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Accomplishing Robotic Autonomy: The Complexities of Sociotechnical Care and Agency in the Laboratory

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Abstract

Effective ethical interventions in emerging technologies such as robotic autonomy demand situated understandings of the practices that shape them. Drawing upon a year of participatory ethnography, this study examines the sociomaterial practices used to accomplish robotic agency in an engineering research laboratory. Ironically, the robot was often a helpless, even pathetic, figure. Roboticists displayed an attitude of surprisingly genuine, diligent, and self-effacing care toward the robot as they helped enable it to perform basic competencies such as picking up a bottle. Using a practice theory, we show how roboticists' care practices, motivated and sustained by anticipatory narratives of robotic agency, accomplish robotic autonomy. We argue that interventions must acknowledge and engage with the complex dynamics of technologists' care to be effective.

Keywords: agency, anticipatory narratives, care practices, practice theory, robotics development

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Introduction

The increasing integration of advanced artificial intelligence (AI) into embodied agents such as autonomous robots pervasively impact research, development, and deployment of commercial technology, and, increasingly, daily experience. While advanced technologies have brought numerous changes that have resulted in more convenience and efficiency to daily life, concerns surrounding the use and implications of these technologies are proliferating. These include the in/visibility of labor (Suchman, 2007), machine ethics (Gunkel, 2022), negotiation of human agency and machine control (Gibbs et al., 2021; Kirkwood et al., 2022). Keeping pace with these developments demands ever-more situated and participatory engagement with emerging technologies and their impacts.

There is a growing body of literature which centers on the potentials and problems surrounding the development and use of robotics technology. The effects of robots in workplaces have been consistently examined (Barrett et al., 2012; Beane & Orlikowski, 2015; Sergeeva et al., 2020). Actual or potential harms have been traced to roboticists' normativity (Brandão, 2021), unexamined assumptions about users (Cheon & Su, 2017), or values that recapitulate harmful social dynamics (Benjamin, 2019; Castañeda & Suchman, 2014). In response to these findings, many studies have urged the adoption of specific design frameworks or theoretical perspectives (Johnson, 2023; Wagman & Parks, 2021). These laudable interventions have had uneven success and much of technical robotic research seems to continue to see its work as minimally connected to ethical or societal concerns.

This study, based on over a year of participatory observation in a robotic autonomy research laboratory, traces the intricate social dynamics of robotic development activities to answer the following research questions: What sociomaterial practices accomplish robotic autonomy? For whom is the accomplishment of robotic autonomy a form of agency? What is the meaning of robotic autonomy and the agency that results from it? We were surprised to find that robust, genuine, and prosocial practices of care were central to technical robotics research as practiced in our site. Acknowledging and building upon these preexisting forms and sources of care is, we argue, an under-explored avenue for ethical intervention in robotics. Our findings contribute to an emerging body of research seeking ethical and prosocial potential in roboticists' existing practices (Cheon & Su, 2016; Fischer et al., 2020). The care practices we locate within technical robotic autonomy research reveal that the issue of care in robotics exceeds the bounds of specific applications or outcomes of robotic autonomy (Coghlan, 2022; Santos et al., 2021). Extending Liboiron's (2016) arguments that care and solidarity must inform interventionist research, the possibilities for new engagement with robotics we uncover suggest viable pathways for the *reconfiguration* of robotics (Coeckelbergh, 2021; Serholt et al., 2021), underway in critical human-robot interaction (HRI) which can expand fluidly into *purely* technical subfields like robotic autonomy (Bischof et al., 2022).

Theoretical Background

Autonomy, Agency, and Practice

Common engineering definition of autonomy refers to the capability of achieving its goal or task within a defined scope without human interventions (Ezenkwu & Starkey, 2019). Our fieldwork is intimately framed by the accomplishment of robotic autonomy, which was the overarching goal of the research activities we observed. Influenced by posthumanism and new materialism, we adopt a relational and performative perspective on robotic autonomy, emphasizing the inseparability of humans and nonhumans and the distributed relational dimensions of agency generated through human and nonhuman encountering (Kuhn et al., 2017). This is complementary to prior work by Endacott and Leonardi (2022), who examine autonomy as the level of capability a system can communicate its decisions autonomously with others. Our approach shares with this prior work on the perspective that autonomy, even as typically defined by robotics, is not simply a technological attribute. It is, rather, a co-constructed, negotiated, and contested arrangement of humans and robots intimately shaped by practices and conceptions of *human intervention*.

In light of this focus, it is important to distinguish autonomy and agency. Robotic autonomy is a property of robots that roboticists can achieve. The degree to which robotic autonomy is achieved confers agency, the potential for action, upon the roboticists responsible for it. Robotic autonomy and roboticists' agency are intertwined in our site, and both are socially constructed. They are nonetheless distinct within our data, which has influenced our choice of analytic approach. Social scientists understand agency as a capacity derived from resources, rights, and obligations that individuals have (DeSanctis & Poole, 1994; Giddens, 1979). Latour (2005) advanced an influential, relational take on agency wherein its locus of emergence resides in networks of human and nonhuman others. Critiques of Latour's approach have centered upon the difficulty of recovering the social. Orlikowski and Scott (2015), and, more recently, Leonardi et al. (2012) locate agency in the inseparably sociomaterial practices that continually (re)produce the phenomena we see as technology. Thus, machine agency (*the robot can . . .*) is enacted through sociomaterial practices in which the social and material become constitutively entangled with human agency (*I/you/they can . . .*). This view pushes research investigations toward a consideration of performative enactment of agency and its multiple meanings.

