Operating in the Shadows: The Productive Deviance Needed to Make Robotic Surgery Work

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SUBMITTED TO THE MIT SLOAN SCHOOL OF MANAGEMENT IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY
SEPTEMBER 2017
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Abstract

Though a 2.5-year mixed-method study comparing robotic surgical practice to traditional surgical practice, I explore how crucial outcomes require productive deviance: norm- and policy-challenging practices that are tolerated because they produce superior outcomes in the work processes governed by those norms and policies. My empirical focus was fortunate – I show that productive deviance is likely especially important in the first ten to twenty years of significant technical reconfiguration of surgical work. I open my dissertation through a comparative empirical introduction to my context and a review of the literature on deviance in organizations. The second chapter of my thesis is a history of how the surgical profession has relied on productive deviance for integrating new technologies since the early 1800s, ending with a deeper treatment on robotic surgery. My third chapter focuses on how only a very few surgical residents managed to gain confidence and competence with robotic surgical methods given significant barriers to such learning. In contrast to what the standing literature on learning would predict and in tension with the norms for learning within the surgical profession, these residents engaged in a suite of practices I call “shadow learning” - involving premature specialization, abstract rehearsal and undersupervised struggle. I explore how each of these practices both allow progress and create unintended negative consequences for the profession. My fourth chapter explores a case in which surgical teams routinely used new, well-maintained robotic surgical devices and occasionally faced the stressful and practically difficult task of using an under-maintained, unreliable surgical robot. In this chapter, I show quantitatively that patients did just as well on the degraded robot, and I outline the often invisible, undervalued “compensatory work” that professionals did to ensure such outcomes. The main contribution here is to explicitly treat affect as integral to coordinated work that is grounded in suboptimal material arrangements. Through these studies, I solidify and enrich our conception of productive deviance and show how it is critical for a range of professional and organizational outcomes.
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Reflections and Acknowledgements

I know all too well how to dodge responsibility, buck authority and make claims outside my purview. And while I tend not to break rules, I do tend to treat them as “optional reading.” This semi-acceptable-path-of-least-resistance approach has been my modus operandi since I was quite young, and I have met with mixed success sublimating it as an adult. My dissertation is essentially a meditation on similar dynamics in some of the most highly skilled, tightly coordinated, failure intolerant work on the planet: robotic surgery. So, in my case in particular, the old “we study what we are” adage is true.

I think there is poetic justice here. I have been told most of my life that I should become an academic, yet rejected the call well into mid-life. Then I applied, and MIT invited me in. Whatever tales I may have told about the experience, my doctoral trajectory is rife with productive deviance, revealing my ambivalence about my worthiness as an academic, for organizational scholarship and the academy in general. In my penultimate chapter I resolved this ambivalence in favor of a startup, rejecting the academic call once again, retreating to this dissertation before the sun came up each day. I could not have asked for a more robust test of my academic commitment and a better opportunity to come to terms with myself.

To my surprise, and in the eleventh hour, the academy and organizational scholarship emerged as the right and final resting place for me as a mature worker and adult. I have found a professional community that gratefully accepts me as a scholar of deviance. I gratefully accept it in return, and will do my best to enrich and extend it, however deviant my methods. This dissertation therefore marks a decisive, positive turn in a quite spiritual geas to turn my foibles into something of value. Life does not often offer such redemption.

Journeys like mine require a great deal of support and challenge, and no one in my academic travels has done more – or more significant – work on these fronts than my advisor Wanda Orlikowski. First and foremost, Wanda, you offered me a professional north star: a model of a committed scholar who compassionately asserts exacting standards for the work at hand. Each time we explored ideas and data – whether in person or in writing – you generously offered an astounding amount of focused attention, intellectual courage and conceptual precision. You pushed me to take my scholarly work seriously by kindly yet firmly depriving me of the wiggle room I was so accustomed to securing through guile, charm and sloppy thinking. This was a great relief, and a true gift. Practically, I am humbled by your investment in my work and career, and greatly appreciate your tolerance for my deviant doctoral trajectory. You have responded quickly and extensively to every memo, paper and now chapter draft that I have sent to you. You have offered up your calendar, scheduling whatever meetings were needed. You have made many connections for me throughout the academy. And to my absolute amazement you decisively and warmly supported my choice to take a job in a startup at the end of my first run at the academic job market. Your generous support allowed for the true test I described above, and means the world to me personally. I will do what I can to repay your debt through my commitment to quality scholarship and our scholarly community.

