Reconfiguring Boundary Relations:
Robotic Innovations in Pharmacy Work

Robotics is a rapidly expanding area of digital innovation with important implications for organizational practice in multi-occupational settings. This paper explores the influence of robotic innovations on the boundary dynamics of three different occupational groups — pharmacists, technicians, and assistants — working in a hospital pharmacy. We extend Pickering's tuning approach to examine the temporally emergent process that entangled the mechanical elements and digital inscriptions of a dispensing robot with the everyday practices of hospital pharmacy work. We found that engagement with the robot's hybrid and dynamic materiality over time reconfigured boundary relations among the three occupational groups, with important and contradictory consequences for the pharmacy workers' skills, jurisdictions, status, and visibility.

Robots have long captured our imagination as high-tech innovations. The robotics field has expanded into a multi-billion dollar industry, with robots being adopted within numerous work settings — including factory floors, deep sea exploration, emergency response, hazardous environments, and healthcare (Lanfranco et al. 2004). The increasing use of robotics is expanding the digitalization of work processes (Yoo et al. 2010) throughout organizations. As a result, the conditions and consequences of integrating such digital innovations into the workplace are important areas of inquiry.

Prior research on technological innovations and particularly digital innovations has found that they play an important role in reorganizing work among different occupational groups; for example, altering roles and relations across diverse work contexts (Zuboff 1988, Barrett and Walsham 1999), triggering jurisdictional disputes and renegotiations (Barley 1996; Gendron and Barrett 2004), and shifting subgroup interactions in a range of industries. The emphasis in these studies has been on tensions and strains arising between two groups. In multi-occupational settings such as healthcare organizations, these strains may be exacerbated as cognitive, social, and political boundaries among groups inhibit the spread of innovations (Ferlie et al. 2005). Such groups may also use technological innovations to engage in "boundary work" (Abbott 1988) and "distinction practices" (Burri 2008), through which occupational boundaries are fought for, established, strengthened, maintained, contested, or lost over time (Arndt and Bigelow 2005).

Despite some important work on occupational boundaries and innovation, there is currently a gap in the literature in two respects. First, we lack accounts of what happens when multiple occupational groups influence each other as their work and relations are restructured around a new digital innovation. We suggest that going beyond a singular or dyadic focus in understanding boundary work and tensions between groups is important given the increased emphasis on multidisciplinary workplace cooperation that often accompanies such innovation. Second, there has been relatively little attention paid to how the materiality of digital innovations is entangled with the restructuring of work practices and boundaries (Gal et al. 2008, Jonsson et al. 2009). Previous work has emphasized how diverse technologies have served as an *occasion for* social reorganization, rather than how these material technologies might, in part, *constitute*, the reorganization. Thus, analyses have centered on how social agents interact to create new forms of work and relations around the technology, while the material performance of the technology itself has not been given sufficient attention (Orlikowski 2007; Nyberg 2009). Because robots are powerful digital technologies that are increasingly being integrated into organisational settings (Yoo et al. 2010), we believe studying their materiality relationally can yield important insights into how digital innovations are reconfiguring work boundaries and relations in practice.

In this paper, we examine how a newly introduced digital innovation — a pharmaceutical dispensing robot — influenced the work, interests, and relations of three occupational groups within two UK hospital pharmacies. Extending Pickering's (1995) concept of "tuning," we focus on the temporally emergent and iterative change process that entangled the heterogeneous materiality of the dispensing robot with the everyday work practices of the pharmacies. We find that engagement with the dispensing robot reconfigured boundary relations among the occupational groups, with important consequences for the workers' skills, jurisdictions, status, and visibility.

Our study builds on recent work (Gal et al. 2008, Levina and Vaast 2008) that highlights the way boundaries within innovation networks are used by occupational groups as sources of distinction, creating status inequalities as well as sites of cooperation, and blindsiding (intentionally or not) some occupational groups in their practices. We contribute to the literature in three ways. First, we extend Pickering's tuning approach by accounting for the robot's shifting and hybrid forms of digital and mechanical materiality, articulating how these perform together to reconfigure boundaries in the workplace. Second, we examine how boundary relations are implicated in the adoption, appropriation, and adaptation of dispensing robots within the pharmacy, and the resulting consequences for occupational groups' status and control. Third, our perspective opens up a new area of robotics research that emphasizes the entanglement of robotic materiality in relation to multiple occupational groups in the workplace.

In the following sections, we review the literature on robots, digital innovations, and boundaries. This is followed by an account of Pickering's tuning approach and our extension of it to examine robotic materiality as performed in relation to multiple groups. We then present our research methods and setting, followed by our analysis and discussion. We conclude by highlighting the contributions of our study and their implications for research and practice on digital innovations.

Robots, Digital Innovations, and Boundaries

Robotic innovations have a relatively long and intriguing history, from early automata in the eighteenth century through the industrial machinery of factory automation to contemporary sociable artificial intelligence (AI) robots (Thrun 2004). Robots have changed substantially over the years as have our conceptualizations of them. Lanfranco et al. (2004, p. 14) note, "Robot, taken from the Czech *robota*, meaning forced labor, has evolved in meaning from dumb machines that perform menial, repetitive tasks to the highly intelligent anthropomorphic robots of popular culture." Thrun (2004) notes the range of definitions of robots in the field, including one from the Merriam Webster dictionary — "an automatic device that performs functions normally ascribed to humans or a machine in the form of a human."

Thrun (2004) argues that robots can usefully be grouped into three broad categories based on their practical applications. *Industrial robots* respond to hard-wired instructions to manipulate objects or navigate physical environments in industrial settings (e.g., a robotic arm that provides precision welding in automobile manufacture). *Professional service robots* are guided by humans to manipulate objects or navigate physical environments in professional settings (e.g., voice-activated robotic arms to manoeuver endoscopic cameras). *Personal service robots* interact with humans to help or entertain them in domestic or recreational activities (e.g., robotic assistants to the elderly or disabled).

Much of the early sociological examination of technological innovations (including robotics) was focused on industrial automation and grounded in Braverman's (1974) treatise on the capitalist workplace, in which he contended that managers seek to reduce complexity and creativity in the labour process by substituting machines for human labour. Managers, he argued, design technology to control and rationalize work, resulting in degraded jobs and deskilled workers. Empirical studies sought evidence for this deskilling thesis in various settings (Burawoy 1979, Noble 1977, Zimbalist, 1979, Kraft 1979), but results were ambiguous and contradictory, and the deskilling thesis was subsequently criticised (Adler and Borys 1989, Barley 1988). More recent work on robotics has shifted away from focusing on automation and the labour process, and towards psychological and cognitive perspectives that explore robot sociability (Breazeal 2002, Sabonovic et al. 2006) and human-robot interaction (Hinds et al. 2004), reflecting the increased prevalence of professional and personal service robots in the workplace.

The pharmaceutical dispensing robot we examined is a hybrid of Thrun's (2004) professional service and industrial robots. On the one hand, the robot is located within a professional service setting (a hospital pharmacy) and it assists professionals in their dispensing of medications. In these regards, it shares characteristics with professional service robots. On the other hand, the operational space of the robot is partitioned off from that of the human workers and most of the robot's operations are hard-wired, reflecting scripted instructions inscribed within the system. These characteristics more closely resemble industrial robots (Thrun 2004, p. 17). The robot thus integrates mechanical components from industrial automation with digital components from information technology (Ein-Dor and Segev, 1993). This hybridity of materialities makes them a particularly interesting case of digital innovations, defined as innovations enabled by digital technologies that lead to "the transformation of socio-technical structures that were previously mediated by non-digital artifacts or relationships" (Yoo et al. 2010, p. 6). Of particular interest here are the implications of digital innovations for the nature and boundaries of professional service work.

In understanding the boundary implications of innovations in professional work, various concepts such as boundary strategies, boundary disputes, and role and task boundaries have emerged in the literature (Ancona and Caldwell 1992, Lamont and Molynar 2002, Vallas 2001, Wimmer 2008). A few scholars have proposed adopting dynamic and relational approaches to studying boundaries, advocating an inversion of the usual priority given to groups before boundaries. In this view, it is not that occupational groups first exist and then enter into relation with other entities. On the contrary, as these scholars argue, people engage in boundary work involving boundary-defining acts of exclusion, which serves to construct and maintain distinctions between themselves and others (Lamont 1992, Abbott 1995). Understanding boundaries as relational thus focuses attention on the dynamic nature of boundaries as they are enacted in practice, and the shifts in boundary relations that may result. Of particular interest for our research is the extent to which such shifts are associated with new digital innovations.

Prior literature on technological innovations has shown that they are often strongly shaped by and significantly influence boundary relations in the workplace (Boland et al. 2007; Holmstrom and Boudreau 2006, Zuboff 1988). In the case of healthcare organizations, researchers have found that technologies can occasion shifts in tasks, roles, and relations, producing new patterns of interaction among occupational groups (Aydin and Rice 1992, Davidson and Chismar 2007). For example, Barley (1986) showed how new CT scanning technology triggered jurisdictional disputes within two radiology departments, changing the task domains of radiologists and technologists, and altering established divisions of radiological work. In another example, Burri (2008) found that a new MRI imaging technology shifted existing practices of image production and interpretation, challenging radiologists' disciplinary authority to read images. Radiologists responded by renegotiating their traditional responsibilities and competences so as to reassert their professional identity and status. More generally, technologies have been studied as boundary objects in knowledge sharing across professional and organizational boundaries (Bechky 2003, Carlile 2002, Gal et al. 2008, Levina and Vaast 2005). While this literature has examined how boundary objects enable and constrain forms of interaction and cooperation (Barrett and Oborn 2010), it has paid limited attention to how these technologies materially reconfigure groups' work practices and boundary relations.