The study of sociomaterial practices builds on the established and rich tradition of practice-based studies of organization. Practice theory, broadly, shares the presupposition that everyday actions are consequential in producing the structural contours of social life and urges researchers to study actors' consistent actions, performances, routines, and patterns as they utilize them in accomplishing their work (Bourdieu, 1977; Feldman & Orlikowski, 2011). While there are variations of practice theory, practice theorists share an interest in analyzing practices and how they are organized to explain social phenomena (e.g., Gherardi, 2019; Tsoukas, 2018). Scholars have theorized and operationalized practice theory to understand a plethora of social phenomena, such as changes in people's work practices as new technologies are introduced (Barley, 1986; Lammi, 2021; Leonardi, 2015), the interdependency of nursing practices and the environment where people experience their health (Bender & Feldman, 2015), the work of pharmacy staff caring for patients and robotics technology to ensure medicine safety (Fudge & Swinglehurst, 2021), how the use of robot representations in design practices shapes user images (Fischer et al., 2020), and how design representations influence the range of innovation outcomes (Henderson, 1998). Additionally, practice theory acknowledges the importance of materiality in the production of social life (Latour, 2005; Suchman, 2007). The relational viewpoint of Orlikowski and Scott (2015) focuses on the mutual entanglement of discourse and the material and emphasizes their conjoined existence. Put differently, humans and technologies constitute a specific configuration through their material engagement that is open to interpretation, change, and reworking (Barad, 2007). This relational and performative ontology helps us focus on the material-discursive nature of the construction of robotic autonomy by considering the inherent relations between humans and nonhumans/robots and the outcome of specific relations.

Care in Technoscience

As our inquiry progressed, we were surprised to see practices of care in our data. From a practice-oriented perspective, caring is understood as a material practice that comes with ethical implications such as devalued labor (de la Bellacasa, 2011). Care practices are omnipresent in technoscience and are typically located in the context of care robots (Frennert et al., 2021; Yuan et al., 2023). Previous research has demonstrated care robots cannot substitute for human carers but instead are dependent on human labor taking care of them (Chevallier, 2022; Kerruish, 2021). Despite the significant role of care practices in enabling robotics technology, care is devalued and invisible due to the social, political, economic structures that produce (human) care (DeFalco, 2020). Influenced by a confluence of philosophical paradigms, such as posthumanism, feminist new materialism (Barad, 2007; Haraway, 2016; Latour, 2005) and indigenous cosmologies (Todd, 2016), scholars advocate for a more-than-human approach to understand care (Lupton, 2020). Care ethics and relevant concepts such as "matters of care" and "thinking with care" (de la Bellacasa, 2017) call for attention to the entanglement of humans and nonhumans in caring relations. That is to recognize the distribution of human and nonhuman capacities in care assemblages and pay attention to the affective dimension of care and how it operates as a practice of knowledge production, as well as shaped by politics. From this perspective, the notion of care expands to a more-than-human dimension and can be theorized as attentiveness to the relations and entanglements between humans and nonhumans (Haraway, 2015; Puig de la Bellacasa, 2017). Lupton (2020) argues that a "thinking with care" approach can generate awareness of the affective, social, cultural, and political dimensions of human-machine assemblages as the condition of our being is always partially formed by others, an intimate entanglement with more-than-human others (Latimer & López Gómez, 2019). Care approaches offer a useful sensitizing lens for investigating caring relations between humans and robotics technologies and understanding how our practices of world-making (e.g., building, making, and representing things) are entangled with nonhumans in different configurations with each having affects and effects on lives.

Following this line of research, the work performed by humans to enable machine capability can be interpreted as more-than-human care. The definition of care varies, for nursing studies, (human) care is defined as "a set of relational practices that foster mutual recognition and realization, growth, development, protection, empowerment . . . [nurturing] relationships that are devoted . . . [to] assisting others to cope with their weaknesses while affirming their strengths" (Benner et al., 1996, p. 13). Swanson's (1991) theory of care offers a similar but more concrete conceptualization—care as doing for, defined as "comforting, anticipating, protective of the other's needs and performed competently and skillfully" (p. 163); enabling "to facilitate the other's capacity to grow" (p. 164); being with as "being emotionally present to the other" (p. 163); knowing as "striving to understand an event as it has meaning in the life of the other" (p. 163); and finally, maintaining belief to "sustain faith in the other's capacity to get through an event or transition" (p. 162). Drawing on feminist approach, Murphy (2015) offered additional definitions. Care means to "provide for, look after, protect, sustain, and be responsible for something"; care also indicates "attention and concern, to be careful, watchful, meticulous, and cautious"; additionally, care is "to be troubled, worried, sorrowed, uneasy, and unsettled" (Murphy, 2015, p. 721).

Anticipatory Care Within Sociotechnical Imaginaries

Borup et al. (2006) argued that science and technology are constitutively future-oriented activities, and they are entangled with promises concerning the prospective impact of techno-scientific projects. Practices such as anticipation work frame projects in a forward-looking sense to cultivate future imaginaries and maintain those futuristic visions. Such practices that consist of actors' everyday lives also move actors toward the imagined future through mundane work (Steinhardt & Jackson, 2015). Connecting to the notion of a sociotechnical imaginary, defined as "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by . . . advances in science and technology" (Jasanoff, 2015, p. 4), these promissory discourses and imaginaries are constitutive and performative in that they drive and legitimize techno-science innovations as well as attract significant interest in the field (Borup et al., 2006; Lipp, 2022a).

However, the imaginaries and anticipation of powerful technology have critical societal implications as they create discourses around expectations, fears, and beliefs about these technologies. These discourses are likely to hype the capability of technologies because they are not necessarily aligned with the existing roles these technologies play in our society (Barbour et al., 2023). Extent studies have shown the gap between what the technology is promised to accomplish and what it achieves on the ground (Fox et al., 2023; Ganesh, 2020; Hsiao & Shorey, 2023; Lebovitz, 2019). For instance, a recent study on robotic recycling technology that employs computer vision to detect recyclables sheds light on the human labor that occurs in the space between what AI technology purports to do and what it actually accomplishes (Fox et al., 2023). However, the imaginative power of machine visions encodes human labor as unstable and invisible (Hsiao & Shorey, 2023). Studies also demonstrate that how a technology, such as a robot, can shape human relations with that technology, regardless of what it objectively is (Coeckelbergh, 2021, p. 199). Through public media representations and discourse, these technologies appear as capable, agentic actors, shaping our understanding of them at the expense of hiding the human labor that goes into supporting them in the first place.