Kate Kellogg, you are the brilliant and positive tactician behind my campaign for competent membership in this profession. Whenever I had key practical choices to make – whether on research design, the argument in a paper, target journals and editors, or the job market – you were ready with a sensible recipe for success. I quickly learned to simply do whatever you recommended. Beyond developing my academic horse-sense, you have left me with a repertoire of well-worn research gambits that simply work, and that I can draw on under pressure. Beyond this – and perhaps most importantly – you have been a key cheerleader. You did not give praise lightly, but you freely and quickly offered it when it was warranted. Through you I began to viscerally understand that my work had significant merit, and this provided a crucial psychological anchor amidst the currents of doctoral life. I cannot thank you enough.
John Van Maanen, without you, my MIT summer’s night dream would have had no Puck. I knew as I read your packet for my first class—Banana Time, the Asshole, On the Making of Policemen—that I had found my intellectual, methodological and political inspiration. Doing inductive ethnography offered me a noble opportunity to redeem my subversive tendencies—by joining and interpreting a messy world with a sympathetic eye to the everyday Josephina just trying to make some meaning and a buck. It’s hard in this scholarly life to do valuable work that does not further concentrate power in the hands of a few, and you showed me a way. If that weren’t enough, you gave me my ontological and epistemological sea legs by reminding me of my pragmatist sympathies. You, Pearce, Dewey, Rorty—you all remind us that truth is what works, and in particular what the people around you will let you get away with. We’ll see what I can pull off.

And now a note for my power committee as a group: you were fantastic together—a true treasure. I think you appreciated this, too. Each of you brought such difference to the table—orientations to the world, our profession, our methods, ways of expressing yourselves, of writing and different approaches to me. But in conversation and in support of me you sang with one voice. As far as I can tell, this collegial alchemy is rare in general and particularly rare on thesis committees. Truly, I count my blessings for your willingness and ability to collaborate on my behalf.

Incredibly, this story of sympathetic support from world-renowned experts does not stop here. Leslie Perlow, you’ve been right at the center of my apprenticeship as a qualitative, inductive researcher since the beginning. For me, your deepest lesson revolved around courage. You watched me go through a great deal of trouble to get truly interesting data only to use it to extend someone else’s theory. By noting that then watching me do it anyway, you taught me to insist on the final inch of the qualitative journey—the one that results in a genuine contribution.

You, Michel Anteby and numerous others conspired to give me the gift of a rich qualitative community. To my fellow Crafters: our group was a touchstone for me, a safe space to take a flying leap with an underdeveloped manuscript, and an opportunity to practice catching you when you did the same. Thank you for your feedback, tolerance and encouragement, especially Julia DiBenigno, Curtis Chan, Emily Truelove, Elana Feldman, Pat Satterstrom, Luciana Silvestri, Ryann Manning, Elizabeth Hansen, Mike Lee, Arvind Karunakaran, Hila Lifshitz-Assaf, and Tiona Zuzul. May we stay connected and pay it forward.

I am honored and delighted to cite many other influences and supports at MIT and beyond. Ezra Zuckerman, your exacting standards and cheerful support were an invaluable combination, and I have really enjoyed forging a deeper connection as my doctoral experience drew to a close. JoAnne Yates, I have always found our conversations about academic life straightforward and interesting—I am far better prepared for the administrative side of this profession as a result. Nelson Repenning, it was a positive delight and an education to work with you. You are one of the most compelling teachers I have ever seen—I will strive to live up to your example. Tom Malone, as in apparently all things, you typified grace and charity as you “let me go” to follow my robotic muse. I will carry your example of humble confidence with me for the rest of my days. Erik Brynjolfsson, they say that the opportunity of a lifetime arrives once a month at MIT—you performed this function for me three times: by introducing me to iRobot, involving me in the Digital Frontiers Group and now the Institute for the Digital Economy. David Shumway, many, many thanks for the trail of historical breadcrumbs for me to follow on my first historical foray. Ethan Bernstein, before we knew each other well you freely and cleanly gave me a wakeup call about my commitment to scholarship. I appreciate it greatly, and look forward to collaborating.

