Pebble in Still Water: How Implementing 3D Printing Reconfigures Boundary Relations in a Hospital

ABSTRACT

This paper examines how occupations mobilize, expand or defend their jurisdictional boundaries while simultaneously collaborating when a new technological innovation creates upheaval. We report on a two-year, longitudinal qualitative study of how medical 3D printing – a technology that transforms digital models into physical objects – was implemented in a UK hospital organization. We adopt a practice lens for examining boundary work practices as enacted by different occupational groups, viewing boundaries as relational, dynamic, and in a state of becoming. We extend theory on how occupations enact boundary work practices not only during adversarial encounters but also during multidisciplinary collaboration across disciplinary and knowledge boundaries. We focus on how jurisdictional boundaries are challenged over time; how new competencies are developed, new roles established, status and legitimacy challenged or reinforced and with what occupational consequences for the groups involved. Our findings highlight the ongoing jurisdictional contestations between four groups, presenting an opportunity for unpacking how the materiality of artifacts and spaces is constitutive of the way occupations mobilize, maintain and expand their jurisdictional boundaries.

Keywords:

Occupations, boundary work, collaboration, practice lens, materiality, 3D printing, healthcare

INTRODUCTION

Brain surgery is changing. Surgeons are using 3D printed titanium plates to replace parts of patients' skulls… before 3D printing, metal plates were hammered out by hand and adjusted during surgery, but their fit was not perfect, and up to one in 10 patients developed infections. One of the first patients to have a 3D printed plate fitted, who collapsed with an aneurysm and needed emergency surgery to fix blood vessels in her brain, shared that "I don't feel like I am sort of a monster [chuckles], I am very pleased with the way it looks and the way it feels" (BBC, 2017)

As the excerpt above illustrates, 3D printing (3DP) has gained much interest in the medical world, and is widely viewed to have great potential to improve patient lives. Heralded as the third industrial revolution (Economist, 2012), this emerging technology transforms powerfully digital models into physical objects. Implementing 3DP at work, however, is challenging. Prior research on technological innovations has reported that they play an important role in reorganizing work among different occupational groups. For instance, by serving as an occasion for social reorganization (Barley 1986), triggering jurisdictional disputes and renegotiations (Barley, 1996) and shifting identities (Barrett & Walsham, 1999), occupational roles (Bailey, Leonardi, & Barley, 2012; Zuboff, 1988), and boundary relations (Barrett, Oborn, Orlikowski, & Yates, 2012).

New technology implementation may be particularly challenging as cognitive, social, political and knowledge boundaries can inhibit the spread and use of innovations (Ferlie, Fitzgerald, Wood, & Hawkins, 2005). Occupational groups may use technological innovations to engage in boundary work (Abbott, 1988; Gieryn, 1983) in an attempt to provisionally establish, maintain or expand their jurisdictional boundaries and expertise (Barrett et al., 2012). As such, occupational groups draw on their knowledge and expertise to establish and maintain authority over which tasks to perform (Abbott, 1988; Anteby, Chan, &

DiBenigno, 2016) and use artifacts to strengthen their knowledge, authority and legitimacy claims during conflictual encounters (Bechky, 2003a).

Despite the noteworthy focus of these studies, previous work tends to emphasize conflictual or adversarial interactions in the form of jurisdictional battles and contests, downplaying cooperative interactions and collaborative relations with other occupations (Anteby et al., 2016; see Okhuysen & Bechky, 2009 for exceptions). Some scholars have examined jurisdictional battles between occupational groups before elucidating how occupational groups overcome this conflict via collaboration, using team scaffolds (Valentine & Edmondson, 2014), boundary objects (Carlile, 2002), or trading zones (Kellogg, Orlikowski, & Yates, 2006). However, further research is necessary to examine systematically how jurisdictional boundaries are actively reconfigured when a new technology is introduced, which simultaneously has the potential to reshuffle jurisdictional boundaries between these groups and, at the same time, requires multidisciplinary collaboration between them.

This path seems fruitful to explore further. This is especially the case with technological innovations such as 3DP, which require collaboration amongst diverse occupational groups with different disciplinary, knowledge boundaries and expertise, embedded in a web of clinical fields, practice patterns and different technologies (Mol, 2002). Contemporary workplaces are likely to include multiple occupational groups with a diversity of interests, values, competencies and practices, which nevertheless require an increased emphasis on multidisciplinary collaboration (cf. Barrett et al., 2012). As such, examining both conflictual and collaborative interactions between multiple occupational groups can provide a holistic account of jurisdictional boundary reconfigurations and ensuing dynamics when a new technology is introduced at the workplace. We therefore examine *how do* *occupations mobilize and protect their jurisdictional boundaries when collaborating with a new technological innovation?*

The purpose of this paper is to extend theory (Locke, 2001) on how occupations enact boundary work practices when a new technology that requires multidisciplinary collaboration is implemented in an organization. We report on a longitudinal qualitative study of how occupational groups collaborated across disciplinary and knowledge boundaries using the innovation of 3DP in a hospital. We focus on how their jurisdictional boundaries are challenged over time; how struggles to obtain status and expand task jurisdictions are negotiated in practice, new work task domains established, authority and legitimacy challenged or reinforced and highlight the consequentiality of boundary work practices for their status and boundaries.

To do so, we adopt a practice lens for examining boundary work as enacted by different occupational groups with the introduction of 3DP in a hospital setting (Feldman & Orlikowski, 2011; Nicolini, 2012). Such a lens conceptualizes boundaries as relational (Abbott, 1995), looking at the dynamic, unfolding relations between groups in a continual state of becoming (Tsoukas & Chia, 2002), and pays attention to material aspects of boundaries and how these may be reconstituted through the introduction of 3DP (Barrett et al., 2012). For the purposes of this paper, we conceive practices as recurrent, materially mediated, and situated activities (Schatzki, Knorr-Cetina, & Savigny, 2001), organized as sociomaterial sayings and doings guided by practical concerns (Nicolini, 2012) that are consequential in producing and reproducing boundaries (Feldman & Orlikowski, 2011). In this way, we examine how situated, material practices are configuring, maintaining and extending boundary relations through jurisdictional claims, leading to boundary reconfigurations.

We contribute to the literature in three ways. First, we provide further insights on jurisdictional boundary reconfigurations, where ‘doing jurisdictions’ is intertwined with ‘relating as collaborating’ (Anteby et al., 2016).While previous work examines how occupational groups may resist collaborating when their jurisdictional boundaries are under threat in light of organizational change (Truelove & Kellogg, 2016), we examine both conflictual and collaborative practices and respond to the adversarial focus limitation identified by Anteby et al., (2016). Second, our findings unpack how the materiality of artifacts and spaces is constitutive of the way occupations mobilize, maintain and expand their jurisdictional boundaries, not just representational and subject to interpretation (cf. Bechky, 2003a). As such, we join studies paying attention to the materiality of boundary work which includes other organizational artifacts beyond boundary objects (Barrett et al., 2012; Lindberg, Walter, & Raviola, 2017), such as how resourcing space is constitutive of jurisdictional boundary reconfigurations and how artifacts such as 3D modelling enact group status and legitimacy, respectively. Finally, we emphasize boundary work practices that are understudied in the boundary work literature, such as the importance of knowledge expertise and knowledge devaluing practices, which were key in relationally reconfiguring boundary relations between different groups when organizing for the innovation of 3DP.