Methods

Site and Participants

Our research site consists of an engineering research laboratory housed in a large university in Southwest North America. There are around 25 robotic engineers affiliated with the laboratory and actively working on robotics projects. They come from various technical disciplines, such as mechanical and electrical engineering and computer science. The majority of roboticists are graduate students, with some help from undergraduate roboticists. This lab specializes in technical robotic autonomy and engineering research. The lab researches a range of problems and applications, and has a history of bipedal humanoid robot development, one of the most technically demanding areas in the field. The lab's research focus areas are not internally seen as inherently related to the more obviously human-oriented fields like human-robot interaction or social robotics (despite the evocative nature of, for instance, humanoid platforms).

Our fieldwork focused on two robot-centered research projects actively designing, developing, and building robots, aligning well with our goal of understanding the sociomaterial practices that constitute robotics. The first project revolved around the development of a humanoid robot Dra (pseudonym). The teams intended to make Dra walk and complete various simple tasks such as opening a door, opening a bottle, picking up things, via pre-programmed codes and teleoperation. The second project centered around the design of a chair-looking robot (BBot, pseudonym) for transportation of hospital inpatients. In total, 16 roboticists have worked on these two projects since our observation. All participants' names are pseudonyms.

Data Collection and Analysis

We have conducted a year of ethnographic observations in the engineering laboratory and multiple semi-structured interviews with seven key members working on these projects. We conducted 45 field visits in total, each visit consisted of between 2 and 5 hours of fieldwork.

As our fieldwork evolved into a study of care in robotics, we deliberately incorporated a care ethics approach. Part of our method is caring *alongside* our participants as a component of our participation in the site (Tillmann-Healy, 2003). This approach does not prevent access to the epoché attendant to interpretive insight (Pedersen, 2020; Throop, 2018) but rather grows from a direct result of epoché and authentic participation in the site. The first author immersed herself in the site by not only participating in the public spaces but also attending the private spaces where participants struggle to make meanings of their work and engaging deeply and sincerely with the participants' everyday experience. Interpretive work like such requires enacting of care and attending to the caring relations between participants and researchers, as the participants naturally change their behavior in an effort to care for the researcher (Toombs et al., 2017). By entering our site seeking out what matters to our participants, we are led to care alongside them. When we care, and even hope, alongside our participants, we gain access to their lived experience not otherwise available to inquiry. Resonating with friendship method that invests in participants' lives and puts fieldwork relationships on par with research project, we approach our participants from "a stance of friendship, meaning we treat them with respect, honor their stories, and try to use their stories for humane and just purposes" (Tillmann-Healy, 2003, p. 745). Instead of approaching the site with an objective perspective of the researcher characterized by a bracketing of researchers' values and vulnerabilities, we must acknowledge the values and ideologies necessary to engage with social issues to curb in interventionist tendency (Toombs et al., 2017). The othering inherent to "objective" observation has a place in this site but is in need of a complementary approach that seeks to locate ethical potential by suspending ethical judgment that we would normally bring to our research.

We adopted Grounded Theory (GT) to approach data collection and analysis (Charmaz, 2006). We sensitized our analysis with theory of care (Swanson, 1991) to interrogate the situations that form the structure of the studied phenomena, roboticists' actions and responses to issues, and consequences of actions/interactions. While we apply theories of care in a robotics context, we acknowledge the differences between roboticists and nurses in terms of their work culture, environment, means of care and subjects of care (Trainum et al., 2023). Nonetheless, the premise of our approach is that the categories of care that nursing scholars have articulated through decades of research on the nature of their profession and its sociocultural history (Swanson, 1993) are an apt theoretical instrument for seeing and understanding acts of care in the laboratory that we might not otherwise notice. Upon the completion of data analysis, we conducted a member check with participants and nonparticipant roboticists for external validity and ensure the participants' perspectives are represented.

Results

As we sensitized our inquiries to themes of care, we increasingly saw the relationship between the team and the robots as a kind of carer-patient relationship. We illustrate each type of care (summarized in Table 1) through care practice sub-themes specific to our site, drawn from specific events or interview data.

TABLE 1 Categories of Care Practices With Examples (Discussed Further in This Section)

Care Practices Category	Examples
Anticipating/Protecting	Teaching each other how to physically support Dra, marking parts of the lab with tape for clarity Rewiring BBot's cables so they could not get caught or snag
Accommodating Inability	Pre-opening ramen and carrying water for Dra Making Dra bigger feet
Maintaining Belief	Neatly wiring BBot in unseen areas under body panels [Re]telling stories of how robots will become useful and relevant when introducing Dra and BBot
Knowing and Showing	Celebrating Dra's first time successfully opening a bottle Staying off camera in the demo video until after Dra is shown cooking ramen

Care as Anticipating and Protecting From Harm

The roboticists look after, protect, and are responsible for progressively developing new abilities for the robots they work with. They are careful, meticulous, and cautious about their actions as their changes in the robots can impact robot performance and accomplishment of autonomy. I explicate these care practices in the section that follows.