Recent work focused specifically on digital innovations has begun to emphasize the important role of materiality in shaping boundaries and relations in the workplace. For example, Jonsson et al. (2009) challenge the view of boundary-spanning as a purely social activity by arguing that the use of information technology changes the definition of boundaries. In line with calls for greater attention to materiality in organization studies (Leonardi and Barley 2008, Orlikowski 2007, Orlikowski and Scott 2008), they argue that boundary-spanning is a complex socio-technical activity producing new socio-technical ensembles that influence organizational boundaries in both expected and unexpected ways, reinforcing existing boundaries and creating new ones. In another study, Nyberg (2009) explores how the distinctions and boundaries among customer service operators and their computers are not predetermined but co-emerge in the everyday practice of customer service calls.

Theoretical Perspective: Extending the Mangle of Practice

Building on the prior research, we develop a perspective that views materiality as performed relations, rather than preformed substances (Orlikowski 2007), and focus on the multiplicity of views, interests, practices, and hybrid materialities that dynamically constitute digital innovations over time. Such a relational-material perspective extends Pickering's (1995) tuning approach to the study of digital innovations in the context of multiple occupational groups interacting in the same workplace. This approach emphasizes the *mangle of practice* — the "reciprocal and emergent intertwining" through which human and material agencies are produced in practice (Pickering 1995, p. 15). In Pickering's account, human plans, interests, and activities are shaped and transformed during encounters with technologies in relations of innovation, and vice versa. Practices and technologies thus configure and reconfigure each other, while at the same time shifting the nature of the boundaries involved.

Arguing that human and material agencies are temporally emergent, Pickering develops the concept of *tuning* to account for the recursive and unpredictable way in which (human) plans and practices are entangled with technological agency. Tuning is an emergent process of resistance and accommodation that is both generative and entails tension. Pickering defines resistance as the failure in practice for human actors to achieve intended capture of material agency (e.g., electrons not aligning within a particle accelerator), emphasizing that this can only be determined in practice and through a process of emergence. Accommodation, he suggests, is the active human strategy of responding to material resistance. This includes revisions to goals, modifications to the material form of the technology, shifts in human frames and activities, and adjustments in the social or political relations associated with the innovation. Pickering illustrates the tuning process using the example of a scientist developing a bubble chamber to advance research in particle physics. The chamber repeatedly resists the action of the physicist by not producing the desired outcomes. In a series of accommodations, the scientist adapts by building his bubble chamber out of other substances, altering its size, modifying his techniques of experimentation and eventually revising the theoretical assumptions underlying the initial experiments. In this way, Pickering highlights that the social (i.e., plans, interests, knowledge, etc.) is constituted through the material, and vice versa.

We believe that examining robotic innovations in professional service work offers an important opportunity to extend Pickering's analysis. In particular, such workplaces are rarely constituted by single human actors, but rather include multiple groups of actors, thus entailing a diversity of (often conflicting) interests, values, norms, competencies, and practices. As Suchman (2007) has argued, shifts in agencies have political consequences for the redistribution of authority and knowledge within work practices, thus influencing boundary relations and how boundaries are (re)drawn. Similarly, the innovation in question is rarely a singular entity but a shifting and heterogeneous assembly of multiple materialities. In the mangle, what becomes important is where and how one chooses to make the cut analytically. Our 'cut' is to focus on the digital and mechanical materialities of the robot as these play out in relation to different occupational groups in the workplace. Thus, our perspective expands the scope and span of who and what is entangled in the tuning process to include multiple groups and multiple materialities.

Drawing on the various insights from Pickering (1995) and Suchman (2007), we examine how plans and practices are enacted through the process of tuning a new digital innovation, and how this may reconfigure distinctions and boundaries among workers as different activities and relations become salient. Such shifts, in turn, may influence the performance and materiality of the digital innovation, leading to further shifts in plans and practices, and so on, as the tuning process continues over time. Some plans may be more successful than others, materialities may be modified or expanded, new practices may become possible, and knowledge may be created, lost, or reframed. By attending to the recursive accommodation and resistance that entangles the workers, the work, and the digital innovation over time, we account for how specific and shifting materialities reconfigure the nature and boundaries of professional service work, and with what consequences. We found that such a relational-material perspective was particularly useful in our empirical examination of the introduction of a dispensing robot into the work of hospital pharmacies. In particular, our relational-material analysis highlighted how and why boundary relations among different occupational groups were reconfigured through entanglement with the robot's digital and mechanical materialities, and with what implications for the workers' skills, jurisdictions, status, and visibility.

Research Site and Methods

Our inductive field study involved data collection at two hospital pharmacies in the UK, both part of an acute care health organisation called Royal Trust.[1] Data were also collected from field-level actors such as robot vendors and occupational associations, as well as from documents such as healthcare policies (specifically those focused on new technologies in healthcare), robot instruction and training

[1] Names of all institutions and individuals have been disguised.

manuals, and pharmacy procedural documentation. At the time of our study, government policy promoted robots in hospital pharmacies as a way of reducing costs and errors in the dispensing of medicine.

Research Setting

Royal Trust has two pharmacy units[2] (here called Duke and Princess) located in separate buildings some 20 miles apart. While geographically separated, the two pharmacies enjoyed a cooperative relationship, maintaining regular contact and collaborating on common issues.[3] Overnight "on call" coverage was shared between the pharmacy units, so that all pharmacists and most technicians were familiar with both sites. The chief pharmacist, who was in charge of both sites, had close ties with the pharmacy faculty at an affiliated university. At the time of our study, each pharmacy dispensed between 300 and 350 prescriptions daily, and each had approximately 12 full-time equivalent workers, with 7-8 working in dispensing and 4-5 in distribution. Our research access was negotiated with Duke, which was in the process of installing a dispensing robot and developing a research program as part of a negotiated agreement with the vendor for a reduced purchase price. Both the robot and the research program were strongly supported by the senior pharmacists in Duke and Princess, as well as attracting interest from affiliated pharmacy faculty. About a year after the installation of the robot within Duke, the chief pharmacist negotiated a similar deal with a competing vendor, and a dispensing robot was also installed in Princess. We subsequently requested and received permission to also study the Princess implementation.

Both the Duke and Princess pharmacies were responsible for *distributing* stock to hospital wards and clinics, and for *dispensing* medicines to specific patients based on doctors' prescriptions. The distribution staff consisted of unskilled pharmacy assistants[4] who were responsible for maintaining stock levels in the pharmacy as well as the wards and clinics. For the pharmacy, the assistants shelved the tablets, fluids and other stock items delivered daily from the hospital inventory "stores." For the wards

[2] The units we studied were called "dispensaries" in the hospitals, as they are a subsection of the total pharmacy department, which includes such activities as aseptic preparations, ward rounds, stores and purchasing, research and education. We are only focused on the dispensing activities in this study.
[3] In this respect, our hospital site differs from that in Barley's (1986) study of CT scanners, where the two hospitals had no formal relationship or regular contact. In our case, technicians and pharmacists at Duke and Princess frequently worked together to solve issues arising from use of the dispensing robot.
[4] Assistants are not expected to have any prior training before starting their jobs.

and clinics, the assistants picked items from the stock sitting on the pharmacy shelves and delivered it for general patient use within the hospital. Traditionally, assistants needed little supervision from technicians or pharmacists; neither did they need to coordinate tasks among themselves.

The dispensary staff, comprising technicians[5] and pharmacists,[6] issued medications prescribed for specified patients. The dispensing process involved four activities: screening, labelling, dispensing and checking. Only pharmacists were allowed to perform the screening task, while the final check could be done by either pharmacists or accredited technicians, though the latter were not allowed to check their own dispensing. The labelling (typing patient labels onto the medications) and dispensing (picking items from shelves) could be performed by either pharmacists or technicians, though this was most commonly done by technicians. This process of going around the shelves and picking medicine boxes to fill a prescription was considered mundane work, and was often referred to as "shopping." Prior to installing the dispensing robot, pharmacists, technicians, and assistants worked in parallel in the pharmacy, performing interrelated tasks. While the pharmacists and technicians tended to work in the front end of the pharmacy, and the assistants in the back end, the shelving area that occupied the bulk of the pharmacy floor space was used by all workers and thus formed a locale for contact, visibility, and interaction.

UK hospital pharmacists have been strongly encouraged to adopt dispensing robots within their healthcare. Such robotic innovations were strongly endorsed by a policy report of the Government's Audit Commission (*A Spoonful of Sugar: Medicines Management in NHS Hospitals)* issued in 2001. The report cited the potential of robots to reduce dispensing errors and improve pharmacy efficiency, both of which are key concerns in the healthcare field. Within Royal Trust, the business case for dispensing robots was made to hospital administrators by the chief pharmacist, and argued primarily on the grounds of the robot's capacity to reduce errors and improve productivity. A secondary case was made for the robot helping to recruit good pharmacy staff by promoting the image of a modern, technologically advanced department.