To the extent that there’s anything interesting in this document, it is also because of the day-in, day-out generosity of the surgeons, medical residents, scrubs, nurses, and hospital administrators at my field sites. They invited me in to their worlds, asking little in return and shared more than any of us expected. To each of you: thank you. Come find me if you think I missed a part of the story, and don’t hesitate to reach out if you think I can do anything to repay your kindness and vulnerability.
You’d be right to expect a story like mine originated with some interesting parents. Mom, you gave me your father’s compulsive, warm wackiness and your mother’s sharp wit, and your own appreciation for music and language. I am thankfully compelled to build my life with these tools, and they have brought joy and helpful insight far more often than not. You also modeled the courage to remake an adult life for authenticity’s sake, even when doing so would bring clear, serious, negative consequences. As you can see I have internalized that lesson – thank god. Dad, you gave me the delight, skill and camaraderie that came from carpentry, basic mechanical work and just getting outside. Relatedly, you showed me by example that school was often bullshit, but that it didn’t have to be. I was probably eight when you introduced me to your work with “troubled” youth, and soon after people like Neil Postman, Paulo Friere and Leo Buscaglia. From then on, I could not help but protest, reconfigure and refuse my educational experience when it seemed wrong. Mom, Dad, I owe you everything, and I love you both.

And lastly, truly: words cannot honor, cannot celebrate, cannot cherish her properly, but I can at least dedicate this dissertation to my wife, Kristen Kolakowski. Kristen, I tell anyone that asks that it was you who asked “When’s a better time?” when I protested that it was a horrible time to upset our lives by applying to far-flung doctoral programs outside my expertise. From your days convincing wide-eyed friends that you could together bring genie spirits into lake rocks drying in the sun, to freeing $2500 of your father’s Argentinian bait frogs in a nearby pond, to wrapping your family’s snowmobile around a tree, you have been a free spirit, a kind, leonine heart and a people alchemist. My life is a dream because you have given these qualities and the rest of your being to me – unquestioningly, unflinchingly and eternally. Without question and by measures unknown to science and logic, our love is the greatest achievement, solace and source of inspiration in my life. I cannot wait to start our next chapter together.

For years, and even now, doing qualitative inductive scholarship on robotics in organizations has felt like being a blindfolded child swinging at a piñata. And while they may have spun me around a bit, everyone above and many others have turned me roughly in a healthy direction again, again and again. Connecting the bat with this piñata is therefore a collective achievement. We will see if I have managed to liberate any candy.

Matt Beane
July 27th, 2017
Cambridge, MA
Chapter 1: Pushing Surgery to The Robotic Edge

As a second-year Urology resident at Fairtown hospital, your morning shift begins the same way whether you’re assigned robotic or open surgical work: at 5:45am you enter the resident locker room to change into a sterilized blue surgical uniform, surgical clogs, and a disposable bonnet and facemask, take the elevator to the basement and walk down a windowless hallway towards the center of the building. To your right is a pushbutton to open two double doors, each displaying large, red and white block lettering: “ENTERING INNER CORE: AUTHORIZED PERSONNEL ONLY, FACEMASKS AND SCRUBS REQUIRED.” You swipe your badge and the doors swing inward without you having to touch them, releasing a slight breeze as the positive air pressure from within does its work to limit inbound airborne pathogens. A 200-foot-long corridor stretches out in front of you. Every 20 feet or so a set of double doors opens to the right and to the left; each of these opens into an antechamber with medical paraphernalia and another set of doors that open into an operating theater. You are now in the inner core of the hospital.