Collaborative and Embodied Practices of Protection

Though the roboticists identified the robot's safety with specific physical tools or devices, the robot was kept safe by collaborative, embodied practices instituted and revised by the team itself. Dra was connected to an adjustable tether mounted to the ceiling and via a harness on its torso. Roboticists explained the harness, which prevented the robot from falling or exiting the testing area, was critical to protect the robot and reduce any damage, especially if they had to use the "emergency stop" button to stop its motors. Other protective devices were more informal or even improvised. Later, when Dra had to be placed horizontally on a desk to facilitate some repair work, the roboticists carefully lifted Dra and placed it on the desk with thick foam layered on top as cushioning.

The extensive equipment dedicated to the safety of the robot nonetheless required that roboticists use their bodies to avoid damage. On a subsequent visit, the team was training Dra to autonomously complete a simple task—grabbing a hammer-like object and placing it in a box—with new code they had written for this purpose. During each release of Dra, it took several people to coordinate the effort. Specific protective actions, sequences of embodied movements coordinated amongst the team, and improvised marks in the laboratory were integral to maintaining Dra's safety. Each time the code was tested, Tangerine put his feet on the heel of Dra to maintain its stance, since stability was required for the task but not something the code directly provided. They launched Dra again, Tangerine was standing aside to watch the experiment while John was holding Dra, Tangerine kept reminding him, "You should hold it (Dra)!" When it was Thomas's turn to hold Dra, John patiently explained to Thomas about the specific sequence of the action: one hand on the tether's switch to drop down the robot, one hand on the robot. As new conventions were proposed and accepted, Dra's position with respect to the table and the hammer on the table was memorialized on the floor and the table with bright-colored tape so each team member could more easily perform this alignment. The harness and other safety equipment were necessary but incomplete for keeping the robot safe.

This was a moment of collaborative improvisation and standardization of practice. Roboticists constantly revised their practices to protect the robots by not only providing physical support to protect the robot. Roboticists pointed out technical artifacts such as the harness as key aspects of keeping the robot safe, but ultimately accomplished this goal with their bodies. Multiple bodies were required for several repeated tasks, leading the team to instruct each other to perform these protective actions are done correctly.

Monitoring and Anticipating Needs

Roboticists carefully monitor robots' behavior and make design modifications to anticipate issues robots may encounter and their needs to safely operate in a human environment. While this might be interpreted as especially prudent engineering practice, we observed it tinged with an emotional meaning and valence that sharply distinguished it from the *move fast and break things* ethos that permeates technology and technical research. Researchers spent two of their most limited resources on these anticipatory care practices: time and attention.

One afternoon, members of the team had gathered around the BBot and were trying to solve their issues. Miles constantly asked Peter about electrical issues such as rewiring the robot's cables, because he was worried that the cables would be stuck in the way when

BBot moves. Therefore, he tried to shorten a lot of the cables and wrapped around the good ones instead of cutting them down. Miles also tried to find a spot to install a thermometer to detect BBot's temperature change because they were worried about BBot overheating.

Miles took care of the robot by anticipating the issues the robot would encounter with the extraneous wiring. He identified that the main concerns were the power distribution of BBot and the wiring work was done awfully. He was committed to do the rewiring to facilitate BBot's free movement. He also anticipated that BBot may overheat which would lead to hardware damage, so he tried to install a thermometer to enable real-time monitoring of the robot's condition. By anticipating the issues BBot may encounter and its needs, Miles protected BBot from potential breakdowns. On the other side of the laboratory, Dra was going through a testing session. Dra was getting a little heated, with its arms swinging. Thomas argued to terminate the test instead of stretching Dra further, team members were worried and started constantly touching Dra to gauge its temperature. Soon after, John called to stop the testing because Dra's posture was off. In a similar fashion, John and Thomas were invested in monitoring any abnormal behavior from Dra, such as rising temperature and worrisome posture. Through these acute observations, they anticipate the potential breakdown of Dra and take protective measures to reduce damage.

Care as Accommodating Inability

Roboticists see a malfunction as impacting robots' capability, as soon as they discover a software bug or hardware issue they diligently research to understand and diagnose the problem with the goal to restore the robots' ability. They engage with one other to collectively make sense of what might have led to its inability and come out with creative solutions. Breakdown may delay roboticists' research and publication progress which may act as an external motivation for diagnosis and repair. However, in moments of breakdown, roboticists were occupied with the thoughts to understand the issues of cause and eliminate obstacles that hinder the robots' capability rather than considering the external problems to which breakdown may lead. This separates practices of caring to restore robots' capability from acting due to external problems. Diagnosing overlaps with supportive practices such as repair and tinker but it focuses on the dimension of knowing and understanding robots and breakdown.

Accommodating the Robots' Inability

There are many occasions when the robot cannot complete the tasks due to its design constraints and incompatibility with the environment. However, the roboticists rearrange the environment and even redesign the task to enable the robots. When the humanoid team was testing Dra's capability to grab and put down a hammer, it was difficult for Dra to reach the items on the table due to Dra's limited range of motion. The team marked the floor and the table with bright-colored tapes to ensure they put Dra, the table, and the items on the table at the same spot where Dra could reach the items. Similarly, during the session of training Dra to cook ramen, the team opened the ramen package ahead of the shot and provided a plastic seasoning bottle, since the small foil seasoning packet was difficult to manipulate due to the design of its grippers. The task of pouring water into the pot was taken out of the planned shots because of its potential to damage the robot if water were to spill on it.

The roboticists redesigned these tasks to make them feasible for Dra to perform and they did so off-camera to avoid weakening Dra's perceived ability. Roboticists deliberately manipulated the environment and the robot's situation within it to accommodate its current abilities. This was a departure from earlier efforts, which had focused on increasing Dra's abilities. The apparent autonomy and capability of the robot in the video demanded the human practices of care we observed. Recalling and interestingly inverting Lipp's (2022a) findings on the reciprocity of care robotics, the relations of care became reciprocal when the roboticists are shown eating ramen prepared by the robot they care for.

