting co-workers and nearby operators at the beginning and end of their shifts, might enhance the social environment in these settings. Second, collaboration by definition requires a coordination of actions for which communication and social cues are critical. Therefore, future collaborative robots must be designed with the necessary communicative functions to facilitate this coordination. For example, basic language capabilities could be added to allow workers to ask the robot questions such as "What's wrong?" when there is a problem or to seek guidance from the robot in addressing it by asking "How do I fix it?" Additionally, future designs could draw on the cues that workers currently rely on to monitor the robot, such as the sound of its operation or the direction of its gaze, to support this implicit form of communication.

Supporting Different Relationships

We found that different stakeholders made different attributions to the robot, maintenance and management staff perceiving the robot in more mechanical terms and operators viewing it as an agent with whom they can build a relationship. These different attributions resulted in different behaviors toward the robot and different characterizations of relationships with it.

Prior studies of the introduction of technology into organizations found similar differences in the responses of different stakeholders to the technology. For instance, studies of the introduction of delivery robots into hospitals found varying perceptions among stakeholders based on worker familiarity and time spent with the robot [13], on the organizational role and gender of the workers [20], and on the workload of and emotional demands on the workers [16]. The design recommendations made by these studies included creating different behaviors that are better suited to the communication needs and context of different stakeholders, such as employing subtle light displays to alert high-workload employees at an oncology unit and using entertaining, pre-recorded voices that contribute to the cheerful social environment of a postpartum unit [16].

The design of future collaborative robots for manufacturing settings must similarly accommodate different perspectives and interactions with the robot. For instance, future designs could draw on the social elements of the robot's design to improve the robot's sociality for maintenance and management staff to help reshape perceptions of the robot from industrial equipment to a more sociable co-worker. Social behaviors could be built into the types of interactions that these stakeholders are engaged in, such as integration, programming, and troubleshooting. While many existing collaborative robots including Baxter are equipped with capabilities for interactive programming, such as learning from demonstration, these capabilities could be augmented to include conversational elements for input and feedback.

Limitations

While our findings offers many interesting insights into the integration of collaborative robots into manufacturing settings, our study has limitations that point to follow-up studies and analyses and future research directions. First, many of our results highlight the importance of sociality in worker interactions with and perceptions of the robot, which in large part might have been shaped by the robot's humanoid form [2]. However, prior work suggests that people's responses to robots are shaped by a broader set of design elements, such as how the robot's appearance matches its task [8]. Future work should examine worker interactions with collaborative robots with different morphologies, such as robotic arms, performing different types of tasks. Second, our study sites included some of the very first manufacturing facilities to own and use collaborative robots, who as early adopters, might have experienced integration issues that may become a rarity as the technology and integration practices mature. A smoother integration process might change some of our observations, such as the mechanical view that maintenance and management staff had of the robot. Future studies that focus on the integration process could clarify the role of integration problems (or lack thereof) on worker perceptions of collaborative robots.

CONCLUSION

The introduction of collaborative robots into manufacturing organizations is poised to revolutionize how work is done in industrial settings and how workers adapt to and interact with a robot "co-worker." To better understand these changes and guide the future design of these technologies, we conducted an ethnographic study at three manufacturing sites located in the continental United States that were early adopters of a particular type of collaborative robot. We conducted fly-on-the-wall observations and interviews at each site with different stakeholders, including managerial employees, maintenance staff, and operators. Our Grounded Theory analysis found four main themes of interest: (1) the close, social relationship that operators built with the robot, (2) attributions of positive and negative humanlike characteristics to the robot, (3) the wide range of social interactions that workers had with the robot for troubleshooting and coordinating work, and (4) worker responses to the morphological and behavioral characteristics of the robot's design.

Drawing on our findings, we recommended that future designs augment the social capabilities of collaborative robots, specifically to support the coordination necessary to perform manufacturing work and to enrich the social environment in the workplace. We also suggested that future designs accommodate the expectations and needs of different stakeholders, such as improving the social capabilities of the robot not only for immediate collaborators, but also for workers who have less frequent and different types of interactions with the robot. These improvements will help manufacturing organizations to more smoothly integrate collaborative robots into their work practices and the social environment. The findings of this study contribute to our broader understanding of interactions with robotic products in real-world settings, and these recommendations offer designers concrete guidelines for better supporting work and improving user experience in these settings.

ACKNOWLEDGMENTS

We would like to thank our contacts at the study sites for their cooperation, Brandi Hefty, Jieni Peng, Marley Crews-Hill, Chris Ward, and Catherine Steffel for their contributions to data analysis and writing, and National Science Foundation awards 1149970 and 1426824 for financial support.