[5] Technicians are members of a national body for licensed healthcare professionals in the UK — the Healthcare Professions Council or HPC. They are required to have a minimum of two years of practical college training that emphasises accuracy in identifying and dispensing medicines. It is noteworthy that at the time of our study, technicians' training did not include topics related to technology or systems, but was focused on techniques for correctly managing medications.

[6] Pharmacists are required to complete at least four years of university education, and a subsequent practical training year before being licensed to practice independently.

The first robot was installed in the Duke pharmacy in Spring 2004. This robot consisted of two closet-like modules equipped with mobile picking arms and tightly fit storage shelves arranged in a honeycomb configuration. Subsequent additions to the robot were phased in over time. An extended feed belt was added in January 2005, and a third closet-like robot module in June 2005. Furthermore, a distribution interface system and a medicine ejection chute were installed in February 2006. In October 2005, the Princess pharmacy purchased a larger dispensing robot with a single module.

Yoo et al. (2010) propose a number of characteristics of digital materiality, and a number of these are evident with varying salience in the dispensing robots installed in the pharmacies. The robots were *programmable* in that they allowed the pharmacists to adapt and modify robot operation to accommodate specific layouts and routines. Each robot had a mobile picking arm that could place and remove items from the honeycomb shelves. Though the robots in the two pharmacies relied on slightly different handling technologies, both had a storage capacity of around 10,000 items and used barcodes to store and retrieve items. The robot thus had *senseability* to read the bar codes and *memorability* to store and retrieve the identifier information when supporting the movement of the arm in relation to the physical storage or retrieval of the medicines. Retrieved items were transported via output chutes to the front of the pharmacies for checking by pharmacy staff. The robots' software systems interfaced with the pharmacies' stocking, inventory and purchasing systems (via *communicability, memorability, traceability,* and *associability*). Figure 1 shows a schematic view of the Duke pharmacy before and after the dispensing robot was installed.

* * * Insert Figure 1 here * * *

While assistants were the primary stockers of the robot, all occupational groups could request items from the robot, albeit through different means. Technicians and pharmacists would use the dispensing computers (located at the front of the pharmacy) to access the pharmacy stock system and request items. Through this interface, the robot would respond as to stock availability and which of the robot's output chutes would deliver the item (*two-way communicability*). If available, the robot arm would swing across to its appropriate shelf, pick the requested item, and deliver it to the waiting technician (or pharmacist) via one of the output chutes (terminating at the front of the pharmacy). When items were not available in the robot, the technician or pharmacist would manually pick the required item from the pharmacy shelves. The assistants did not (initially) have access to the two-way stock system. When they required items from the robot (e.g., to fulfil ward distribution requests), they requested these in bulk from the robot's one-way direct control terminal (*one-way communicability*) located near the back of the pharmacy. When items were not available in the robot, the assistants would retrieve these directly from the shelves or from items lying on trolleys waiting to be loaded into the robot.

Research Methods

Our study focused on the everyday organization and performance of hospital pharmacy work as practiced by three occupational groups. We collected data through site visits, observations, formal interviews, informal discussions, and publicly available documents. Our goal was to understand how the plans, interests, activities, relations, and boundaries of the pharmacy workers were shaped and changed during encounters with the digital and mechanical materialities of the dispensing robot.

We spent 20 (interspersed) days of observation at the two hospital pharmacies, and conducted 41 formal interviews with pharmacists (12), technicians (9), assistants (7), as well as relevant administrative workers (2), and key vendor representatives (2). The interviews ranged from 20 minutes to 2 hours, with the majority lasting about an hour. Interviews were conducted in private offices or meeting rooms and were recorded. Key participants were interviewed several times over the period of study. Our interview questions focused on understanding, through participants' eyes, the pre-existing practices and relations of the different occupational groups prior to the robot introduction, the process of procuring, installing, and working with the robot, and the challenges and changes in practices and relations that emerged over time. At the pharmacist level, our discussions also covered strategies adopted by the national association to enrol use of robots in furthering pharmacists' professionalization efforts.

We attended five project meetings held by senior pharmacy staff to discuss implementation strategies and issues faced with the robot implementation. We also reviewed documents generated by the pharmacy research staff, including comparative studies of "before and after" dispensing errors and dispensary efficiency conducted by pharmacy faculty under the auspices of the broader university research program. We also regularly scanned bulletin boards regarding staff news in the two hospitals, as well as the UK healthcare field. Technicians, in particular, used these boards to communicate about registration efforts with the Health Professions Council and ongoing developments with dispensing robots.

Our research sought to answer the question, "What are the implications for work practices and boundary relations of using dispensing robots in hospital pharmacy work?" We analyzed the data in four rounds of coding, progressing from local and situated patterns to cross-cutting themes and theoretical insights. The first round of coding, conducted during the fieldwork, developed descriptive categories of the changes occurring in the two pharmacies. Two fieldworkers first coded the data for each pharmacy separately, and in this round, we noted strong similarities between the sites including such topics as "pharmacy efficiency," and "robot malfunctions." A second round of coding sought to develop more theoretic themes, producing such categories as "boundary interactions." We then looked for comparative themes, and in the third round of coding we developed tables and charts to represent and compare data across the occupational groups (Eisenhardt 1989, Langley 1999). We clarified and discussed our emergent understandings with participants prior to completing the fieldwork. These cross-group themes were then developed into theoretical narratives (Golden-Biddle and Locke 1997) and connected more explicitly to relevant literatures on boundaries, innovations, materiality, and the organization of work.

In the fourth round of coding, we explicitly extended Pickering's tuning approach to develop our understanding of how the hybrid digital and mechanical materialities of the dispensing robot performed in relation to the work of the pharmacy staff. In particular, we paid close attention to how different aspects of the robot's digital (e.g., programmability, memorability, senseability, etc.) and mechanical materialities (e.g., picking arm, chutes etc.) and various aspects of the pharmacies' physical materialities (e.g., patient queues, front-end vs. back-end workspace) were entangled with the human agencies (e.g., plans, interests, and activities) and boundary relations of the multiple occupational groups. What emerged was a specific understanding of how engagement with the robot by the three occupational groups in the pharmacy served to shift work practices and reconfigure boundary relations over time, with considerable and differing consequences for pharmacy workers' skills, jurisdictions, status, and visibility.

Tuning the Robot and Reconfiguring Boundary Relations

Extending Pickering's tuning approach, we focus on the recursive and emergent process of resistance and accommodation that unfolded with the adoption and use of the dispensing robot: how the specific and hybrid materialities of the robot became entangled with the diverse plans and practices of multiple occupational groups; how new challenges, dependencies, and visibilities emerged as a result; and how the ongoing tuning process served to reconfigure boundary relations among the three occupational groups over time.

Robot materialities

Two critical and interrelated components of the dispensing robots' materiality were evident to the pharmacy workers: mechanical and digital. While both were developed by the manufacturer during construction, their design allowed for some modifications during operation. The *mechanical materiality* was the most visible component, with robots incorporating one or more closet-size modules configured with thousands of storage locations. Operating within the closet was a mobile picking arm designed to reach each of the thousands of honeycomb shelves. The robots also included external conveyor belts: one feed belt at the rear of the robot to load items into storage; three output chutes to deliver requested medications to the pharmacy front end for dispensing; and one ejection chute at the rear of the robot used in cases of malfunction. The *digital materiality* of the robot consisted of numerous software programs that were coded to perform specific operations on receipt of information communicated from various sources: parts of the robot (e.g., item detected on feed belt); associated information systems (e.g., hospital inventory system); or human operators (e.g., entering commands through computer interfaces).

The robots' digital and mechanical components were tightly intertwined and interdependent. For example, the motion of the mechanical picking arm was controlled by a digital program ensuring the arm would accurately scan, identify, grasp, pick-up, and move thousands of items to desired locations upon request. Similarly, the number and sizes of the storage locations in the robot's closet were controlled digitally and by re-specifying the dimensions of the honeycomb shelves, the robot could be expanded or contracted to suit different local requirements. The digital and mechanical materiality of the robot thus allowed for some flexibility in configuration and operation, and, as we discuss below, the pharmacists understood and took advantage of this flexibility.

Digital senseability was another key aspect of the robot. The robots were programmed by pharmacists to read the relevant pharmaceutical products through unique manufacturers' barcodes. Once programmed to accept certain barcodes, boxes would be individually scanned and loaded into the robot by the assistants. The robot then digitally determined — depending on item size and shelving availability — the optimal location to store each item. For example, small eye drops were put on narrow shelves to maximise the use of space. If the robot could not locate a suitable vacant space, the item would be "rejected" and released through the ejection chute located at the rear of the robot. Items would also be rejected by the robot if the barcode was unrecognized or if the product did not match its pre-specified dimensions. RFID tags were expected to replace barcodes in the future, enabling the addressability and traceability of medicines from production through sales and patient use. The modular design and digital materiality of the robot meant that this anticipated future adaptation would be accommodated relatively easily in the current robot system.