Becoming Skilled at Repairs

Even with roboticists' careful and meticulous handling of the robot, breakdowns are frequent. Roboticists spend a significant portion of their time repairing robots in social groups. This is because repair is not just an occasional inconvenience; it is an integral part of development. On the technical side, repair work fixes technical problems; on the other hand, repair entails caring for the robot through careful monitoring and meticulous tinkering to improve the design and functionality. In an interview, Miles scrupulously explained to me his inquisitive tinkering work on BBot, hoping to find out a solution to enable its functionality. Dra has also gone through countless sessions of repair and redesign. The team installed bigger and wider feet for Dra to achieve a better and stable stance; they have also installed electronically adjustable tether to release Dra from the ceiling much easier. Repair is not about recovering a status quo of Dra but rather about creating a new set of practices and possibilities for Dra to work.

Repair work involved creativity, experimentation, and the display of skill. This dynamic at times recalled aspects of nursing practice, where skills combined from each nurse's experience and personal experimentation enable efficient and effective care that is nonetheless typically devalued in relation to other kinds of work. When Dra needed repair of broken motors, Peter's repair work was treated by all involved as mundane, but it required knowledge about the source of breakdown, where to repair, and how to proceed with the repair. Peter soldered the wires connected to the newly installed sensors and an amplifier, and finally blow-dried the fuse. He told me that he learned some of these skills from previous work but mostly just from playing around to see what would work. The contrast between the mundaneness of repair work and its difficulty generated a need for narratives that gave the work meaning. John, who had also participated in Dra's repair, told me the tedious process of repair and that he remembered one time they spent around 2 hours on just one stripped screw, and still failed to fix it. Such stories memorialize the frustrations of the lab, but also celebrate their diligence in resolving issues that have arisen with the robot. These narratives cement roboticists' identities as diligent, creative tinkerers and give meaning to the frustration they endure in resolving robots' incapacities into the functionalities required for autonomy.

Care as Maintaining Belief

Like most research robots, Dra is regarded as an impractically expensive technological failure in relation to the autonomous humanoid robots its creators strive to make not only possible but commonplace. Nonetheless, the roboticists we observed still pour in their energy and time to try to understand its design and breakdown, and better the design of the robots. The stories shared within the lab during moments of celebration, repair, and group troubleshoot sessions help to sustain their belief that one day, the robots will be capable of completing the tasks and achieving autonomy.

Beautifying Robots' Appearance

Throughout the initial phase of BBot design, aesthetics was a priority, and it was being repetitively emphasized during group meetings and directed oriented design efforts toward an aesthetically pleasing prototype, as judged by the designers. During the interview with Jack, the lead of BBot project, he specifically stated his design goal was to make BBot look cute to show friendliness. To do that, he had been working on making the outer shell a panda design that would cover the mechanical and electrical core of the robot. Resonating with this intention of beautifying the appearance of BBot, Miles's rewiring work on BBot not only serves a protective function, but his work also situates in the effort to make BBot look nice and professional, even though all the wiring work would be covered by the shell as a final product. In a sense, the rewiring work is unacknowledged and invisible to the end users. However, this was not Miles's concern as he dedicated himself to make the cherished robotic creation look nice to the best capability possible.

Envisioning Robots Benefiting Humans

Throughout my field work within the robotics laboratory, we have heard of multiple versions of the same stories that robots would benefit *users* (so-called, despite the fact that no participants were involved in this research) by improving their lives. These stories were futuristic in nature, however, they direct concrete design objectives that seek to bring the imagined future into a reality. The stories were created and shared during a wide variety of kinds of group work sessions. For example, Miles, Jared, Peter, and Jack shared the vision that BBot will free nurses' time from wheeling around patients in wheelchairs and delivering items, so nurses can be more efficient at their jobs. Mirroring a broader trend in the literature (Trainum et al., 2023), nurses were not directly involved in the project, indicating that these narratives may envision a form of robot relevance not shared by those in the site of potential deployments.

John stated that humanoids would achieve more human-like capabilities and they could use these capabilities to save human lives by, for instance, going into places to rescue people in disasters. When Jared was asked about why he chose to be a roboticist, he said that he believes there is a hope that robots can help humans and make our lives better. He affirmed his belief in that robotics technology will do good for humanity by replacing labor from dangerous jobs,

> . . . in particular the idea that you want to reduce the need for humans to do dangerous, dirty, dull jobs . . . So, what jobs do we have today that are horribly dangerous that we can make robots to do so that people don't have to do those dangerous jobs . . . ? If the thing that I'm building is assistive technologies to help the elderly live more autonomously. So that they're able to sort of preserve a sense of autonomy later in life . . . they (robots) are giving them a better life, like allowing them to feel the agency over their day-to-day lives and feeling like they can complete tasks. (Jared, Interview)

Such narratives convey roboticists' hope and coordinate care practices that carry out specific tasks to enable the robots. Maintaining belief that their robots will do good in society, even without specific evidence to back it up, helps the team stay motivated and focuses on the labor-intensive caring practices for individual robots that may or may not realize this potential.

Demos and In/Visibility: Care as Knowing and Showing Robotic Ability

During meetings and informal gatherings, demos are frequently employed so that the team can have direct experience of a robot's potential capability. This experiential knowledge of the robot's potential is a prerequisite for effectively showing it to audiences outside the lab. Demos come in various forms. Typically, they are video or image representations of the robots that are created via computer simulation or photo software. For example, Peter showed a short simulation video of Dra stepping through a door to prove that in theory, Dra is capable of such movement. During our initial visit of the laboratory, the lab lead enthusiastically explained the goal of a robotics project with vivid pictures that depicted robots being integrated into a community, while human operators were in an observatory where they can *see through the eyes of robots*. Other times, demonstrations were physical. For example, members of BBot project physically operated BBot to move around in the laboratory via controlling a joystick, even though the goal was to have BBot transport a person sitting on top autonomously. These forms of demo are communication tools to facilitate roboticists' collective understanding of what the robots might be capable of despite their actual inability in any given moment of a project.