The rest of the paper is organized as follows. In the next section, we review the jurisdictional boundaries literature, followed by the literature focusing on how technological artifacts can transform work practices and reconfigure boundaries. 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 on (boundary) work, occupations and technological change.

THEORETICAL BACKGROUND

Occupations and Jurisdictional Boundaries

Jurisdictional boundaries among specialized workers with localized knowledge and goals are prominent in organizations (Abbott, 1995; Cyert & March, 1992; March & Simon, 1958). Managing this localized knowledge requires boundary-spanning mechanisms for decision making, coordinating activity and innovating (Carlile, 2004; Okhuysen & Bechky, 2009). In this process, occupations and professions actively compete with one another by making jurisdictional claims, which are consequential for occupational group boundaries of core work domains (Abbott, 1988).

A notable stream of literature examines micro-level jurisdictional contests in the workplace. The focus is on occupational boundary contests, where inter-occupational contestation illustrates jurisdictional claims of occupational members. For instance, Bechky (2003a) compares the knowledge, authority and legitimacy claims of three occupational groups – engineers, technicians, and assemblers, and how their use of artifacts consequentially strengthens these claims. She notes that "occupations fiercely guard their core task domains from potential incursions by competitors" (p.721). Kellogg et al., (2006) examine coordination between four different occupational groups at an online marketing solutions organization. They found that cross-occupational attempts to coordinate work on client projects were thwarted by conflicts over issues of jurisdictional control, identity, and accountability.

This stream of research demonstrates how occupational groups' division of task labor in terms of jurisdictional claims is consequential for their relative standing and for organizational outcomes, such as shifts in jurisdiction, status, power and resource allocation (Anteby et al., 2016). Previous work, however, tends to emphasize conflictual or adversarial interactions in the form of jurisdictional battles and contests, ignoring cooperative interactions and collaborative relations with other occupations (Anteby et al., 2016). Technological innovations such as 3DP require multidisciplinary collaboration across different boundaries, hence, examining both conflictual and collaborative interactions between multiple occupational groups can provide a holistic account of jurisdictional boundary reconfigurations and ensuing dynamics when a new technology is introduced at the workplace.

Occupations, Technological Change and Cross-Boundary Collaboration

Parallel to the research stream above, there is an extensive literature that highlights how technological artifacts can transform work practices and reconfigure boundaries, exploring how the introduction of a new technology can challenge and change situated occupational roles (cf. Leonardi and Barley, 2010). For example, in his studies of radiologists and technicians, Barley (1986, 1990) finds that occupational roles shifted with the introduction of new medical imaging technology. Similarly, Bailey et al., (2012) also demonstrate how new technology introductions may shift occupational roles. In healthcare, more specifically, previous work has explored how occupational groups perform distinction practices to obtain access to a newly implemented technology in order to maintain or strengthen their power and legitimacy (Burri, 2008).

More generally, studies have explored how boundary objects are used in knowledge sharing across professional and organizational boundaries (Bechky 2003b; Carlile 2002; Gal et al. 2008; Levina and Vaast 2005). For example, Carlile (2002) develops a pragmatic approach to knowledge and boundaries in innovation, by showing the role boundary objects play in representing, learning and transforming knowledge across syntactic, semantic and pragmatic boundaries. Although these studies have examined distinction practices and how boundaries are spanned, fewer studies have looked at how these boundaries are reconfigured over time with the introduction of a new technologies, and with what occupational consequences. An exception is a study of the introduction of a robotic innovation in a pharmacy setting by Barrett et al., (2012). The authors contribute by emphasizing the importance of examining multiple boundaries and show how multiple robotic materialities (both digital and mechanical) are entangled with the groups' status, control and autonomy, such that they reconfigure boundary relations between three different groups. They contribute by explaining how, why and with what (contradictory) consequences technological innovations can reconfigure multi-occupational boundary relations.

As previous studies illustrate, research in this tradition emphasizes how particular occupation members may reinterpret and enact their roles, status, and autonomy in the face of new technology implementations, or through the constitutive role of multiple materialities. We build on these insights and more specifically on Barrett et al., (2012) to provide further theoretical insights on the role of materiality in reconfiguring boundary relations. This is an important focus, as the authors argue, insofar the materiality of spaces may be generating contradictory implications for skills, jurisdictions, status and, ultimately, boundary reconfigurations. In our case, the materiality of resourcing spaces for each of the occupational groups and the materiality of artifacts such as 3D modeling were constitutive of the boundary reconfigurations that we observed.

Theoretical Framework

We adopt a practice lens for examining boundary work practices as enacted by different occupational groups with the introduction of 3DP in a hospital setting (Feldman & Orlikowski, 2011; Gieryn, 1983; Nicolini, 2012). Boundary work, that is, work that discursively and materially shifts or maintains conceptions of the boundaries between the different groups (Gieryn, 1983), has been a key concept for organizational and social science research (Lamont & Molnár, 2002; Zietsma & Lawrence, 2010). By drawing on boundary work and a practice lens, we are able to examine how practices establish, obscure or dissolve distinctions between occupational groups, viewing boundaries as relational, dynamic, and in a state of becoming (Tsoukas & Chia, 2002).

For the purposes of this paper, we conceive practices as recurrent, materially mediated, and situated activities (Schatzki et al., 2001), organized as sociomaterial sayings and doings guided by practical concerns (Nicolini, 2012) that are consequential in producing and reproducing boundaries (Feldman & Orlikowski, 2011). In this way, we examine how situated, material boundary work practices are configuring, maintaining or extending jurisdictional boundaries. Our findings provide further insights on jurisdictional boundary reconfigurations, where 'doing jurisdictions' is intertwined with 'relating as collaborating', unpack how the materiality of artifacts and spaces is constitutive of the way occupations mobilize, maintain and expand their jurisdictional boundaries, and finally, emphasize boundary work practices that are understudied in the boundary work literature, such as the importance of knowledge expertise and knowledge claim devaluing tactics.