Access to the robot, whether through the dispensing computers or the direct control terminal, was controlled through security codes that allowed different users selective access to functional capabilities. While the mechanical components of the robot were readily visible, they were relatively fixed. They could be changed by the vendor or by acquiring additional mechanical components such as adding a closet module or output chute. The dimensions of the shelving spaces could be digitally altered, but this was a time-consuming task, as all the medicines would first have to be removed. The digital components were less visible but more malleable through their programmability. As users entered new parameters and codes into the robot's software system, the capabilities of the robot could be modified. Doing so had to be learned, however, which required time and training; but once learned, the robots' software could be altered relatively quickly. As one pharmacist explained,

> *[Princess pharmacy has] had to do lots … to make the process work. For example, every time … you change that barcode, at the distribution end when they scan their stock list the product doesn't come up because its barcode has changed. So we've had to put in [an] extra bit of programming.* (Pharmacist)

In general, the robot's security access codes were set to allow pharmacists and technicians — but not assistants — to digitally alter the robot's capabilities, thus reinforcing well-established distinctions in the pharmacy between the less-skilled assistants and the other two occupational groups.

Installation plans

The business plan for the robots' purchase focused on reducing dispensing errors and increasing work efficiency. These were key government priorities as explicitly articulated in the UK Government's Audit Commission report. The initial proposal to acquire the robots was made by the chief pharmacist, and linking the rationale for purchase to these external criteria helped to justify the investment and legitimate Royal Trust as a leader in pharmacy innovation and practice.

While the pharmacists — as the most powerful occupational group within the pharmacies — could have made plans and decisions regarding the robot independently, they chose to collaborate with the technicians. Together, these two groups visited the vendor to examine the robots, and then suggested several modifications (primarily digital) to align the robot software more closely with local practices. One of the system administrators (a pharmacist) explained the kinds of changes that were requested to the robot's initial specifications:

> *We had lots of discussions [with the vendor] …We were not going to accept the spec as it was; we didn't want to play that game as the original interface they had was a one-way. [With a one-way system] you may request something …and if it shows up you know it's in the robot and if it doesn't show up you just assume it wasn't in the robot. So it doesn't speak to you … but now it actually talks back …saying 'yes I've got it'… We like our robot talking.*

The digital materiality of the robot allowed it to communicate with the operators — that is to "talk back" — by indicating on the screen that an item was/was not available, thus improving the value of the robot as a collaborative actor in the pharmacy.

Members of the pharmacist and technician groups met regularly over several months to discuss requirements for the robot as well as the process of implementing it within the pharmacies, and particularly how the robot software interface could be made compatible with existing systems such as the hospital inventory system. In this way, the process of tuning the robotic innovation to interests and intentions began many months prior to the robot's installation, and through the involvement of both pharmacists and technicians it served to distinguish these two occupational groups from assistants at both an instrumental (who could do what) and symbolic level (whose ideas and plans had worth).

In addition to predicting improvements in productivity and drug safety, the pharmacists expected the robot would add interest and novelty to their work and free up significant time, space, and resources.

> *It was a project I wanted to do and I'm not saying I was bored with my job, but it was something [different]…and the team of people working with me… were equally enthused about it.* (Pharmacy Manager)

Pharmacists particularly wanted to be relieved from what they saw as the mundane work of dispensing, and hoped that the robot would allow them to spend more time doing research or consulting with patients on the wards. Furthermore, they anticipated that robots would be useful in pharmacists' ongoing occupational struggles for increased legitimacy and professionalization within the healthcare field. As a result, they actively advocated the purchase and adoption of robots, both locally in their own pharmacies and more broadly across the country (via their national association).

Meanwhile, technicians were keen to develop new skills in using the robot, carve out a new role for themselves in managing the use of the robot technology, and thus shore up their status and authority within the pharmacy workplace. The high-tech materiality of the robot enabled technicians to begin to understand their work in more professional terms.

> *It looks more professional. It makes it look better to have a high tech machine in the dispensary. Previously it was like being in a supermarket, picking these things off shelves. Now the robot is picking for you. It is like a step up… so it makes you feel good. You feel better about the workplace.* (Technician)

Assistants were not included in the planning process, and were less aware of the range of changes it would introduce. They perceived the robot as a novelty, and while they were mildly enthusiastic about its impending arrival, they did not expect that its use would provide significant work benefits to them.

Loading difficulties

The assistants became involved with the robot once it was installed in the pharmacy. They were made responsible for loading stock into the robot, a process that became particularly time-consuming at both pharmacies. A number of difficulties became apparent early on that contributed to loading delays.

Not all products could fit into the robots as intended, resulting in many items backing up on trolleys. Thus, unloading the trolleys could not be completed efficiently (as had been done previously); items had to be loaded one by one into the robot to accommodate the availability of the mechanical picking arm. The loading process thus dragged on throughout the day with assistants confined spatially to the rear of the robot. The distribution area became messy and cluttered, with large numbers of items scattered on multiple trolleys or on the floor.

Not only was space within the robot limited, but also the picking arm could only manipulate one item at a time. With involvement of technicians and pharmacists but not assistants, its software had been programmed to prioritise requests to pick the dispensary orders (for delivery of medicines to waiting patients), then to complete distribution requests (for delivery of medicines to hospital wards and clinics), and only finally to accept loading requests (for replenishment of stock in its storage). This digitally inscribed operating hierarchy was particularly noticeable to the assistants, who often had to wait for the robot to become available to them for loading.

> *[The robot] takes too long to load. They (nods towards front of dispensary) are the most important ones, and then us [in distribution], I suppose. And then it is loading. So it is about prioritizing.* (Assistant)

The loading delays were most pronounced around noon when the hospital clinics sent a wave of patients to the pharmacy. Assistants became acutely aware that their primary work of stocking medicines was less valued than the work of the others. As they saw it, even the robot had downgraded their work.

In response to the difficulties generated by loading delays (e.g., increased stock outages), several accommodations were made. At Princess, one of the assistants was asked to start working earlier (7:00 am rather than 9:00 am), thus enabling her to load the robot with replenishment stock when it did not have competing demands. Similarly at Duke, schedules were changed; the replenishment stock was brought to the pharmacy first thing in the morning, rather than in the afternoon as had been the practice. Another accommodation to the slow loading process was a decision to reduce the number of items stocked in the robots. The chief technician made a list of certain items that she felt should be split between the robot and the traditional pharmacy shelves. This reduced the volume of items to be loaded into the robot. But having the stock in two places meant that assistants had to keep track of where items were kept:

> *Before we had one big job to do, but now we have two smaller jobs. Half goes in the robot, and the rest on the shelves… so there is more to think about now.* (Assistant)

This accommodation, over which the assistants had little control, required the assistants to process data and multi-task in an unprecedented way. They now had to juggle the performance of several activities in parallel — identifying the appropriate location of items, loading the robot, and stocking the shelves — while still ensuring that stock was available whenever it was requested at the front end. Assistants were frustrated that to accomplish these new multiple activities they were required on occasional to miss breaks and even work late to keep up.

The robot's materiality also influenced the physical spaces within the pharmacy. The robot was a large physical presence in both pharmacies, occupying significant floor space. Its location in the centre of the workspace (see Figure 1), while conveniently situated between the front and back, also served as a barrier, accentuating the division between the back end where the assistants worked and the front end where the technicians and pharmacists worked. In addition, the robot freed up some floor space at the front end of both pharmacies, making this workspace more appealing and less crowded. In contrast, the back workspace became cramped, crowded, and untidy. The assistants complained about the look and feel of their cluttered workspace. They perceived these changes — along with those of scheduling and multi-tasking — as undermining their work activities and degrading the quality of their working conditions. For some, it also symbolised a demotion in their status within the pharmacy.

In a further accommodation to the loading problems, a senior pharmacist at Duke discussed the difficulties with the robot vendor, who was working on a similar issue at another pharmacy. In response, the vendor developed an extended feed belt for the robot and made it available a few months later. Installing this mechanical extension to the robot (along with the associated reprogramming of the digital code) allowed the assistants to scan up to 60 products onto the robot's feed belt, which would then be loaded when the robot was idle. This improved loading efficiency, allowing assistants to move on to other tasks even though the robot had not yet physically stored all the products in its closet.

Streamlining the physical loading process involved reorganizing the pharmacy workspaces, adjusting work activities and schedules, and constructing additional material and digital components for the robot. The initial material resistance to efficient loading was produced by both the single picking arm working sequentially through orders and the digital inscriptions that prioritised front end dispensing. The burden of accommodating to the robot fell to the assistants. Not being able to influence the robot directly — either digitally or mechanically — the assistants had to rearrange their daily practices and temporal-spatial routines. Over time, the tuning also involved material changes in the technology as the pharmacists negotiated with the vendor to construct and install a mechanical extension to the robot (including related software updates), and these in turn, required additional adjustments in assistants' schedules and activities.