Though you saw the schedule last week and have known for months that you were going to be on an initial robotic rotation, you find out much more clearly what kind of day you’re going to have when you see the procedure assignments in “air traffic control” – a 20 x 12 room through the first set of doors on your left-hand side. This room is constantly abuzz, and one wall is covered floor to ceiling with large LCD monitors displaying the day’s schedule – who’s performing what surgery on whom, in what room and for how long, and so on. From 7:30 in the morning until 11 at night most of these operating rooms (ORs) are occupied with teams that were assembled that morning to perform intensive surgeries. For a number of years now many hospitals have staffed surgical teams much as airlines have staffed flight crews: a variety of roles must be fulfilled, schedules must be managed to minimize white space so hospital costs can be reduced, and so each team is often temporary – contingent on the task at hand. And while it is not uncommon for you and your collaborating surgeons, nurses, scrub techs, medical students
and other medical residents to know each other well, it is also not uncommon for some of you to meet each other for the first time shortly before a patient is cut, and to never work together again.

As expected, today starts with a prostatectomy with Dr. P, and though this is only your fourth procedure, you’re hopeful he’s going to let you defat the prostate. Second year residents like you really shouldn’t expect this, especially given that there’s a chief resident who’s supposed to be learning by operating, but she’s pretty far along and you’ve been practicing. A lot. You’ve been taking some flak for it from your peers and the night rounds coordinator (not to mention your spouse!), but you have the top score on the simulator and you’ve done a lot of play-by-play analysis of the best videos out there. You’ve watched Patel, Menon and Samahdi’s prostatectomies, you’ve watched Dr. P’s, and you’ve got your notes and questions ready and have mentally rehearsed your moves. You head from air traffic control to the admitting and prep area, the space where patients meet with the circulating nurse (or circulator) for the procedure, get consented and changed, get onto a gurney and take their initial sedation. You introduce yourself to the patient and get their chart, refreshing yourself with their scans. This one’s a Gleason 3+4, not too serious – good news for this patient. Good for you, too – a Gleason 8 or higher and Dr. P. would want to have their hands on the tiller for much more of the operation.

The circulator heads back into the central core to prep the operating room with the scrub. You wait with the patient, review their chart and fill out some paperwork until their sedation takes effect. You then wheel them down the hallway you came through. Halfway back to air traffic control you take a right through two double doors with a large, red number 15. When you go through these doors, you are entering one of three ORs for robotic surgery in this hospital. The room is perhaps 45’ x 35’ and so is relatively large by OR standards. But in many ways, it is like every other OR at Fairtown. The walls and floor are white, antiseptic linoleum, with the exception of two colored, concentric circles in the center of the floor. In the middle of these circles stands the operating table – one that can be moved and reshaped with an electronic hand controller to put patients in a variety of positions. A “boom” – a rotatable, articulated arm that supports crucial equipment as well as a conduit for gases and power – protrudes 8’
down from the ceiling to the left of the bed. An anesthesiologist’s cart, computer and chair sit near the head of the bed, a networked PC sits on a desk in one corner, one wall is dominated by glass equipment cabinets, and shining stainless steel tables on casters line the walls stacked with boxes of surgical supplies.

Another reason to be hopeful: the scrub is experienced with the robot, and is well into setting up the room in the ways that Dr. P. prefers — you notice that includes leaving several recommended instruments unopened and setting up two extra sets of gloves. You two work well together — most of the time you’re at the bedside, and they’ve really helped you learn the ropes. They have checked that all basic supplies for surgery are present — this includes things like sutures, drugs, needles, drapes, sterile gowns, masks, gloves and so on. Generally, these tools and implements are made available the previous night, brought in by staff and placed in sterile containers wrapped in sterile dressings on the surgical tables in the room. They have long since moved these wrapped containers into appropriate locations for the surgery and unwrapped them — generally onto rolling tables. Underneath all the wrapping, the containers themselves are rectangular boxes made of metal. This allows them and their contents to be autoclaved, a procedure that uses extreme heat to sterilize previously used surgical implements. The circulator and scrub are counting the last of these as you enter, and the circulator makes a paper record of their use and ultimately enters this into an information technology system at the computer on their desk in the corner of the OR.