REFERENCES

1. Bickmore, T., and Cassell, J. Social dialogue with embodied conversational agents. In *Advances in natural multimodal dialogue systems*. Springer, 2005, 23–54.
2. Breazeal, C. Emotion and sociable humanoid robots. *Int J Hum-Comput St 59*, 1 (2003), 119–155.
3. Brogårdh, T. Present and future robot control development—an industrial perspective. *Annu Rev Control 31*, 1 (2007), 69–79.
4. Fogg, B. J. Persuasive computers: Perspectives and research directions. In *Proc. CHI '98* (1998), 225–232.
5. Forlizzi, J. How robotic products become social products: An ethnographic study of cleaning in the home. In *Proc. HRI '07* (2007), 129–136.
6. Forlizzi, J., and DiSalvo, C. Service robots in the domestic environment: A study of the Roomba vacuum in the home. In *Proc. HRI '06* (2006), 258–265.
7. Glaser, B. G., Strauss, A. L., and Strutzel, E. The discovery of grounded theory: Strategies for qualitative research. *Nurs Res 17*, 4 (1968), 364.
8. Goetz, J., Kiesler, S., and Powers, A. Matching robot appearance and behavior to tasks to improve human-robot cooperation. In *Proc. ROMAN '03* (2003), 55–60.
9. Hirschfeld, R., Aghazadeh, F., and Chapleski, R. Survey of robot safety in industry. *Int J Hum Factor Man 3*, 4 (1993), 369–379.
10. Kock, S., Vittor, T., Matthias, B., Jerregard, H., Kallman, M., Lundberg, I., Mellander, R., and Hedelind, M. Robot concept for scalable, flexible assembly automation: A technology study on a harmless dual-armed robot. In *Proc. of ISAM* (2011), 1–5.
11. Kopp, S., Gesellensetter, L., Krämer, N. C., and Wachsmuth, I. A conversational agent as museum guide–design and evaluation of a real-world application. In *Proc. IVA '05* (2005), 329–343.
12. Lee, M. K., Kiesler, S., Forlizzi, J., and Rybski, P. Ripple effects of an embedded social agent: A field study of a social robot in the workplace. In *Proc. CHI '12* (2012), 695–704.
13. Ljungblad, S., Kotrbova, J., Jacobsson, M., Cramer, H., and Niechwiadowicz, K. Hospital robot at work: Something alien or an intelligent colleague? In *Proc. CSCW '12* (2012), 177–186.
14. Matthias, B., Kock, S., Jerregard, H., Kallman, M., Lundberg, I., and Mellander, R. Safety of collaborative industrial robots: Certification possibilities for a collaborative assembly robot concept. In *Proc. ISAM '11* (2011), 1–6.
15. Moon, Y. Intimate exchanges: Using computers to elicit self-disclosure from consumers. *J Consum Res 26*, 4 (2000), 323–339.
16. Mutlu, B., and Forlizzi, J. Robots in organizations: The role of workflow, social, and environmental factors in human-robot interaction. In *Proc. HRI '08* (2008), 287–294.
17. Nass, C., and Lee, K. M. Does computer-generated speech manifest personality? An experimental test of similarity-attraction. In *Proc. CHI '00* (2000), 329–336.
18. Nass, C., and Moon, Y. Machines and mindlessness: Social responses to computers. *J Soc Issues 56*, 1 (2000), 81–103.
19. Shibata, T. An overview of human interactive robots for psychological enrichment. In *Proc. of the IEEE*, vol. 92 (2004), 1749–1758.
20. Siino, R., and Hinds, P. J. Robots, gender & sensemaking: Sex segregation's impact on workers making sense of a mobile autonomous robot. In *Proc. ICRA '05*, vol. 3 (2005), 2773.
21. Sung, J.-Y., Christensen, H. I., and Grinter, R. E. Robots in the wild: Understanding long-term use. In *Proc. HRI '09* (2009), 45–52.
22. Sung, J.-Y., Grinter, R. E., Christensen, H. I., and Guo, L. Housewives or technophiles?: Understanding domestic robot owners. In *Proc. HRI '08* (2008), 129–136.
23. Sung, J.-Y., Guo, L., Grinter, R., and Christensen, H. "My Roomba is Rambo:" Intimate home appliances. In *Proc. UbiComp '07* (2007), 145–162.
24. Vertesi, J. Seeing like a rover: Embodied experience on the mars exploration rover mission. In *Proc. CHI '08 Extended Abstracts* (2008), 2523–2532.