Dispensing challenges

At the same time that the assistants were struggling with loading delays, technicians complained of delays in receiving their orders, sometimes with up to ten minutes of waiting. In addition to loading the robot, assistants were also responsible for requesting and then delivering distribution orders for the wards and clinics. These orders frequently involved bulk quantities that took the robot several minutes to pick, preventing the robot's use by others during that time and resulting in a queue of orders from the front end. The robot's materiality had now introduced an important new dependency between two pharmacy practices — the distribution work at the back end and the dispensary work at the front end.

> *We have a very big eye clinic here and yesterday, for example, one of the girls in distribution was topping up the eye clinic and needed 40 of an eye ointment. So she ordered 40 at once. … The dispensary in the meantime have ordered lots of one-off boxes for patients and they had to wait… I don't want the robot wasting 5 minutes picking those 40.* (Technician)

In response, the system administrator (a pharmacist) worked with the chief technician to reprogram the robot to cap the maximum quantity of a product that could be requested from the robot at any one time. This modification to the robot's software inscriptions increased the distinctions drawn by the robot as to what kinds of orders would be processed. Orders requiring more than nine of one item — typically made by the assistants — would no longer be processed by the robot, thus requiring such orders to be manually picked from shelves. The new software inscriptions further reinforced the robots' prioritizing of work, explicitly privileging support of the front-end work over the assistants' ward deliveries. While this accommodation successfully sped up the front-end work for technicians and pharmacists, the back-end work of the assistants was further slowed down as their picking process, like their loading process, became further fragmented. While technicians were able to influence the robot through software reprogramming carried out in consultation with senior pharmacists, assistants in contrast lacked the authority, knowledge, and access to negotiate digital accommodations with the robot.

While changes to the mechanical aspects of the robots were relatively rare, the need to reprogram the software arose regularly. For example, after a few months of using the robot, the pharmacists realized that new barcodes had become available as hospital contracts were renegotiated with suppliers or as drug companies altered medicine doses, added new formats, and resized packages. The materiality of the robot's initial database design only accommodated one version of a pharmaceutical product per barcode and could not recognize multiple instances of the same product.

> *We had this pre-marked idea that we could amend the database but … we can't. … The contracts will change and it'll be the end of [many] of the [drug coding] lines… The barcodes … define the form … but if the product changes from a 28 day pack to a 30 day pack [or liquid to tablet form], it's a different product and it's a new line.* (Pharmacist)

In response, the pharmacists had to work out how to make product aliases so that the robot's database would accommodate changes in dosage, format, or size. This involved considerable learning by senior pharmacists in particular, as they read manuals and contacted the vendors for assistance in altering the software code. Over time, these modifications to the robot's digital inscriptions became routine, and many of the reprogramming tasks were passed on to the technicians. New areas of distinction in expertise and jurisdiction were thus emerging from the tuning process.

Robot malfunctions

Through intermittent malfunctions, the robots resisted and challenged the anticipated improvements in service performance. When the robots encountered errors or ceased functioning, work in the pharmacy became difficult to perform as medications housed inside the robot became inaccessible. Mechanical difficulties ranged from boxes getting stuck on the conveyor belts to the picking arms becoming jammed in the closets. Ladders were kept ready at hand to enable technicians to quickly manipulate a jammed arm or reach onto conveyor belts to shift stuck boxes. Accommodations to the robot's mechanical failures were accomplished through the creation of new routines in pharmacy work, such as climbing ladders, clearing belts and chutes, and resetting robot arms. In accommodating to the robot's malfunctions, technicians went on training courses to learn how to fix and maintain the robots. While technicians previously had little to do with machines or computer technology, they were now engaging extensively with both the mechanical and digital materiality of the robots.

> *Our work is more technical now…we have to do more tasks that involve checking the systems and doing housekeeping on the robot… [For example] we have to clear [the system errors] every morning.* (Technician)

The technicians enjoyed this new challenge, overcoming the robot's resistance by increasing their own knowledge about the robot. It increased their sense that technicians' work was professionalizing, with beneficial consequences for their work identities.

> *I guess all the medical professions are competing with each other, comparing their various technologies and seeing who has got what. So now we have got a robot. It makes it more impressive. We are not just sitting there, picking drugs off the shelf, but it is a lot more complex.* (Technician)

When the robot broke down, technicians would be the first ones on hand to try to sort it out. If they were unable to solve the problem, they would call in the pharmacists and together they would agree on a workaround while waiting for the vendors' technical crew. Over time, the senior technicians' increasing knowledge of the robots made them indispensable, further improving their status.

> *[The chief technician] knows everything about the robot so, I mean, it's difficult to replace her… [If she were to leave] we'd be stuck.* (Pharmacist)

The adoption and use of a dispensing robot further extended the technicians' area of jurisdiction in the workplace. They acquired new skills, knowledge, and responsibilities that established their occupational role as caretaker of the technology. Engaging with the robot enabled the technicians to feel "better about their workplace," offering instrumental and symbolic legitimacy for "a step up" on the occupational ladder. Engaging with the robot also sanctioned technician work as an expanding sphere of practice, contributing to their professionalization efforts aimed at the formal registration of technicians as allied health professionals.

Altered dependencies

Assistants continued to experience significant frustrations when attempting to fulfil their ward and clinic distribution orders. Because they had no stock interface system in the back end of the pharmacy (only the direct control terminal), assistants at both sites queued at the dispensing computers in the front end to fill their ward and clinic pick lists. While waiting, they would manually retrieve those items that were available on the shelves. Unaccustomed to collaborating, assistants would issue requests independently of each other. Occasionally, their requests would accumulate and create problems for the front end.

> *The assistants are needing to communicate with each other more…They can't just all put their stock through at once [or they will be queuing and waiting]. So they need to work together more.* (Technician)

Assistants' additional waiting time to complete tasks added further delays, interdependences, and multi-tasking to their workload. Assistants believed they had lost their previous autonomy as their work had now became organized around the inscriptions, priorities, operations, and processing times of the robot.

> *He [the robot] gets too busy, has too many things to do. There is picking for the ward and then putting away and then when they get busy up there [points to front end], we have to wait. … I can see how it benefits the dispensary. [Pauses] But you know how it is just easier to pick up a bunch of boxes from the shelves [when you need a few] – rather than wait for the robot to do it. [Pause] … It prioritises their work, I think. So it can take ages sometimes to get the order out.* (Assistant)

In addition, the assistants were finding their time at the dispensing computers frequently interrupted by technicians and pharmacists, who would "jump the queue," generating considerable frustration for the assistants. Technicians and pharmacists had developed digital "workarounds" to speed product delivery during periods of peak use. When products did not arrive within a few minutes, they would go to the robot terminal at the back of the dispensary to release their requested product on the "emergency" ejection chute, bypassing the regular dispensing queue process and interrupting the assistants. These work interruptions highlighted the capability and authority of the technicians and pharmacists to develop material workarounds to accommodate their interests and override the robot's normal mode of operating. Drawing on their knowledge of the robot's procedures and their privileged access, technicians and pharmacists could negotiate a means of improving their work efficiency, while neglecting the impact of these workarounds on the assistants.

The tight work coupling that followed the introduction of the robot made assistants more dependent on technicians, as they remained unable to fix even the simplest mechanical jams of the picking arm. The hierarchy of pharmacy work was reflected in and reinforced by the differential allocation of access and tasks to the three occupational groups.

> *It's annoying because I feel like a second-class citizen … It is not necessary you know… It really isn't necessary to have some having a password and not another. It only causes division. That is what it is for – to separate … It's not like we're not capable.* (Assistant)

Assistants perceived a substantial loss of control and discretion in their work, as they now had to wait for technicians equipped with digital passwords to resolve any problems that occurred within the robot closets. The following excerpt from our field notes highlights these experiences:

> *The assistant loading the robot comments, "Oh the bloody thing. It has gotten stuck." She walks off toward the dispensary in the front end. Soon a technician slowly walks to the back. The technician opens the robot door and walks in, goes to the picking head, and seems to just move a box slightly, coming out a few seconds later. She offers a clarification to the assistant about resetting the robot, "The box was out of position and the robot couldn't find it." With that explanation, the technician returns to the front end.*
>
> *The assistant says, "Sod 'em. They don't want to show me. That took five seconds [to fix], and I have to run up there [to the dispensary end to fetch someone] each time… Why should I care if they don't want to show me. I'll just sit down and have a cup of tea. … I have tried to mention it a few times. But if you haven't been to college or uni[versity], they don't want to show you. It is like we are not good enough." The assistant goes on to explain that she has had to call on a technician five times so far today to deal with the [robot] alarm bell.*

This exasperated assistant felt frustrated and belittled. Each time the robot picking arm ceased to function, an error message flashed on her terminal screen, indicating a problem. Being physically located at the rear of the robot and watching the picking arm freeze as it attempted to input the stock, she became immediately aware of the problem, while the technicians working at the front end remained unaware of the difficulty. The assistant then had to go and tell a technician about the problem, and request help. The assistant attributed this dependency to her lower status and lesser educational qualifications. In practice, the assistants' ongoing and unanticipated dependence on technicians to get their work done highlighted the occupational boundaries within the pharmacy in new ways. It deepened and made more visible the distinctions between technicians and assistants, calling attention to the unskilled nature of distribution work, and signifying a demotion in assistants' relative status and autonomy within the pharmacy.