METHODOLOGY

Our study aims to extend theory (Locke, 2001) on how occupations enact boundary work practices when a new technology is implemented in an organization. We followed an inductive research design, starting from an interest in organizing 3D printing practices across occupational boundaries, and remained open to emerging fieldwork insights. Informed by a practice lens (Feldman & Orlikowski, 2011; Nicolini, 2012) and a process research approach (Langley, 1999), we collected detailed longitudinal data on how different occupational groups enacted boundary work practices, by deploying ethnographic methods and by following key episodes of jurisdictional claims occurred and experienced between multiple occupational groups processually (Garud, Berends, & Tuertscher, 2017; Langley, 2009).

Research Setting

We performed a fieldwork study in a UK, National Health Service (NHS) hospital, spanning two years. The health care sector is an important one to examine boundary work and reconfigurations, as hospitals increasingly adopt 3DP technologies, with considerable implications for reconfiguring care practices, jurisdictions, work roles and identities (Barley 1986; Barrett et al. 2012). Additionally, health care is an ideal setting for exploring boundary work practices given the large number of occupational groups and their high degree of stratification (Abbott, 1988). Our study hospital supports and accelerates the development of innovative medical technologies with the aim of addressing unmet patient needs, while improving patient safety. 3DP was one such technology that was introduced to the hospital and required organizing across diverse occupational groups, such as biomedical engineering - comprised of mechanical engineering technicians, R&D clinical engineers, as well as radiologists, surgeons and technicians who work collaboratively to design, develop and implement innovations at a centralized services lab (3DLab). Table 1 summarizes the different occupational group roles, initial practices before 3DP and transformed practices after the implementation of 3DP.

Insert Table 1 here

Data Collection

We have collected longitudinal data over 24 months. Table 2 summarizes our data sources. The first author was granted almost unfettered access to the hospital as an honorary researcher, and regularly interacted with R&D, technicians, surgeons, radiologists and managers, developing several close informants at the hospital. The honorary researcher role was a natural one to conduct participant observation because the first author was an accepted, yet temporary, member of the hospital. Our primary data sources include ‘zooming in’ on

3DP practices (Nicolini, 2009), ethnographic, non-participant observations (343 hours), detailed field notes (400 single spaced) of how 3DP projects were negotiated and transformed over time (Emerson, Fretz, & Shaw, 2011), in-depth, semi-structured interviews with participants from various hierarchical levels and occupational groups (55), informal, in-situ interviews that regularly occurred while observing work (90), and finally, archival data (20GB of project progress documents, emails, technical specifications and design files of 3D printed medical devices). We also focused on critical events such as jurisdictional claims and tensions as they emerged.

Insert Table 2 here

Data Analysis

We adopted a process research approach (Langley, 1999, 2009), tracking the flow of events and boundary work practice enactments over time. The analysis consisted of multiple readings of the interview transcripts, field notes and documentation, the open coding of discursive and other practices, as well as issues related to everyday work. We employed a multitude of strategies for analyzing the data, such as narrative strategy (Langley, 1999; Pentland, 1999), zooming in on practices (Nicolini, 2009) and visualizing patterns across jurisdictional tension events (Langley, 1999). We then focused on writing extensive theoretical memos and case narratives on our emerging findings and compiled an event-history database in Atlas.Ti throughout the fieldwork (Poole, Ven, Dooley, & Holmes, 2000). By performing temporal bracketing (Langley, 1999) while constructing our narrative, we brought together jurisdictional events based on our interviews, field notes and archival data, and traced the enactment of boundary work practices for different occupational groups, structuring our narrative in six phases. Finally, we traced how jurisdictional boundaries were reconfigured with the introduction of 3DP, and identified linkages and patterns between different types of events and practices which were consequential for boundary work.

FINDINGS

Figure 1 summarizes our main findings and processually identifies key episodes and events throughout our fieldwork, structured in six phases. We analyze boundary work practices, moves and countermoves between different occupational groups and how these are consequential for jurisdictional boundary reconfigurations over time.

Insert Figure 1 about here

Phase 1: R&D Expands Jurisdictional Boundary vis-à-vis Technicians

Extending R&D Resourcing Space: The gradual shift in the technicians' practice was associated with the introduction of the R&D occupational group in their workspace. According to a member of the R&D group, "the design room [located in the technician workshop] used to be [technicians'] office, and one day, the head of our group would come in and plainly announce 'you have to empty the room', R&D is coming in". Another interviewee reflected on the gradual re-appropriation of the technician workspace:

"In the past, a lot more manufacturing took place than currently, but now R&D took over. There's a lot more documentation involved … so it's really a struggle because R&D are heavily involved in the innovation process, they have a scientific framework of thinking, they critically ask questions about why they are doing things and they strategically use their time and resources, while mechanical engineering don't really understand the documentation R&D go through".

(Field notes, Medical Devices Evaluator, July 1st, 2016)

R&D Knowledge Expertise Extends Group Legitimacy: The documentation mentioned in the quote above refers to the quality system assurance necessary to meet appropriate medical devices legislation when 3D printing medical devices. This issue was very important to the R&D group, as one of their core activities is risk managing, through the technical documenting of the devices they design and/or 3DP. They continuously spoke of the importance of the technical file documenting practice for risk management and for regulatory compliance. They emphasized that going through this process minimizes the chances of something going wrong. As the technicians' occupational group did not have the background or skills to go through the required technical documentation, their manufacturing projects were gradually taken over by the R&D occupational group, who used their knowledge expertise of technical documentation to extend their legitimacy vis-a-vis the technicians. They did so by claiming expert knowledge to justify their status in the process of innovation, hence convincing others that their approach was the legitimate one.

R&D Gradually Extend Task Boundaries through 3DP: Additionally, the R&D group's vision was to embed technology innovation at the heart of healthcare delivery, through their unique position as a bridge between front-line clinicians, patients and industry. They added value by rapidly prototyping medical device concepts in collaboration with clinicians, using design thinking principles and tools such as 3D modeling software. Their innovating practice, which used 3D printing technologies, enabled them to gradually take over the technicians' tasks in the past years, such as collaborating with clinicians on crafting medical devices. In sum, R&D progressively expanded their jurisdictional boundaries vis-à-vis the technicians. First, they extended their resourcing space, enhanced their legitimacy using technical documentation knowledge expertise and then expanded their task boundaries through designing and innovating practices, including activities such as rapid prototyping and quality assurance documenting. At the same time, however, they were not the only occupational group using 3DP in the hospital. Other groups were eager to provide a centralized 3DP service to the hospital.

Phase 2: 3DLab Established Independently of other Departments

Establishing Task Boundaries and Space Jurisdiction: Centralizing the 3DLab away from any specific hospital department at a 'neutral place' was key, as the place where the 3D printers would be physically located played a crucial role in the process of innovation. There was debate for where to place the 3D printers, with options for centralizing the lab as a hospital wide service, or departmentalizing the printers at discipline-specific departments (e.g. Craniomaxillofacial surgery). The radiologist who secured funding described the situation:

"Surgeons are engaging in empire building… presented with the opportunity, they will use any funding available to them to purchase a 3D printer solely for their own use with little regard about the rest of the hospital […] departmentalizing the 3DP service is wasteful and duplicating resources, a process prone to politics".