**Doing Surgery with a Robot**

A quick glance around indicates that this is no ordinary OR. Five monitors are mounted on the walls and equipment. A control console sits in the corner: it is perhaps five feet tall, three feet wide and three and half feet or so in length, has armrests and a face rest with two eyepieces. Five foot pedals are at its base. Two multi-jointed receptacles for a surgeon’s hands protrude from the middle of the console. Another of these consoles sits adjacent to the first. Across the room, you see “the tower:” a six or 7-foot-
tall stack of computers mounted on a mobile base. Many cables run from the tower to both consoles and to the robot itself. It is perhaps 6 ½ feet tall, weighs over 1000 pounds, is 3 feet or 4 feet wide and about 4 feet long. Aside from a weighty base, the robot is essentially four robotic arms, each with a slot for a surgical instrument. In order to prepare for this kind of surgery the scrub and nurse have already secured and checked through a range of these robotic instruments such as scissors, cameras, hooks and graspers, and have they jointly calibrated the camera and draped the robot with sterile plastic.

You know that for the bulk of this procedure, you’ll be standing at the bedside, using a sticklike device to keep the surgical field clear, removing, swapping and cleaning the camera as well as swapping instruments in and out of the robot. If it’s reasonably quiet, and you yell, you can get a question or two in to Dr. P. as they operate, or respond to their yelled questions. And while you might not be central to the surgical action, you will get some laparoscopic practice with your sucker: you can use it to retract tissues, and keeping it out of the surgeon’s view is helpful and a fun challenge.

---INSERT FIGURE ONE ABOUT HERE---

The anesthesiologist arrived perhaps ten minutes before you did and set up their equipment and drugs. You arrive with the patient at about 7:15. The circulator and anesthesiologist ask the patient to slide from the gurney to the operating table, make sure he is comfortable, and explain to him that they will shortly administer a general anesthetic. The patient is generally under general anesthesia by 7:25. Dr. P. arrives at 7:30 with the chief resident and sometimes a few medical students. Dr. P. sets up his Bluetooth speaker and turns on some music while you all don sterile garb. Dr. P. runs through a verbal “time out” (modeled after a pre-flight check) and then you all sterilize, prepare and drape the patient’s abdomen and groin. As you lay the final drape over the patient, Dr. P. says to you “We’ll see if we can get you on the console this morning.” “Awesome,” you say. The chief gives you a strong look – they don’t seem too happy, but then again, not too upset. You’ll take it. You’ve got a shot at getting on the console, and you’re not going to mess up.
Living at the Surgical Edge

You’re one of the “lucky” ones – you enjoy these robotic cases and want to learn more. You feel like you can really follow along, you love to see the surgical action unfolding at 10x magnification, and you enjoy the precision and control that comes with this impressive, expensive tool. It’s the future. But many hate this work. They’re bored out of their skulls because they’re not “in the mix” – the circulator retreats onto Facebook, the scrub fidgets and stares off into space, and everyone’s fixated on the TVs, not looking around for issues like they should be. Another resident in your role who wasn’t focused on robotic surgery would tune out, only responding to commands, not retracting when they could, not being ready to swap in instruments or take out tissues when needed. When you show up in the morning and see some of these folks on the staff list, you know things are going to run rougher. Handoffs won’t be as smooth, requests will have to be repeated, the action will pause to accommodate for both. The procedure will take longer. It’s the damn robot, from their perspective: extra stuff, extra steps, extra failures. They have splintered views on any trouble, they can’t really see each other and it’s hard to hear each other. The OR is crowded and cords crisscross the floor, waiting to trip someone. The whole thing’s a headache for them, and the $1.5 million-dollar price tag doesn’t seem to make medical outcomes any better.