New visibilities

Meanwhile, an unintended consequence of the extended feed belt installation was becoming increasingly evident. The new loading feed belt was producing a novel type of error: the wrong medicine would sometimes be dispensed.

> *[The robot] is meant to reduce errors. But sometimes we get things that we haven't asked for at all. So we get some new errors in the process.* (Pharmacist)

The cause of this new error appeared to be digital, but the technicians and pharmacists reasoned that the problem had to be human in origin. Assuming that the "robot can't get it wrong," they started to observe assistants loading stock into the robot, to monitor the fine interplay between digital reading of barcode and physical placement of the product on the conveyor belt.

> *[The assistants] had problems filling [the robot] accurately. So the technicians and ourselves would stand and watch them. You would think it would be easy, but actually it wasn't. When you were doing it repetitively and there were things that we hadn't realised were inbuilt to the system… that made it harder. We couldn't understand why they were having problems filling [the robot], but when you started looking at it, it wasn't surprising, wasn't surprising*. (Pharmacy Manager)

Ironically, the robot that was intended to decrease errors was providing an occasion for new errors (which were never resolved during the time of our fieldwork). While up to this point, the pharmacists had not been involved in the assistants' work processes, they now began to pay closer attention, and assistants' work attained more visibility. Technicians became centrally involved as well, giving direct instructions to the assistants on loading techniques as they closely supervised the assistants in order to counter the robot's digital resistance in delivering incorrect items. As one irritated assistant exclaimed to the fieldworker after one of these supervised sessions: "If you ask me what I think about that robot, I might bite your head off!" While previously, assistants had gone about their day largely unobserved by pharmacists and technicians, they were now subject to close surveillance and regular micro-level directives.

While some of the frustrations associated with robot use were gradually being alleviated over time, one pharmacy manager reflected that this relief was comparatively late in coming for the assistants.

> *[Assistants]… had a lot of pain before they got their gain… The [others] had pain and the gain almost simultaneously… So it was a much more neutral process [for pharmacists and technicians,] whereas the distribution workers had a backslope… [they] were double keying… and we hadn't appreciated that.* (Pharmacy Manager)

As the assistants experienced significant costs and few benefits in using the robot, they believed the robot had primarily benefited the work of technicians and pharmacists. The benefits that assistants did accrue in the tuning process were largely due to mechanical extensions (such as a new chute and feed belt) that had taken some time to materialise.

> *[It took a long time] to get that distribution chute functioning. We were happy to let it ride because it didn't affect me and it didn't affect what they were doing at the front of the dispensary. It did affect the distribution staff and I don't think we actually quite realized that [it] had.* (Pharmacy Manager)

The mangle emerging from the tuning process came to symbolize pain for the assistants, and gain for the technicians and pharmacists. The disregard of assistants' "pain" was facilitated by the pharmacists' own excitement over the role of dispensing robots in expanding their opportunities to do more research and clinical work, and furthering their professionalization agenda. As pharmacists' attention focused on their expanding professional jurisdiction and status, the largely silent distress of the assistants was neglected.

> *We got [the robot] to free up [pharmacists] to take them out to the wards … to facilitate discharge and, you know, counsel patients … In our enthusiasm we perhaps forgot about some of the other staff, and just assumed that the assistants would accept it, adapt to it … we forgot about them.* (Pharmacy Manager)

The new role for the technicians heralded by government policy and enabled by the robotic innovation was actively facilitated by the pharmacists at both sites, since they now relied heavily on the technicians to maintain daily operations in the pharmacies. Despite the continued professional distinctions between pharmacists and technicians, there was no heightened tension between them, since they were both benefiting from the operations of the robot. Indeed, their expanded work jurisdictions and spheres of control were complementary and allowed them to work cooperatively. The robot's entanglement in their work practices improved dispensing efficiency and overall error rates, helping both hospital pharmacies achieve improved performance as measured on these targets.

Discussion

Our study sought to address the research question of how a newly introduced digital innovation — a dispensing robot — influenced the work practices, interests, and relations of three interdependent occupational groups. Below, we elaborate on the significance of our findings in three different areas.

First, we discuss how the distinctive materiality of digital innovations such as robots reorganizes the work of diverse occupational groups, leading to a reconfiguring of boundary relations with implications for occupational status and control. Second, we extend Pickering's tuning approach to develop insights into how the robot's shifting and hybrid forms of digital and mechanical materiality perform together in relation to multiple groups in the workplace. Third, our relational-material perspective opens up a new area of research into digital innovation by highlighting the value of attending to the multiplicity and variability of robot materialities as these become entangled with multiple groups within the contemporary workplace.

Reconfiguring boundary relations among occupational groups

Our study builds on recent interest in relational and material aspects of boundaries to focus on the dynamic enactment of boundaries, and how these may be (re)constituted through the introduction of a digital innovation (Jonsson et al. 2009). In so doing, we further develop and offer a more granular understanding of Abbott's (1995) relational and enacted view of boundaries. Furthermore, and in contrast to Abbott's largely social perspective, we highlight the entanglement of the social and material in the constitution of boundaries. Extending Pickering's (1995) tuning approach, we examined the performative way in which robots' digital and mechanical materialities (such as access codes, passwords, inscriptions, workspaces, and queues) were constitutively mangled with human agencies (such as coding skills and dispensing activities) over time. In the process, boundary relations among the occupational groups were reconfigured, generating contradictory implications for workers' skills, jurisdictions, status, and visibility.

Consider first the boundary relation between pharmacists and technicians. Introduction and use of the robot allowed pharmacists to maintain control of the dispensary at a distance and freed up their time to engage in research and patient-centred work. In so doing, they reasserted their privileged position in the pharmacy hierarchy, while also increasing their institutional legitimacy within the hospital. As pharmacists reduced their engagement in dispensing work, technicians upgraded their technical skills and abilities, becoming competent and authorized caretakers of the robot. Prior to the robot's arrival, technicians' expertise related to their work with medicines. However, working with the robot required the technicians to acquire knowledge of robot technology—both digital and mechanical. Pharmacists were not threatened by this expansion of technicians' expertise and role, even though it involved new levels of dependence on them. The technicians' expanded jurisdiction was not seen as an encroachment on the pharmacists nor was it experienced as a zero sum game, where the technicians' gain was the pharmacists' loss. On the contrary, the expanded jurisdiction was cooperatively negotiated — a form of bilateral expansion (Wimmer 2008) — with the pharmacists embracing the shift in technician skills and roles, as it held positive implications for their own aspirations. In this case of digital innovation, unlike in earlier studies of automation, neither pharmacists nor technicians perceived the robot as deskilling their work or downgrading their jobs.

A relation of ***boundary cooperation*** thus emerged between pharmacists and technicians that was reciprocally supportive and mutually beneficial. This cooperation involved boundary spanning by pharmacists and technicians who were united by their common interests in professionalization, forming what Levina and Vaast (2005) refer to as a new joint field. In the process, pharmacists delegated operational control of the robot to technicians and utilized the traceability enabled by the robot's digital materiality to enable supervisory control. However, in this boundary relation, the new digital innovation was not used primarily to reproduce the authority of traditional roles within the pharmacy (Zuboff 1988). Rather, use of the dispensing robot allowed both pharmacists and technicians to imagine alternative futures and roles that encompassed new forms and areas of jurisdiction.

As indicated in Table 1, when digital innovations are seen to be advantageous to groups' interests and aspirations, they are more likely to be taken up and quickly integrated within the groups' daily practices. Furthermore, to the extent that the groups are highly interdependent, their members are more likely to develop relations of boundary cooperation during the adoption and use of such innovations.

* * * Insert Table 1 here * * *

The second boundary relation salient in our study — that between pharmacists and assistants — was far from collaborative. Pharmacists did not solicit input from the assistants in planning the robot implementation; the assistants' lack of voice meant their interests and concerns were not systematically incorporated into the tuning process until quite late, if at all. Rather, pharmacists developed plans and strategies to improve and prioritize the visible, front end, "real work" (Star and Strauss 1999) of dispensing.

The robot was inserted into assistants' daily practices, rearranging their workflows and workspaces, and restructuring their tasks and schedules. Their work became more difficult, more fragmented, and more frustrating. The overall inattentiveness to the interests and concerns of the assistants resulted in the enactment of a boundary relation between pharmacists and assistants that we term ***boundary neglect***. Pharmacists, being conditioned by broader institutional structures in the healthcare field (Burri 2008), distanced themselves from the assistants as well as the distribution and dispensing processes, delegating control of these tasks to the robot and the technicians. They became insulated from the assistants' frustrations, as the robot regulated and prioritized dispensary work through its digital inscriptions.

While assistants expected that pharmacists would help them solve key difficulties that arose in using the robot to execute their distribution tasks, they found in practice that they had been forgotten. As one pharmacy manager remarked "[I] could not believe that they [the assistants] were there suffering in silence." She expressed concern this could be misconstrued as pharmacists "not caring." Assistants were forgotten because their activities constituted back-end "invisible work" (Star and Strauss 1999), which was more easily overlooked. The pharmacy managers' subsequent reflections led to a belated recognition that their relations with assistants required attention. Indifference, focus on more visible areas of work (such as dispensing, research, and patient consultation), and lack of attention to invisible practices are boundary conditions that may facilitate boundary neglect. To the extent that the work of groups is highly coupled (as in assistants' dependence on technicians), the contradictory experiences of both increased dependence and increased indifference may be particularly acute and distressing to the marginalized group.