However, the radiologist who initially drafted the 3DLab plan, convinced the surgeons to locate the printers away from their specific disciplinary functions. According to the radiologist, "radiology is the nerve system… in order to take away political tensions, it is useful to find a neutral ground for the 3DLab which is run by technicians and radiologists, rather than specific surgeons/disciplines". As such, they located the 3D printers at a 'neutral place', as they called it, that is, "a place where no hospital division, surgical specialty or departmental politics would influence the use of 3DP". Additionally, the centralized 3DLab was equipped to cross-charge medical specialties for services both within and outside the hospital. As the head of the 3DLab explains:

"We already run as a cost recovery service, where we charge for everything that we do. We already have mechanisms for internal cross-charging within the organization but also invoicing other organizations, this is one of the reasons the service came to us".

By establishing the 3DLab as a centralized hospital service offering anatomical models to surgeons, the group of radiologists and technicians established their task boundary of 3DP anatomical modelling work in the hospital vis-à-vis the R&D group.

R&D Expulsion Work and Knowledge Devaluating: Although 3DLab grounded their task jurisdiction over anatomical modelling services offered to surgeons within the hospital, the R&D group often noted that their anatomical modeling practice was illegitimate and lacking in accountability. They referred to 3DLab as "medical photography", as they did not think their anatomical modeling practice was using the appropriate governance to assure quality of the 3D printed models served to surgeons. As one member of the R&D group noted:

"To provide quality assurance on any medical device, there has to be the appropriate traceability of material, storing of data and the technical file orientation, work instructions for thresholding and CT Scans with which the medical devices are designed… they do not use the appropriate quality assurance processes and workflow".
(Medical Engineer, April 2016)

This was corroborated through our observations. During a meeting between managing directors of the hospital, the inter-occupational jurisdictional tension was highlighted:

Innovation Managing Director: *What do you think is different between what you guys are doing?*

R&D group member: *Fundamentally, they [3DLab] do anatomical models for surgery planning, which is an issue because they recognise there needs to be a quality*

> *assurance structure around that, which they're being very slow at implementing, but we are hoping to support – basically if they just adopt our quality system we can bring them into ours, so they'll be under ISO certification. It's the same with all of the situations, we don't want to be a hurdle, and the trouble is that we are the regulatory gatekeepers… we are seen as the negative people.*

Although the R&D group criticized 3DLab for their lack of accountability and frequently commented that the 3DLab technician did not have the appropriate level of seniority and skills to deal with 3D printed medical devices, they had a solution. They suggested 3DLab could use the R&D quality assurance system (ISO certification) to safeguard the hospital in case something went wrong with 3D printed anatomical models. In so doing, however, they were challenging the jurisdictional boundary of the 3DLab by devaluating their knowledge claims to 3DP, in an attempt to further extend their own task boundary through their technical documenting activities.

Phase 3: Inter-Jurisdictional Tensions between R&D and Technicians

Soon after the commencement of the study, we became aware of inter-occupational tensions between R&D and the mechanical engineer technicians when using 3DP. We unpack these jurisdictional contestations by paying attention to the jurisdictional claims of the occupational members and their consequences for boundary relations. We craft composite vignettes from various data sources to weave our findings together (Jarzabkowski, Bednarek, & Lê, 2014).

Inter-Jurisdictional Tensions between R&D and Technician Groups – Vignette 1: *A new 3D printing project opportunity arrived at the hospital, an order for 3D printing fifty mobile phone cases that would provide additional mobile phone battery for a departmental trial study, with the aim of improving interactions with patients. The project was first* *delegated to the technicians, who attempted to manually machine the phone cases using traditional drilling and computer numerical control machines, but eventually failed to produce the cases. R&D group members were skeptical about the approach adopted by the technicians affiliated with mechanical engineering. They gathered in the R&D room and had a vibrant discussion about the technicians. Andrew, a clinical scientist with the R&D group, commented that "manually machining fifty mobile phone cases as per specification will take ages for the technicians, although they can do very finessed machining using 2D drawings, it is not the way we engineer in the 21st century […] yes, you can manually mill bits of plastic but you are probably talking about 2-3 days of work […] in order to speed the process of delivering design, we use 3D modelling in 3-4 hours and 3D print it or outsource the 3D printing, whilst you are getting on to the next project, and the cost would be a third of our hourly rate, so it's a no brainer really".*

Vignette 1 Analysis - R&D Further Extends Jurisdictional Boundary through 3DP Practices: As the vignette above demonstrates, the materiality of the artifacts each of the occupational groups used in their practices enacted jurisdictional tensions over the 3D printing of the mobile cases project. The technician group used 2D drawings and operated traditional machining tools that require craftmanship and manual precision, whereas R&D used 3D modeling techniques to 3D print medical devices de novo, hence saving time and costs. 3D modeling and printing were used as representations of legitimacy and authority (Bechky, 2003a) to strengthen the jurisdictional claims of the R&D group. As such, the R&D practice of innovating with 3D modelling and 3DP practices were consequential for the boundary relations between the two groups. At the end of this jurisdictional tension, the technician group were removed from 3DP process and R&D took over their projects completely. The tension further demoted the technicians' status at the hospital and left them emotionally frustrated.

Inter-Jurisdictional Tensions between R&D and Technician Groups – Vignette 2 (Technicians defend their artifacts and task boundaries): *Three months after the first 3DP tension outlined in vignette 1 above, another inter-jurisdictional tension occurred at the hospital. The R&D occupational group prepared an innovation project brief to gather investment and renovate the existing mechanical workshop where technicians performed their repairing practices, into a 3DP innovation hub. As they phrased it, the workshop had some "outdated and redundant kit" that could be removed, providing space for rapid prototyping facilities, quality controlled manufacturing areas and meeting spaces. The materiality of the mechanical workshop included an array of milling, drilling and computer numerical control machines, along with trolleys and other medical equipment for repair, as seen in Figure 2 below.*

Insert Figure 2 about here

In other words, R&D envisioned a space for "inspiring innovation through building a creative and safe environment for design, prototyping and manufacture of medical technology, using 3DP". This was an attempt to further reconfigure their jurisdictional boundaries by proposing a reconfiguration of the materiality of the workshop space and a set of new innovating practices. However, their proposal backfired with unintended consequences, as the technicians group actively resisted their proposal to defend their jurisdictional boundaries. The head of the technician group explained in their circulated email that "we've got to maintain some machinery for repairs, we do a lot of bed, scale and chair repairs… the word 'renovation' seems wholly inappropriate considering the small amount of space that may realistically become available, if current maintenance is to continue. Much more discussion is required to achieve a more balanced and prudent document to meet the needs of all". This view, however, was not shared by the R&D group.