"This Is the Future!": Coming to Know Robot's Ability

Roboticists are thrilled about, and they cheer for, the robot's accomplishments, even though many of these accomplishments may seem objectively unremarkable. There were many times during the experiment that Dra successfully completed the tasks (e.g., grabbing the hammer, holding the bottle and taking off the lid) after tons of failures, the entire team gathered to celebrate for the brief moment of success. One excerpt from the field notes demonstrates the performative nature of celebration as practicing care.

> One such moment unfolded at a late night in the lab, the entire team gathered in anticipation. The lab was in silence, because all the eyes were fixed on the robot with undivided attention. As the robot slowly reached for the bottle and opened up the lid jitteringly, the leader of the chair robot team could not contain his excitement and broke the silence, he declared *"This is the future!"* Everyone was cheering as if they all believed that this small victory was a glimpse into a world yet to be realized, a future where robots seamlessly integrated into our lives. This successful moment was captured and became one scene in the demo video. (Dra teleoperation, Field notes)

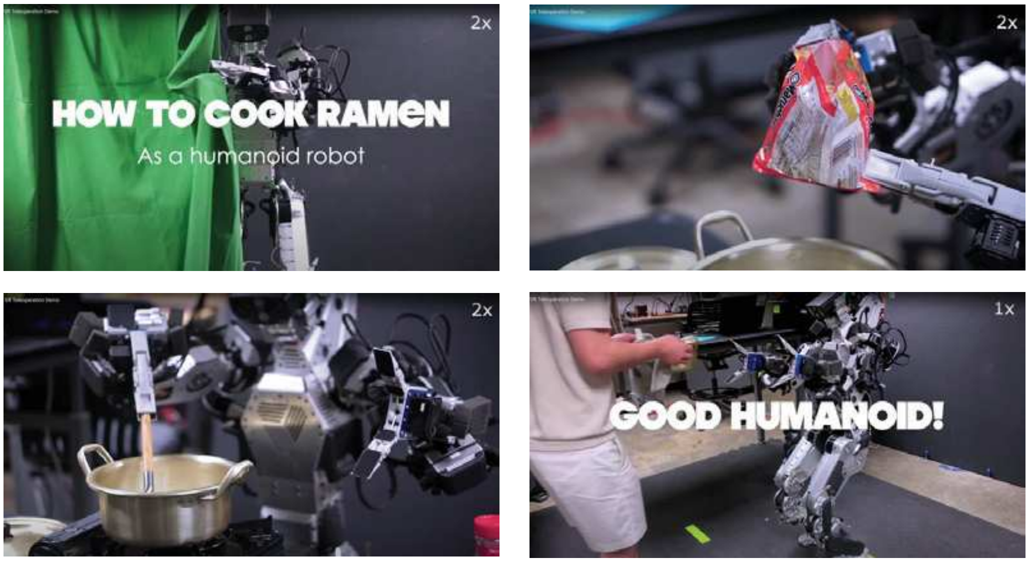
This process almost parallels the practices of taking care of a paraplegic patient to facilitate their capacity and celebrate the robot's achievement. Celebration of the small victories of still-incapable robot performatively establishes meanings of all the mundane work that goes into supporting and enabling the incapable robot. The proclamation, *this is the future,* functions to validate the sustaining beliefs and anticipatory hopes of the robot's capability. Moments of such victory, though based on realizing a concrete design objective, are part of the cultural imaginary that celebrates success and imagines a future of successful technology. Through this, they create a narrative that anticipates the becoming of robotics technologies and maintaining a hope that robots will be beneficial for humanity. Small victories like this were captured and they became critical scenes in demo videos that were meant to promote robot's transformative potential through removing certain human and nonhuman elements and highlighting robotic capability. The demo videos perform the possibility and manifest the imaginary of robots' integral part in imagined everyday futures.

Showing Robotic Abilities With Invisible Assistance

The protective and enabling practices performed in the lab are essential to culminating a futuristic vision indicative of the potential role robots play in our future society, pushing technical development closer to the goal of robotic autonomy. This process includes roboticists maintaining the (in)visibility of certain processes and specific human and material actors. That is, the roboticists' support of the robot is systematically obscured to an external audience, even in videos recorded within the lab itself. Chevallier (2022) and Lipp (2022a) interpreted backstage intervention in the external perceptions of robots in their sites as a form of *staging*. While there was undoubtedly a theatrical dimension to the demonstrations we observed, we interpret roboticists' practices of obscuring their own agency as a stepping back to enable the robot to perform a culminative display of its emerging autonomy. Roboticists participate in the culminative achievement of robotic autonomy through their physical support, constant monitoring, anticipatory care, and experiential skills, but the demo itself can only be performed by the robot.

The team produced a video demo of which still frames are shown in Figure 1, to showcase Dra's manipulation capabilities via a cooking task. The video opens with a "How to cook ramen (as a humanoid robot)" overlaid as a curtain pulls aside to reveal the mechanomorphic robot, which raises a hand and waves. Upbeat music plays in the background and the video is not narrated. The video proceeds through a series of numbered and labeled steps where Dra, alone in the frame, picks up and places a pot on a burner, adds instant ramen from a plastic bag into the pot, adds seasoning from a plastic container, replaces the lid of the pot, and stirs the ramen. The final step is labeled "Serve it to your favorite human." After Dra hands the pot of ramen to a member of the team, the overlay reads "Good humanoid!" The video concludes by cross-fading into an oblique shot of three roboticists eating ramen (an allusion to the post-credits genre of vignettes). The video was shared with a description reading "Excited to share our latest collaborative work on humanoid robot behaviors with [Dra]. We look forward to a day that these robots can help us at home and at work to perform dull and time-consuming tasks!" The "Good humanoid!" overlay performatively memorializes the acquisition of identity the robot's abilities precipitated.