Comment [A1]: This sentence seems to shift the emphasis from the boundary between pharmacists and assts to the boundary between technicians and assistants. The easiest way to fix this is to cut the sentence completely.

Our concept of boundary neglect connects with and builds on earlier literature on boundary spanning by providing insight into occupational marginalization. With the emergence of the new joint field between pharmacists and technicians around the dispensing robot, the assistants were restricted to the back end pharmacy work (spatially, operationally, and symbolically), able to enact only limited boundary spanning-in-practice (Levina and Vaast 2005). These findings support earlier work by Zuboff (1988) that suggests that new technology may reduce or circumscribe the demanding work of face-to-face engagement, allowing supervisors to rely instead on remote management. However, while Zuboff (1988) emphasizes the informating capacity of new technologies as a digital panopticon for surveillance and marginalization, our study suggests that both surveillance and marginalization can also arise as a consequence of who has the authority and coding skills to program the technology in practice.

The third boundary relation to be reconfigured was that between technicians and assistants. This reconfiguration was characterized by a perceived unilateral loss of autonomy by the assistants. Technicians increased control over the where, when and how of stocking, which had become tightly coupled with the robot. They also used their technical authority to deal with robot malfunctions or to pre-empt the regular dispensing queue process. The evident encroachment by the technicians into the workspace and work practices of the assistants resulted in the enactment of a boundary relation that we term ***boundary strain***. Our study suggests that the interlinking and shifting of workplace jurisdictions between the technicians and assistants was not a planned strategy of labour differentiation, but a consequence of the relational-material tuning process. In particular, our analysis suggests that asymmetrical expertise, increased dependency, heightened status inequality, and workspace and task encroachment are critical conditions for the production of strained boundary relations.

As Table 1 highlights, the changing status and role of the technicians as primary caretakers of the robot shifted the focus and emphasis of their work. The robot enabled an expansion of their jurisdictions and simultaneously increased their authority, control, and scrutiny of the assistants' practice (Jonsson et al. 2009). Assistants perceived these distinctions as increasing the institutional and symbolic divisions between occupations (Lamont and Molynar 2002) and reifying the differences in educational levels among workers (Vallas 2001).

Hybrid materiality and the tuning process

A second area of contribution concerns the role of materiality in digital innovations (Jonsson et al. 2009, Yoo et al. 2010). Our perspective highlights the importance of understanding shifting and hybrid forms of materiality as these are performed in relation to the interests and practices of multiple occupational groups. As digital innovations are increasingly combining digital and mechanical components in novel ways (as in robot technologies), accounting for the dynamic interrelationships and interdependencies between digital and mechanical materialities and workplace practices and relations will improve our understanding of organizing for digital innovation.

In focusing on the multiple relational and material dynamics entailed in the adoption and integration of the dispensing robot over time, we found that the different components of the robot led to important differences in the scope and speed of responsiveness available during the tuning process. For example, the slow loading of the robot led pharmacists to ask the vendor to design, build and install a new intake conveyor belt for the robot, a task that took a number of months to complete. In contrast, the digital aspects of the robot could be altered rapidly through changes in software inscriptions. When the assistants' large picking orders blocked dispensing work at the front end, the system administrator (a pharmacist), digitally limited the number of items that could be picked in one order. By the very next day the robot worked differently, with significant implications for the performance of work within the pharmacy and the relative control and status of the assistants. While the system administrator tweaked some digital components in this case, the overall effect was accomplished through a change in the operation of the mechanical picking arm. The digital and mechanical components of the robot are thus deeply intertwined in practice, emphasizing that any distinction of the robot's digital and mechanical materialities can be analytic only.

Who gets to manipulate and control different forms of materiality and how, has important implications for how boundaries and jurisdictions are influenced and reconfigured in the tuning process. For example, while engineers in a distant vendor facility largely defined and developed modifications to the robot's mechanical aspects, members of two of the occupational groups in the pharmacy could alter some of its digital inscriptions. Because modifying the mechanical aspects of the robot took time, the problems with these components were not easily solved, and cumbersome workarounds had to be developed. In contrast, the robot's digital inscriptions could often be adapted in concert with the problems arising in practice, resulting in an expansion of technicians' and pharmacists' jurisdictional boundaries in the workplace and a concomitant loss of control by assistants, who were not given access or training to communicate with the robot.

The digital materiality of the dispensing robot thus facilitated problem diagnosis and solution generation among technicians and pharmacists during the tuning process. By working collaboratively to produce digital solutions, technicians and pharmacists were able to build on each other's insights, and increase their creative engagement in practice (Sennett 2008). Team meetings during the adoption process and subsequent troubleshooting sessions focused on how the robot could be digitally altered, so as to redirect its operations to be more aligned with the interests of improving dispensing work. Had these meetings been constituted by a different membership, or had the assistants been given access to and training on the robot, then the emerging entanglement could have been quite different. For example, the efficiency of distribution work and the working conditions of assistants may have become more salient in the tuning process, leading to alternative activities and outcomes.

Furthermore, the digital materiality of the dispensing robot became a significant sphere and rationale for collaboration across Duke and Princess. Digital solutions developed in one pharmacy — and legitimised by broader institutional assumptions and shared interests concerning access, knowledge, and responsibility — could be shared with the other pharmacy (in ways that the mechanical components could not). We suggest that the relative mobility of the digital materiality in this case is a key reason for the strong similarities observed in the tuning process and outcomes at the two pharmacies, in contrast to the differences across sites observed in Barley's (1986) research.

The configuration and flexibility of the robot materialities evident in our study are highly situated and temporally emergent. That the digital components of the dispensing robot allowed skilled workers to reprogram software inscriptions reflected the particular design of this digital innovation and its specific deployment in the hospital pharmacies. Other digital materialities might be designed and built to be less malleable by operators in the field. Similarly, the particular form of the mechanical materiality in this case meant that it was quite difficult and time consuming to modify in practice. Again, this will vary by the technology at hand, and is always an empirical matter. It is worth noting that as more artifacts become embedded with digital capabilities, it is likely that some will allow for more rather than less manipulation in practice — whether through reprogramming of code, alteration of data fields, or integration with other systems and devices (Yoo et al. 2010). It is also important, of course, to recognize that some changes in digital components might entail considerable time, effort, and specialized expertise (e.g., implementing a complete upgrade of the robot's system software).

As a large object, the physicality and spatial positioning of the robot also influenced the tuning process by more visibly demarcating and separating the front and back ends of the pharmacy. Spatial work paths of all groups were altered, with pharmacists and technicians largely positioned at the front end and assistants restricted to the back. The physical segregation promoted the work efficiency of the pharmacy's dispensing work, while slowing and fragmenting its distribution work. The back of the pharmacy became more cluttered and messy, contributing to the assistants' frustration and demoralisation. The robot's entanglement with the physical materiality of the pharmacy's workspaces thus had both operational and symbolic implications for occupational status, (in)visibility, and performance.

While pharmacists enjoyed identity-shaping developments that enhanced their professionalism, assistants experienced more of a "sharp social edge" (Sennett 2008). As lower-status workers, they found that their work goals and interests were disrupted and even undermined in practice. Many assistants chose pharmacy work because they could "just get on with their job" and take charge of their own schedules. In their encounters with the robot in practice they increased their dependence on and coordination with other workers, and lost both autonomy and control. Earlier work has shown how digital innovations may alter organisational identities (Gal et al. 2008); our study complements this work by showing how digital innovations can also shape occupational identities. The altered dependencies, jurisdictions, and relations evident here were not the direct result of the digital innovation per se, nor did they reflect the purposeful strategy of control over labour by managers (as argued by labour process scholars). Rather, the perspective we have developed here suggests that the shifts in occupational status and worth emerged from the entangled relational-material dynamics that constituted the robot tuning process over time.

Relational-material perspective on digital innovations

Our study also offers an important contribution to hybrid robots and the broader robotics literature. Hybrid robots with aspects of professional services and industrial robots (Thrun 2004) encourage the development of a sociological lens with which to empirically view robotic innovations in the workplace. This is an important yet neglected dimension within the robotics literature, which has tended to focus either on automation studies of industrial robots and the labour process, or on cognitive studies of human-robot interfaces and interactions (Hinds et al. 2004). Our relational-material perspective enables an understanding of how the multiple digital and mechanical materialities of robots are performed in practice and in relation to the multiple different occupational groups that engage with them.

We also provide insights into the nature of human-robot interactions, another area of robotics research. In our case, two occupational groups with access to the digital materiality of the robot could shape their interactions with it to their advantage. For example, early on, pharmacists requested that the vendor program software that allowed the robots to "talk back" to the pharmacists and technicians in the front of the dispensary. This changed the robot's communication from a unidirectional to a bidirectional mode, allowing pharmacists and technicians to engage with the robot in a more collaborative manner, seeing it as another "team member." In another case, modifications of the robot's digital inscriptions allowed capping the size of orders that could be processed, thus favouring pharmacists and technicians, while limiting the interaction of the assistants with the robot and highlighting their second class status.