Indeed, as the head of the group shared with us, "using the limited space we have for bed maintenance is lacking in aspiration and vision… I would say get rid of the beds all together, we can receive £7m of funding from [innovation grants trust], so we must not let this get in our way".

Vignette 2 Analysis - Artifacts Enacting Legitimacy and Status: Vignette 2 highlights the discursive practice tensions between the R&D and technician groups, which eventually led to the abandonment of the space renovation project. Similar to Bechky's (2003a) findings that artifacts can be useful jurisdictional tools, the machinery of milling, drilling and computer numerical control machines were representations of legitimacy, signifying the value of the technician occupational group and used to make judgements on occupational skill and worth, as well as to reinforce occupational status. The technician repairing practice, enacted through these material artifacts, was threatened by the renovation proposal. In particular, the R&D group's proposition to remove their artifacts led the technician group to resist fiercely, defend their task boundary enacted by their practice of repairing and managing equipment, and eventually block the 3DP innovation hub proposal.

Phase 4: Neurosurgeons Bypass 3DLab Services and Collaborate with R&D to Design Cranial Plates

We observed additional boundary reconfigurations between the R&D group and the 3DLab in phase 4. The neurosurgeons thought 3DLab did not have the appropriate accountability processes and knowledge expertise to collaborate with them for 3D printing cranial plates, nor did they have a metal 3D printer in situ to print the plates using titanium metal. The R&D group were keen to collaborate with the neurosurgeons to ensure the appropriate regulatory procedures were met. One R&D group member explained that "[we] like to keep the surgeons away from direct contact with 3DP", while another member explained this more thoroughly:

"A lot of the drive for 3D printing being brought into the hospital comes from surgeons. Whereas, we, one of our roles is to regulate medical classes within the hospital, so we get a little bit… officious. You know, it really is important that people don't just make stuff alone and it is done through a robust design process" (Head of R&D Group, November 2016)

As a result, the 3DLab anatomical modelling practices were deemed inadequate for the cranial plates project. Through their collaborative activities with neurosurgeons, the R&D occupational group expanded their jurisdictional boundaries vis-à-vis the 3DLab, by extending their task boundaries of 3D modelling cranial plates for direct use in surgical practice. Over time, the 3DLab entered into financial difficulties meeting their projected model use as forecasted by their funding proposal, and they were struggling to keep the in-house 3DLab service running.

Phase 5: 3DLab Collaborates Closely with R&D to Expand their 3DP Services

In the face of 3DLab financial difficulty, the hospital management drafted a commercial plan to exploit opportunities for the provision of 3DP services outside the hospital, in February 2017. To make this happen, a closer collaboration between 3DLab, R&D and the technicians' occupational groups was deemed essential, as 3DLab had to work with R&D's quality assurance processes to supply to the external healthcare market. The radiologist at 3DLab explained:

"The majority of our [anatomical] models are used for surgical planning. One of the things that [the R&D group] is going to do for us is, obviously in this department we don't have a quality system, R&D are able to validate the work that we do"

R&D Suggesting Task Boundaries: In the following months, 3DLab and R&D intensified their collaboration for both designing and 3D printing cranial plates, as well as developing external 3DP services for other hospitals. It became apparent to the groups that

3DLab was not doing well financially, as the surgeons were not using their 3DP services as much as they had proposed. R&D drafted an approved process workflow for 3DLab, based on quality system documentation, with the aim of ensuring appropriate governance for 3DP. Specifically, they drafted accountability mechanisms (reporting of all 3D printed items in a quality assurance software tool) and setting up responsibilities and roles. With the decision flow process, the R&D group attempted to define the task boundaries for the collaboration. They proposed that the head of biomedical engineering would be responsible for overseeing the quality management system, while the head of the 3DLab would be responsible for manufacturing and delivering 3D printed medical devices.

Despite the closer collaboration between the different occupational groups, the financial troubles of the 3DLab was a key occasion for the R&D group to reengage in boundary work practices of drafting tasks for the collaborating, thus attempting to reconfigure their boundary relations. We elaborate on this in phase six below.

Phase 6: Further Jurisdictional Conflict between R&D and 3DLab Occupational Groups

In July 2017, the funding body of 3DLab had agreed to extend their funding under the conditions that R&D will be leading the lab and that the technician they employed would be subsumed under R&D. The managing director of 3DLab's funding body thought that the basement location for 3DLab was not the right place for 3DP. The head of the funding body explained that *"I am not ready [for the 3DLab] to remain in the basement at all [...] I think it'd be a good thing if it moved out of the basement".* The main concerns surrounded the lack of the group's resilience and concerns about governance, that is, whether the 3D printed models qualify as medical devices, in which case, should be governed under a quality management framework for in-house manufacturing. R&D had the governance expertise and so the managing director wanted the 3DLab to be subsumed under R&D leadership, for medical device safety assurance. In their words:

“I think I'm entitled to express an opinion here… I think the 3DLab technician and the whole service should move to R&D, I don't think the 3DLab is the right place for it. The only complication with that is R&D do not have billing mechanisms for 3DP. So, then you need some sort of collaboration, where the ‘retail’ end if you like is managed by 3DLab and everything else is done by R&D”.

As seen in the quote above, the arrangement envisioned an intensified collaboration between the occupational groups of R&D and 3DLab; R&D would be running the 3DLab service, while the 3DLab would take care of billing and cross charging the different hospital departments, as it was organized on a cost-recovery basis. Finally, the funding body director thought that 3D modelling practice of the technician at 3DLab was similar to the supervised and regulated practice of radiotherapy professionals and was thus important that the technician had proper supervision and clinical governance under R&D leadership.

However, the above propositions brought about ambiguity and tension over the task boundaries of 3DP work. The head of the 3DLab resisted the proposition to subsume the task area of 3DLab under the leadership of the R&D group, and explicitly mentioned they would resign as head of 3DLab.

DISCUSSION

Our study sought to address the research question of how multiple occupations mobilize, defend, and expand their jurisdictional boundaries when a newly introduced technological innovation –medical 3D printing in our case– creates upheaval. Our longitudinal findings provide granularity as to the different boundary work practices four occupational groups (mechanical engineering technicians, 3DLab - comprised of radiologists and 3D technicians, clinical engineering R&D and neurosurgeons) enacted, and documents how inter-jurisdictional group boundaries were relationally reconfigured through such practices as extending task jurisdictions, resource spacing, expulsion work and knowledge devaluating, as well as using artifacts to enact legitimacy and status. For example, we find that R&D occupational group used their knowledge expertise of quality assurance significantly at different phases of the 3DP introduction and with different occupational, which, in conjunction to resource spacing and the use of 3DP artifacts (e.g. 3D modeling technologies and rapid prototyping), expanded their jurisdictional boundaries vis-à-vis the technicians and 3DLab by improving their legitimacy and status, marginalizing the technicians and shifting their practices to repairing equipment, eventually leading them to fiercely defend task boundary defense in phase 3, when R&D proposed a space renovation. In contrast to other jurisdictional boundary studies which place an emphasis on adversarial interactions and natural tensions, we find that R&D used their collaboration with other groups, such as the neurosurgeons, to further extend their own jurisdictional boundaries. Below we elaborate on the significance of our findings and discuss implications for different literatures.