FIGURE 1 Still Frames From a Demo Video Showcasing Dra's Manipulation Capabilities



Note. The robot is teleoperated by unseen roboticists. A seen roboticist is receiving the cooked ramen (bottom right).

Such lighthearted videos are not uncommon in robotics research. The team adhered to disciplinary norms of transparency by, for instance, overlaying the degree to which the video was sped up (from 2–4×; see upper right of each frame in Figure 1), a common practice that shortens the videos and, perhaps not incidentally, makes robotic motion seem smoother. Furthermore, the video's title clearly identifies it as a "VR teleoperation demo," rather than depicting a fully autonomous robot. Nonetheless, with the contrast between the effortless actions of Dra in the video and the team's extensive backstage efforts to make them possible, it is clear that the video obscures or excludes many actors and processes, some of which were just outside the frames of the video. Supporting and enabling mechanisms such as numerous cables, the tether, and the human operator that controlled Dra's movement via a VR headset were carefully excluded from the camera's field of view. Off-camera, roboticists opened ramen packets and poured water into the pot to set the scene.

The video demo's occlusion of the many forms of support enabled Dra to become a competent robot chef, cooking ramen and serving it to its humans. Many of these forms of support were skillful actions by the roboticists, but it was the skillful hiding of that care that ultimately enable the robot to perform autonomously. The roboticists' withdrawal from the field of view also enabled Dra to present a futuristic vision of robotic capability and the societal relationship with humans this could enable. The configuration of in/visibility of process and actors enabled Dra's performance of autonomy, sustaining belief that this incapable robot could come to matter, socially.

Discussion

In this site, the primary activity was the resolution of robotic inability into, ideally, the capabilities constituting robotic autonomy. This ideal was only partially accomplished, yet the team discerned incremental progress toward it and celebrated intermediate results as shared achievements. Our results detail the range of care practices employed toward this larger goal. By endowing the robots Dra and BBot with these capabilities through practices of care, roboticists simultaneously acquired and experienced the core agency of their profession. Then, by skillfully removing themselves from the frame, the robots were able to perform and locally realize a hopeful, meaningful future of societal relevance. This long chain of actions culminated in a depiction of reciprocal care, where robots could provide for the humans that provided for them. The centrality of care practices in this site and the culmination of these activities in reciprocal forms of care suggests that Lipp's (2022b) call for reciprocal forms of care in robotics is already partially realized in ways that have not been fully appreciated.

When we first visited the laboratory, we noticed the humanoid Dra connected to numerous cables that linked it to computers, power outlets, cameras, and a myriad of other systems. With retrospective sensitization, underneath the technical veneer of the workspace, the arrangement was reminiscent of an operating theater, an intensive care unit, or, most aptly in light of later insights, a rehabilitation facility. In brief, we found that care practices accomplish robotic autonomy, resulting in personal agency for roboticists, shared agency for the team, and a projective agency for the robot. The projective agency for the robot was accomplished in the form of the demo, where roboticists removed themselves from view to better show the robot's abilities. Although interpretations of similar practices observed in prior work, including *staging* of robots (Chevallier, 2022; Lipp, 2022a), exaggerations of machine power and diminishment of the role of human labor (Curchod et al., 2020; Xu, 2023), and the imaginary of powerful machines (Campolo & Crawford, 2020) are certainly available, our results suggest a new and complementary interpretation. Following the through line of authentic, sincere, and pervasive practices of care, we highlight emic ethical motivations behind these practices that demands expression in the interpretation of their meaning.

Care for the Unable Other

Care practices resemble the modes of care practiced by nurses, such as dressing patients up nicely even though they are unable to leave the care facility (Næss et al., 2016). The medial irrelevance of appearance is nonetheless a key form of nursing care that recognizes and endorses patients' societal relevance and value, despite their state of inability. Roboticists *dress* their robots to care for them, in deliberate ignorance of the robots' inability and the technical superfluousness of these adornments. These care practices sustain the appearance of a capable robot, endorsing the robot's societal relevance despite its (current) inability. The belief in the possibility of robots' societal relevance and eventual participation is a difficult but critical form of care in caring for the unable other.

Unlike practices of care for human patients, this vulnerability was not a source of rapport or empathy: the robot was not seen as having the emotional capacity to reciprocate their care. Our participants explicitly disclaimed anthropomorphizing the robot, a pattern Chun and Knight (2020) observed as characteristic of the technical teams. Nonetheless, Dra was a social presence and its states and actions had social meanings to the group. This suggests that their experience was sociomorphism: the attribution of socially meaningful capabilities and states to inanimate objects (Seibt et al., 2020). Our participants' care practices were deployed within the largely unexplored space between full anthropomorphizing and non-affective relationships to the robots. We did not observe the combination of robot's emotional relevance and its sociomorphic status perceived as a paradox or contradiction by roboticists in the site. This implies, however, that in addition to whatever inabilities the team was attempting to remediate, their practices were deployed toward an un-able other able to reciprocate their care only in pantomime (cooking and serving ramen in a demo video).

Caring by Demonstration and Repair: Experiencing Agency by Hiding It

The complex dynamics of in/visibility shaped roboticists' experiences of their own agency. Despite its importance and that repair work is necessary to achieve autonomy, practices of care were withdrawn or rendered invisible in culminating moments of demonstration. The care practices employed in our site were simultaneously required to achieve the team's goal and yet must be rendered invisible to demonstrate progress toward it. The ultimate invisibility of skillful caring interventions was itself a skillful form of care, a recognition and endorsement of the worthiness of its robotic recipients. The audience to whom the labor is made invisible is external to the site of care. Similar to a nurse grooming a patient before a family visit, roboticists willingly and capably obscure the labor that enables their robot to participate in social relevance.