These boundary-shaping interactions that we have identified suggest the need for robotics research to go beyond the traditional focus on human-machine interactions and degree of autonomy of the robot (Thrun 2004). In particular, our study suggests the value of understanding the multiplicity and variability of robot materialities as these are entangled with the multiple occupational groups found in contemporary workplaces. As we have shown, these engagements and their consequences are unlikely to be singular or homogeneous, and they are likely to produce a range of boundary dynamics and unintended outcomes for the particular groups involved.

Conclusion and Implications

Yoo et al. (2010) argue that understanding digital innovations requires that "scholars must take digital materiality seriously" (p. 16), exploring how "digital and physical materiality become intertwined" in practice. In this paper, we examined how the different forms of materiality constituting a novel digital innovation influenced the work practices and boundary relations of disparate occupational groups.

Extending Pickering's (1995) tuning approach, we developed a relational-material perspective to examine the temporally emergent process that entangled the hybrid materialities of the digital innovation with the everyday work practices and boundary relations of the groups involved. By studying the tuning process entailed in coming to grips with dynamic materialities over time, we identified and explored how and why boundary relations among three occupational groups were reconfigured, with important consequences for the workers' jurisdictions, skills, status, and visibility. We suggest six implications of these insights.

First, our relational-material perspective identifies and accounts for different forms of materiality associated with digital innovations. Recently, there has been growing interest in taking materiality more seriously in organization studies (Jonsson et al. 2009, Leonardi and Barley 2008, Orlikowski and Scott 2008), and our study highlights the value of viewing materiality as performed relations. In particular, we found it useful to articulate the different but interdependent forms of materiality — digital and mechanical — that constitute robotic innovations. Our perspective can thus shed some light on how different specific materialities of digital innovations are performed in practice through being engaged and changed by different groups in the ongoing accommodations and resistances of the tuning process.

Our perspective further allows recognition and examination of the hybridity and fluidity of materialities in practice (Latour 2005). The materialities of digital innovations are unlikely to be singular or static, and paying attention to ongoing processes of tuning affords an understanding of materialities as multiple and dynamic. Yoo et al. (2010) identify a number of characteristics of digital materiality (e.g., programmability, senseability, communicability) that are prioritized in the design process, and we have found these useful in making sense of the robots in our study. Of particular value was understanding how these designed characteristics were performed in practice as a result of the tuning process. And as we saw, the manifestation of particular digital materialities in situated practices was temporally emergent and led to multiple and contradictory consequences over time.

Second, in extending Pickering's (1995) tuning approach to understand the accommodations and resistances of humans and technology, we go beyond his view in two significant ways. We emphasize that the actors and technologies entangled in the tuning process are both multiple and heterogeneous, thus expanding the scope and span of who and what is mangled in practice. Further, while Pickering frames accommodation as a human strategy of responding to material resistance, we suggest that accommodation and resistance should be understood relationally and as emerging in practice . In our study, we found instances of both humans accommodating (e.g., changing software code) to robot resistance (e.g., loading delays due to the sequential motion of the mechanical picking arm), as well as humans resisting the inscribed material agency (e.g., when technicians bypassed the dispensing queue to release their requested product on the "emergency" chute). Retaining an open-ended view about who or what is accommodating and resisting should allow for additional analytical insights as increasingly novel digital innovations become entangled in practice with an increasing array of multiple, distributed, and shifting agencies.

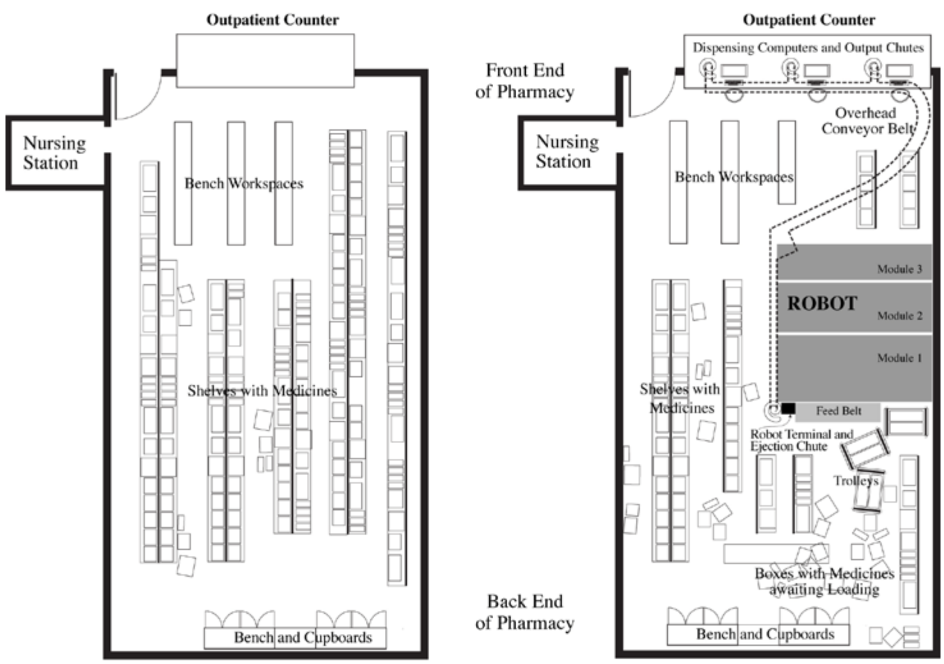
Third, we showed how the adoption and use of a robotic innovation by multiple occupational groups can reconfigure the boundary relations among them, with important implications for work practices, roles, and status. Previous work has pointed out how professional groups may stymie the diffusion of innovation (Ferlie et al. 2005). In contrast, our findings highlight how a digital innovation may be used by certain occupational groups to expand their jurisdictions, expertise, and professional standing. The alignment of the robotic innovation with the pharmacists' professionalization interests and their ongoing accommodations, in particular, to the digital materiality of the robot was integral in furthering the adoption, appropriation, and adaptation of the digital innovation over time. Similarly, the technicians' increased knowledge and control over the robot promoted their occupational authority and prestige, and reinforced their expanding role as caretaker of the new digital innovation. Contrastingly, assistants' work practices became increasingly dependent on both the robot and the technicians, and they lost control over their schedules and work tasks in the process. These varied findings highlight the importance of attending to the many disparate and situated ways in which multiple groups' plans, interests, practices, and relations become entangled with the materiality of the digital innovation in the tuning process.

Fourth, we identified the reconfiguration of three boundary relations that were implicated in the adoption and integration of a dispensing robot within pharmacy work, and suggested some conditions under which these might occur. In examining this reshaping of boundary relations, we go beyond the previous emphasis on boundary cooperation and conflict (e.g., Barley 1986, Vallas 2001) to articulate how boundaries are actively reconfigured, both relationally and materially, in the tuning process. This analysis allowed us to identify how these recursive relational-material dynamics produced contradictory implications, generating cooperation in one boundary relation while producing neglect or strain in others. This points to the importance of examining the complex, shifting boundary relations that are enacted with new materialities across multiple groups, and suggests attending not just to the more dramatic boundary relations of cooperation and conflict but also to the more subtle and less visible ones of strain and neglect.

Fifth, we articulated the entanglement of the robot's materiality with groups' status, control, and autonomy, thus extending understanding of the relational-material dynamics and contradictory effects associated with digital innovations in practice. The enactment of cooperative relations between two occupational groups around the robot allowed these groups to increase their skills, authority, and agentic opportunities. At the same time, another set of relations was being enacted through engagement with the robot, generating negative consequences for the autonomy, visibility, dependence, and morale of a third occupational group. Our findings suggest that while particular digital innovations may be used to enhance occupational groups' intellectual and symbolic value, they may also provide a sharp social edge that produces diminished forms of occupational worth (Sennett 2008).

Finally, our study has emphasised the importance of looking at multiple boundaries in the ecology of interactions across different occupational groups in the workplace. Existing research has tended to employ a dyadic focus in understanding boundary work, but given the increased emphasis on multidisciplinary collaboration, contemporary workplaces are likely to include multiple groups of actors with a diversity of interests, values, competencies, and practices. The perspective we have developed here expands the scope and span of who and what is entangled in the tuning process to include multiple groups and multiple materialities. While we note that our findings are limited to the extent that we only examined the adoption of one particular digital innovation in a particular organizational context we believe our insights are valuable and generative. Future research is now needed to verify and elaborate them, and to examine how boundary relations are reconfigured in other contexts and with other digital innovations.

Figure 1: Layout of Duke Pharmacy Before and After Installation of the Robot



Plan View: Before Robot **Plan View: After Robot**

Table 1. Robot Use and Boundary Relations in Pharmacy Work

Boundary Relations	**Boundary Effects**
Cooperation	• Collaboration between constituents on either side of the boundary in using digital innovations • Bilateral expansion of work jurisdiction
Neglect	• Lack of attentiveness reinforces social structures of domination and marginalization • Indifference to the plans and interests of one occupational group in using the robot
Strain	• Unilateral loss of control • Increased interdependencies and work fragmentation around robot use

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