Implications for Work and Occupations

The literature on occupational jurisdictions has investigated how occupational groups defend and maintain their boundaries at the workplace (Bechky, 2003a; Truelove & Kellogg, 2016), as well as how jurisdictional boundaries shift with the introduction of new technologies (Barley, 1986; Barrett et al., 2012). Key findings demonstrate that occupational groups may resist collaborating when their jurisdictional boundaries are under threat in light of organizational change (Truelove & Kellogg, 2016), draw on their knowledge and expertise to establish and maintain authority over which tasks to perform (Abbott, 1988; Anteby et al., 2016) and how the use of new technologies by multiple occupational groups can reconfigure boundary relations with implications for work practices, roles and status (Barrett et al., 2012). Our paper builds on these insights and contributes by demonstrating how technology, in our case medical 3DP, may reshuffle the possibilities of expanding, maintaining, and defending boundaries between multiple occupational groups at the workplace.

We extend the predominant focus on dyadic, natural tensions between occupational groups in the literature (Bechky, 2003a). Our findings show how cooperative interactions and collaborative relations develop between occupations when a new technology is introduced (Carlile, 2004; Kellogg et al., 2006; Levina & Vaast, 2005). By examining both conflictual and collaborative interactions, we provide further insights on jurisdictional boundary reconfigurations, where 'doing jurisdictions' is intertwined with 'relating as collaborating' (Anteby et al., 2016). We show, however, that even when jurisdictional conflict seems to have subsided and groups seek to closely collaborate (such as in phase 5), R&D members used this opportunity to further engage in boundary work with the aim of extending their task boundaries vis-à-vis the 3DLab, leading to further jurisdictional claims and boundary reconfigurations in phase 6. Hence, although generative relations between occupations may develop, as is indeed necessary for innovating with a multidisciplinary technology such as 3DP, we demonstrate that occupations are actively engaging in ongoing boundary work that may lead to further jurisdictional tensions (cf. Anteby et al., 2016).

Implications for Occupations, Technological Change and Boundaries

Another stream of occupations literature investigates the "inertial" forces guiding occupations, for instance, by emphasizing how a new occupational group may strive for establishing legitimacy through highlighting values of appropriate practice conduct. For example, Fayard et al., (2016) examine how organizations enact epistemic stances to evaluate new IT-enabled practices, which are rooted in the larger organizational and professional fields of the organizations they studied, hence providing insights on *why and how actors* enact practices the way they do. Additionally, Nelson and Irwin (2014) examine the role of occupational identity as a lens for shaping responses to technology, and how the occupational group of librarians shaped Internet search based on their identity. Truelove and Kellogg (2016) focus on the heterogeneity within occupational groups and its congruence with occupation (radical) or organization (moderate) values. In our study, we observed similar 'inertial' dynamics, for instance, when R&D and 3DLab members enrolled 3DP in their innovating practice and actively configured and extended their task boundaries over time, as they drew on their scientific framework of thinking, quality assurance and radiological expertise respectively.

However, this stream of literature downplays the role of materiality in these inertial forces. There seems to be a tendency towards favoring voluntaristic accounts of construction of shaping (Leonardi & Barley, 2010), at the expense of how the materiality of artifacts, digital representations and space matter for boundary reconfigurations. Building on recent insights on the role of materiality in boundaries (Barrett et al., 2012; Jonsson, Holmström, & Lyytinen, 2009; Nyberg, 2009), our study demonstrates how the materiality of artifacts and space is consequential for ensuing jurisdictional conflicts and boundary reconfigurations, not just representational and subject to interpretation (Bechky, 2003a). For example, the extension of the resourcing space of R&D at the expense of technicians and the knowledge expertise of using the technical file orientation, were integral to the boundary extensions of the R&D group in phase 1. Additionally, the 3D modeling software and 3D printing artifacts further strengthened the legitimacy and status of R&D when a 3DP innovation opportunity arose, as opposed to the use of 2D modeling and mill/lathe artifacts in the case of technicians, hence materially excluding the technician occupational group from the 3DP process in phase 3. Therefore, our empirical findings support calls for a sociomaterial perspective on work and organizing (Leonardi & Barley, 2010; Orlikowski, 2010), especially in relation to occupations. This presents an opportunity, going forward, for unpacking how the materiality of artifacts and spaces is constitutive of the way occupations mobilize, maintain and expand their boundaries.

Implications for Boundary Work

The boundary work literature has investigated the strategies occupational groups employ in their attempts to establish, defend or contest professional (Bucher, Chreim, Langley, & Reay, 2016; Burri, 2008), disciplinary boundaries (Lindberg et al., 2017) and status (Apesoa-Varano, 2013) by protecting their autonomy, prestige and control of resources (Abbott, 1988; Gieryn, 1983). Recent work demonstrates the importance of discursive framing strategies that are influenced by occupational field positions based on status and centrality (Bucher et al., 2016), how technologies can challenge professional expertise and identity (Burri, 2008), and finally, how boundary work is a dynamic, material and iterative process constantly in the making (Lindberg et al., 2017). Our findings corroborate the dynamism of boundary work as a material, ongoing process, where boundaries are not given a priori, but rather enacted in practices that include material arrangements and artifacts, that can nevertheless change in meaning and use over time. However, we find that the role of knowledge expertise and wider material arrangements such as resourcing space are understudied in boundary work. For example, in our study, establishing and expanding resourcing spaces was an important boundary work practice for either expanding task jurisdiction (in the case of R&D vis-à-vis the technicians in phase 1), or for establishing a new work domain (as in the case of the 3DLab and 3DP anatomical modeling practice, in phase 2).

CONCLUSION

We studied how four occupational groups enacted boundary work practices to extend their jurisdictional boundaries by improving their status, authority and legitimacy when a new technology created challenges for collaboration in the multi-occupational context of medical 3DP in health care. By adopting a practice lens and using boundary work as an analytical tool, we examine how situated, material boundary work practices are configuring, maintaining, and extending boundary relations through jurisdictional claims. Our findings highlight the ongoing struggles and jurisdictional contestations between these groups and the consequentiality of their boundary work practices for the status and task jurisdictions of the occupational groups involved. We highlight the role of knowledge expertise and wider material arrangements such as resourcing space as important aspects in boundary work. Our findings are limited to the extent that we only examined a specific innovation in a particular organizational context, but we believe our insights are valuable and generative. Further research is needed to verify and elaborate on them, to examine how jurisdictional boundaries are reconfigured in other contexts and with other technological innovations.