The findings accord with Lipp's (2022a) study that a group deploying a care robot staged its autonomy by introducing a spatial divide between the front- and backstage, and frequently breached this divide by way of skillful repairs that would later be rendered invisible to accentuate the robot's ability. Chevallier (2022) found interactions with a social robot in a residential facility for older adults were *staged* to accomplish a certain idiosyncratic conception of success for the grant-funded initiative. Our site featured capable autonomous robots and almost invisible roboticists on the front stage during demoing. Behind the scenes, we saw frail robots that were cared for by the concerned and worried roboticists. These robots are roboticists' cherished creations, and they represent the hard work, and most importantly, their identity as engineers. The work of repairing and redesigning, not just to maintain their functionality but to make them look better and more capable, recalled the practices of "assisted self-presentation" employed by nurses in assisted living facilities (Næss et al., 2016, p. 154). These practices acknowledge the social relevance and identity of patients. For roboticists, similar practices acknowledge and validate the social meaningfulness of their robots (Seibt et al., 2020).

Repair work is integral to robotics development. It sustains possibility, belief, and hope as anticipatory dispositions through periods of frustration and disillusionment. Care practices in this robotics laboratory included repairing, tinkering, exploring the configuration and balancing of sociomaterial relations that together accomplish autonomy. As Winance (2010, p. 111) argues, the work of care involves "a transformation of what these entities are . . . of what they do and, above all, of the way in which they are linked to one another." However, the work of care simultaneously creates the "cutting" of robotic work and precludes certain arrangements between humans and nonhumans from becoming (Barad, 2007, p. 394). Care sustained by repair work creates the perception of robotic autonomy by rendering invisible the constitutive human and technical labor that goes into maintaining it (Lipp, 2022b). As Elish and Watkins (2020, p. 2) urged, "recognizing repair work shifts our focus from those who initiate a project to those whose work and skill is required to make the project work out in the world." Much of current robotics research is populated by prototypes and made available to the public through demo videos and pictures. The public perceives these robots differently via representations from roboticists' understanding of their robots (Fortunati et al., 2022). Despite the intense human labor involved in robotic autonomy, the demos construct agentic and autonomous robots that will soon be our reality by talking autonomy into being (Castor & Cooren, 2006; Laapotti & Raappana, 2022).

Maintaining Belief: Anticipatory Narratives Sustain Care

The imaginaries roboticists actively produce and maintain give meaning to the tedious and mundane work, sustaining these efforts by making them ethically meaningful. Our data shows how care practices that might easily be seen as solely achieving concrete design tasks are oriented toward a sense of building and maintaining robotics futures. Anticipatory behaviors are integral to roboticists' collaborative work. Anticipatory narratives they create, share, and continually re-create enable distributed coordination and calibration of action toward the otherwise imperceptible robotic future that gives them meaning. Meaningful action upon robots gives roboticists access to an identity ultimately defined in relation to this robotic future (Steinhardt & Jackson, 2015).

Robotic autonomy is a precarious achievement that needs to be maintained not only technically but as Lipp (2022a) has emphasized, communicatively. Sustaining narratives of realizable futures of robotic agency are created socially via group work. Small-scale interactions like these help robotic team members transmute frustrating everyday technical barriers into progress toward meaningful, if speculative, purposes. Care practices, the coordinated organization of human work (as in labor) to make robots work (as in function) are thus a mode of creating and experiencing shared identity. Through shared practices of caring for the unable robot, roboticists gain the ability to participate in the narrative of robotic benefit for humanity. The performance of care accomplishes a deeper meaning for this work and the identity of the roboticists. Celebrating small victories of development as achievements of the robot gives them access to future imaginaries of beneficial robotic agency, reinforcing their motivation to work toward this goal. Core to these narratives is the hope in which they believe, a hope that one day their robotic creations will truly better our lives. In our case, hope serves as a powerful anchor that gathers roboticists to devote their time into caring for the robots. By understanding hope, we also acknowledge the fundamental uncertainties and precarities of robotics development work and recognize what brings together these collaborative care practices and what sustains them.

Limitation and Implication

The study's focus yields several limitations. Like much of the field of social studies, our positionality as academics researching an academic robotics laboratory narrows the scope of voices that might contribute to this story. The study did not fully address the power dimension that may have partially resulted in the compulsory aspects of these roboticists' care. This complicates the picture of care as a positive force, especially because robotics training, like many areas of academic technoscience and engineering, is a path to (varying degrees of) financial security, wealth, prestige, and power. As we have acknowledged throughout, the achievement of robotic autonomy is not an ethically neutral pursuit. The care we are focusing upon is not exculpatory for the field's adjacency to the military-industrial uses of robotic technology, for instance. Nor does it invalidate other interpretations of these behaviors, such as Campolo and Crawford's (2020) observation of the construction of enchanted machines. Ultimately, the inherent limitations of our project redound to its urgency and the need for ongoing engaged scholarship in sites of technological meaning-making.

This study demonstrates the importance of the robotics research laboratory as a site of human-machine communication and ethical technology research. We show that robotic autonomy is achieved via material-discursive practices of care for the robot as an unable other, sustained by anticipatory and hopeful narratives of future ability. The technologists in our site are, admittedly, not immune to the temptation of self-serving, exculpating, and potentially harmful sociotechnical imaginaries uncovered in prior work. Nevertheless, we argue that the configuration of the robotic autonomy research laboratory as a site of genuine and prosocial practices of care demands a rethinking of the terms of ethical intervention. The configurations of human-machine relation in our site suggest the potential for much broader participation in the futures imagined and partially realized in the laboratory. Our finding of practices of care at the core of robotic science offers a deeply empathetic starting point for reshaping our shared and ongoing entanglement with technology.

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