Taking Productive Deviance Seriously in Robotic Surgery

While most of the above vignette hews to norms, policies and law associated with robotic surgery at Fairtown, it also outlines notable deviance. Everyone involved would agree: junior residents should be focused on spending time with patients and acquiring generalist knowledge, not learning robotic surgical technique via digital simulation. Senior surgeons certainly shouldn’t let them operate, especially when the chief resident’s in the room. But neither should they be “tuning out” when at the bedside – they should be focused, practicing laparoscopic technique, asking questions and in general advancing the procedure. Scrubs should follow written procedures for preparing the OR, and if the surgeon prefers things done a different way, the scrub and circulator should rewrite their preference card for the work and run it up the
chain. But scrubs also shouldn’t follow the preference card religiously, and as directed – they should assertively set up their space so they can ensure smooth handoffs, and should stay focused on the surgery as it unfolds. The circulator really shouldn’t help the scrub with calibration, nor should they be on Facebook.

Put plainly, I cannot recall a single procedure that I observed at Fairtown or any other hospital that did not involve repeated bending and breaking of convention and rules. Many of my informants spoke readily about the importance of such deviance in their work. The findings in this dissertation revolve around it. Given this, I turn now to position my dissertation relative to the standing literature on deviance in organized life.

Prior Research on Deviance in Organizations

Deviance is not just deviation. Many studies have shown convincingly that organizations persist partly through deviation: people and practices adjusting to circumstance, inventing new ways forward and departing from plans (Weick and Roberts, 1993; Weick, 1995; Orlikowski, 1996; Star and Strauss, 1999; Suchman, 2007). Broadly, these studies focus on adaptive behavior that does not have a strong counternormative tinge. Examples here include how actions get articulated between humans and new copy machines when the manual itself is either missing or hard to comprehend, how different groups of workers appropriate scheduling and communications software to achieve departmental and individual goals with differing feedback from colleagues and management, and how flight crews on aircraft carriers heedfully interrelate to ensure safe landings. The next valuable, unanticipated action is often not in conflict with – albeit not indicated by – the norms and policies in a given organizational context. Yet taking a careful look at these studies indicates that they do involve counternormative behavior in some cases and ways, so the distinction between deviance and deviation is less a conceptual one and more a matter of salience.
To clarify this territory, I skip from deviation over this grey area to the literature that explicitly and formally focuses on deviance in organizations. Empirically, these studies began with a focus on crime, such as illicit drug use and sales (Becker, 1963), theft of company property and colleagues’ commissions (Mars, 1982), reckless driving (Reed, Burnette, and Troiden, 1977) and sabotage (Wilson, 1999). More recent studies have focused on more positive forms of deviance (Spreitzer and Sonenshein, 2003; Warren, 2003; Vadera, Pratt, and Mishra, 2013). Regardless of the value placed on process and outcomes, studies of deviance do not treat law-breaking as a necessary condition for deviance. Definitions vary but are generally consistent with the notion that deviance is “behavior which violates institutionalized expectations” (Cohen, 1959: 462). Scholars of deviance have also made a related point, namely that this contextual, sociological take on deviance meant that it was always “done”: behavior and individuals become deviant in organizations only to the extent that they are labeled as such, whether by insiders or outsiders, and this holds true only insofar as this labeling continues (Becker, 1963; Matza, 1969; Emerson, 1970). Despite the fact that such findings and theories apply to organizational phenomena well beyond crime, the formal deviance literature has overwhelmingly focused there, and has strayed away from deviance in organizations.

A key point from this literature as it relates to this dissertation: early scholars of deviance made it clear that while it often has obvious costs and is problematic in many ways, deviant behavior is also valuable. None preclude the possibility that deviance adds value only for the perpetrators of such behavior, but scholars in this tradition (Dentler and Erikson, 1959; Douglas and Johnson, 1977) clearly show that ostensibly selfish, norm and law-breaking behavior offers direct benefits to victims and bystanders, the groups they occupy, the organizations they constitute and sometimes society at large. Reed et. al. (1977) make this point clearly through their examination of three deviant types in police departments: “door men,” “mouth men,” and “wheel men.” Door men – faced with limited legitimate opportunities to produce value (e.g., through solving complex crimes) – regularly and obviously curried favor with senior officers (e.g., holding doors for them), hoping to secure favorable assignments and
recognition. To the extent that these tactics worked, the perpetrators benefitted, but such behavior added value for those it offended as well, thus ensuring its continuance. Officers knew that senior management listened to door men and that door men would try to take credit for anything they could, so the officers regularly shared sensitive information or risky improvement ideas with a door man as a way of getting them to management without risking their reputations. Similarly, the gossipy “mouth men” could be relied to share a message with the press and wild-driving “wheel men” could be counted on for extremely dangerous, illegal driving in rare car chases.