Table 1: Occupational Groups and Practices at UK Hospital

Occupational Group	Initial Practices	Transformed Practices	Work Activities	Empirical Material
Mechanical Engineering Technicians: Technical experts with significant knowledge and experience in manufacturing (hand crafting) medical devices using such artifacts as 2D modelling, lathes, drilling machines and computer numerical control machines	• Before the introduction of 3DP modelling practices at the Biomedical Engineering department, they collaborated with clinicians across the hospital to manufacture medical devices upon request. • Their occupational group membership was that of mechanical engineering, which provides skilled instrument makers, trained through on-the-job apprenticeship.	*Repairing and Managing Medical Equipment* After the introduction 3D modelling by the R&D group, their practices gradually shifted to repairing equipment	*Repairing Medical Devices* *Generating Spare Equipment Orders*	*"we've taken on contracts regarding the overhaul of hospital beds, scales, hoists, chairs, couches"* Interview, Head of Technicians' Group *"On a yearly basis, we check all our equipment out and then if spares are needed, we have to source those and generate orders"* Interview, Senior Mechanical Engineer
R&D Clinical Engineers: Research and development experts with significant knowledge in embedding technological innovations at the heart of healthcare delivery. They have significant expertise with medical devices regulation, governance, and risk managing, using such artifacts as 3D modelling, rapid	Technical file documenting; the R&D group enacted the practice of collecting all the appropriate documentation that adhere to standards and medical devices legislation.	*Designing and Innovating* After the implementation of technical file documenting, they shifted their practices towards designing and innovating with 3DP.	*Project Briefing* *Designing and Rapid Prototyping of Medical Devices* *Technical File Documenting for 3DP*	*"We create project briefs for 3DP projects, their market potential and design 3D models for review, which guide our practices"* Interview, R&D Clinical Scientist *"At the core of our work is medical device design, applying rigorous scientific principles to approach healthcare problems"* Interview, Medical Engineer *"we do technical file evaluation for medical devices... going through this process minimizes the chances of something going wrong"* Fieldnotes, Medical Evaluation Specialist, March 2016

prototyping and technical documentation. The group was comprised of clinical engineers and registered clinical scientists, who hold a degree in life sciences, complete a 3-year NHS Healthcare Scientist Training Program (STP) and are registered with a national body for licensed health-care professionals in the UK, the Health and Care Professions Council (HCPC).	• As the department of biomedical engineering has to CE-mark 3D printed devices (European conformity standard), their ISO-13485 certification makes sure they meet the appropriate medical devices directive legislation		*Collaborating with diverse occupational and professional groups*	*"we have a multidisciplinary team to sign off [3D printed designs and devices]…between ourselves, the clinicians and the whole surgical team […] we have the scan, we extract using the software [shows the toolkit and examples on the screen], we do the design. We then submit the design in a 3D-PDF, so they can view. Then it gets sign off from the whole group and goes out to additive manufacture. That is the way we have got checks and balances from all sides"* Fieldnotes, Medical Engineer, November 2016
3DLab: A multidisciplinary group bringing together surgeons, radiologists, and technicians for using 3DP. They secured funds to establish an in-house, centralized 3D services lab (3DLab), with the aim of enhancing patient care.	. • Utilized 3D images of human body structures to create 3D models of patients' anatomy and deliver anatomical modelling services to different specialty surgeons. • They set up a digital infrastructure; imaging datasets were obtained from radiology in their raw format (DICOM data) and were imported into specialist software packages.	*Anatomical Modelling* Enacted the practice of anatomical modelling to facilitate surgical planning. This practice was the core 3DLab practice for the duration of our fieldwork. The structure was identified and turned from sliced imaging into a 3D structure, by engaging in segmenting practices, which could be rotated and edited on screen. The software then produced a stereolithographic (stl.) file, required to	*Segmenting CT or MR images* *Consulting human anatomy books*	*[the lab technician] loads the 3D model of the patient skull on his large iMac screen, with what seemed to be a fractured mandible, taken directly from CT scans and modelled instantly. After a period of deliberation, the technician comments that "now I need to remove the parts they [referring to maxillofacial surgeon] are interested in (showing the green areas of the CT scan layers of the model as the bone).* Fieldnotes, January 2017 *"I consult the books all the time. It is very challenging, but usually the end user (surgeon etc.) will sit here with me to help me do the model and explain what they want"* Fieldnotes, January 2017

		communicate with the 3D printer software. Once modelled using CAD software, further adjustments could be made in terms of coloring and sizing, and the finished file was sent to the 3D printer. We summarize the anatomical modelling practice of the 3DLab in table 3.		
Neurosurgeons: Identified opportunity to use 3DP for craniotomy surgical procedure.	• Designed patient-specific, implantable cranial plates. • A cranial plate is a prosthesis to replace a portion of the skull that has been removed through craniotomy. This is undertaken to treat brain injury and manage swelling in the brain.	Neurosurgeons bypassed the 3DLab and directly collaborated with the R&D occupational group to design the patient-specific cranial plates. Outsourced the titanium-metal 3D printing to an external organization.	*3D Printing Cranial Plates* *Collaborating with R&D Occupational Group*	*"there is a patient waiting list, at least 50 people with a hole in the head…we are using a proper 3DP with binder and glue to 3D print these plates"* Interview, Neurosurgeon *"The R&D group are sourcing the 3D software, providing the regulatory expertise and emotional support in the process of innovation"* Interview, Neurosurgery Fellow

Table 2: Overview of Data Sources

Data Collection	Informants/Material	Total
Semi-structured interviews	**Formal (#55) with 48 participants, including:** • Hospital Divisional Directors, Managers, Clinical Scientists, Clinical and Mechanical Engineer, Technicians, Surgeons, Radiologists	60 hours 5 interviews conducted over Skype
	Informal (#90) with participants during fieldwork • These turned out to be valuable sources of data on specific incidents and events. The content of these interviews was captured in detailed field notes	250 hours 24 months of observation
Participant observation	**Meetings** • Design review • Establishing and updating 3D projects	40 hours
	Biomedical engineering • Rapid prototyping • 3D modelling • Repairing and maintaining equipment	150 hours
	3DPLab Practices • Anatomical modelling • 3DP of medical devices	50 hours 400 pages of fieldnotes, single spaced
Archival sources	**Emails** • Evolution of practices between 2014-2017 (e.g. branding material, plans, logos, roadmaps, interactions)	100
	Internal documents • 3DP device technical specification files • Design drawings • Project review documents	150
	Public documents • Medical regulation and legislation directives • 3DP Reports • 3DP Blogs	100

Figure 1: Discrepant Events Timeline, Boundary Work and Reconfigurations

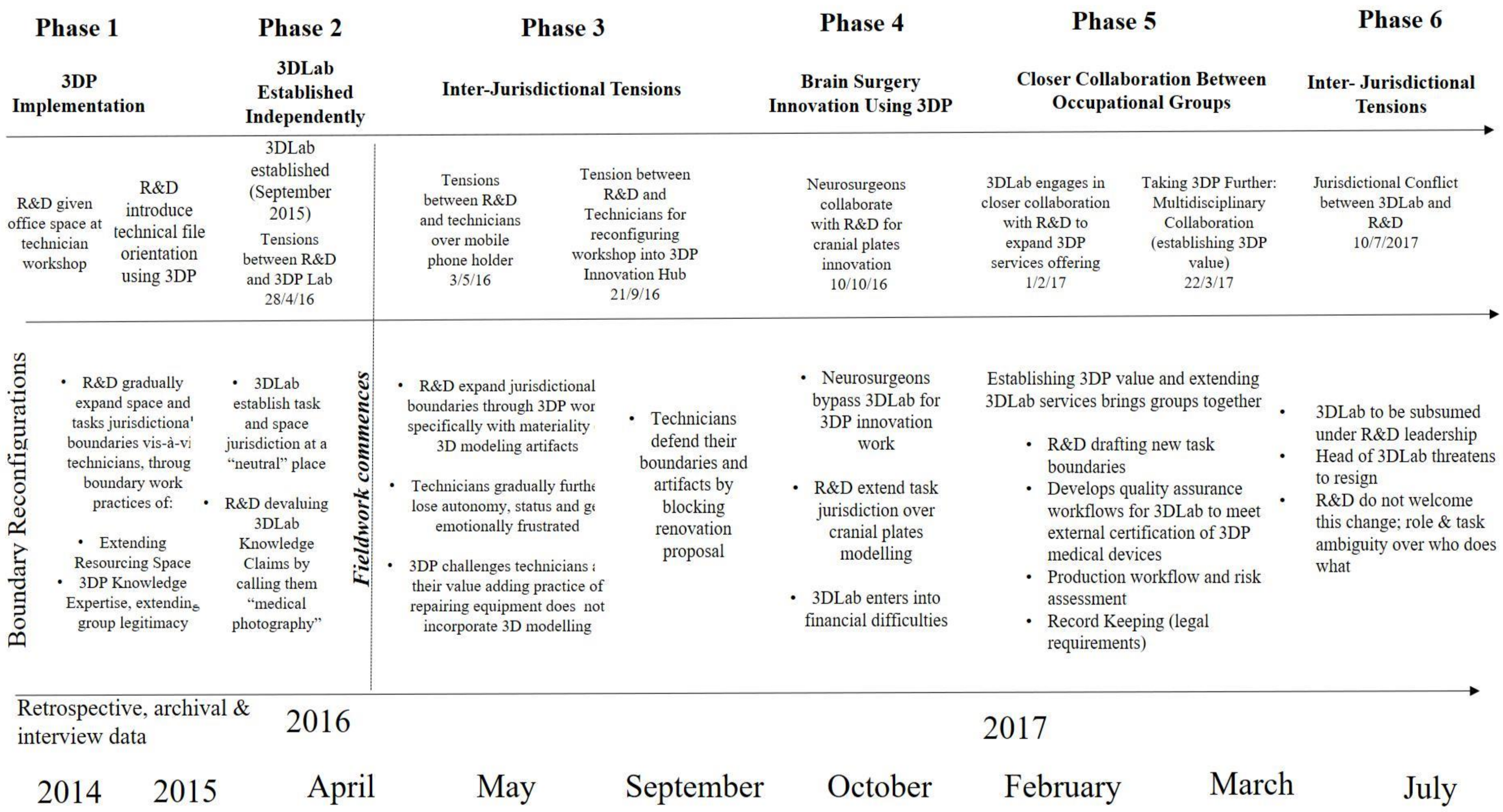
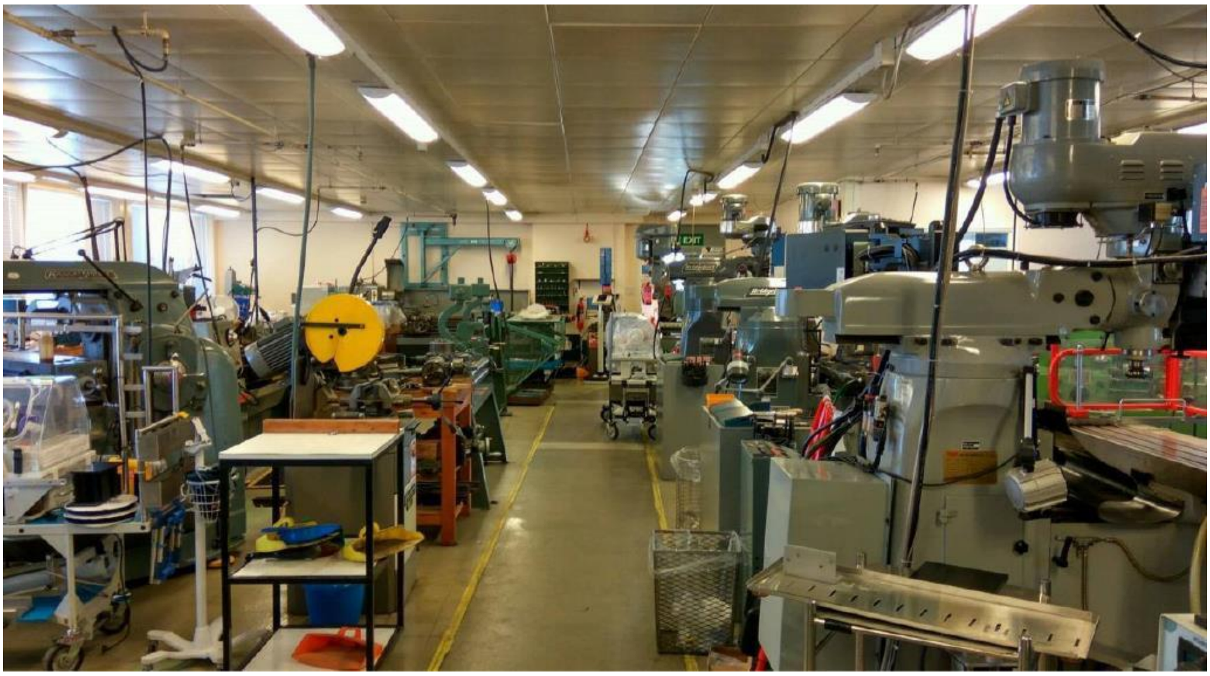


Figure 2: The Technicians' Workshop



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