These scholars often examined deviance that involved relatively extreme violation of institutionalized expectations, and subsequent scholarship has focused on more moderate territory. It is key to note that such scholarship does not typically invoke the term deviance, but nevertheless focuses on practices that violate expectations yet are tolerated for the value they produce. Some of these studies focus on deviance that breaks policy. Managerial leniencies feature prominently here, (Gouldner, 1954; Roy, 1959; Burawoy, 1979; Anteby, 2008) in which front-line workers engage in deviant behavior such as clocking in late or taking arbitrary breaks (Gouldner, 1954; Roy, 1959), making items for personal use on company equipment, with company materials and on company time (Anteby, 2008), and arbitrarily limiting production to stay close to quotas (Burawoy, 1979). All of these practices were tolerated by management in exchange for subsequent control over workers. Another study of “productive resistance” shows mid-level management breaking policy set by senior management in order to contravene corporate change initiatives (Courpasson, Dany, and Clegg, 2012). Senior managers benefitted in some cases when they treated this resistance as valuable input to guide the change work, while successful resisters were ultimately promoted.

Other studies focus on practices that challenge norms but not policy. Prime amongst these are studies of workarounds, where workers adapt work processes involving technology in ways that run counter to stated (often managerial) goals associated with these processes (Ferneley and Sobreperez, 2006; Azad and King, 2008; Bernstein, 2012; Tucker, Heisler, and Janisse, 2014). Gasser (1986) for
example, finds that users of an inventory control system at five sites engaged in three kinds of “adaptation work” to keep work moving when there was a misfit between the system’s capacities and the work it was intended to support: *fitting*, in which users matched their work to the system’s capacity by shifting either, *augmenting*, in which they did extra and/or new work, and *working around*, which involved using the system in unintended ways or working without the system. The deviant behavior inherent in workarounds gives workers a process that makes sense to them and gives managers increased productivity (albeit without full knowledge of how this is achieved). O’Mahony and Bechky’s study of “stretchwork” (2006) shows that contract workers who “bluffed” (i.e. lying to and/or misdirecting potential hiring managers) about their experience secured important career advancement opportunities. These managers got motivated workers who learned faster than most in the bargain.

Throughout all of this literature, it is only Bernstein who uses the term “productive deviance” in his study of factory assembly work in China (2012). He did so to refer to the practices that line workers relied on to improve productivity, especially when managers faced barriers (a curtain, in this case) to observing their work directly. These workers “tweaked” processes dictated by total quality control charts posted in front of each work station – for example they reallocated their labor, changed work sequences and cross-trained in adjacent stations’ work. All of this ran contrary to the norms associated with total compliance to transparent work processes enforced by management. Productive deviance was not his main focus, so it is perhaps unsurprising that Bernstein did not formally define the term. He defined it by example, however, labeling tweaking as productive deviance because it both improved line productivity (satisfying management) and advanced workers’ interests in “making the line feel more like a team,” and satisfying managers ostensibly unrealistic performance targets. He also expressed puzzlement at workers’ willingness to engage in norm-deviant practices that so obviously benefitted management and that offered relatively little in return, but again made no explicit commitment to such apparent imbalance as part of any definition for productive deviance.
So why did we have to wait until Bernstein to find productive deviance? On one level, we shouldn’t be curious. The literature review above shows that we have known for over fifty years that all deviance in organizations is productive, in that it adds value for interconnected parties with diverse interests and power. From this perspective, Bernstein’s contribution is a tautology. But a closer look reveals that many examples of deviance in the organizations literature in fact describe deviance that serves the deviator directly and that provides some ancillary or second-order value to the ostensibly aggrieved. One might call this “exchange deviance.” On this view, productive deviance is not tautological. It arises only when institutionalized expectations frame a particular deviant practice as a direct threat to an instrumental outcome, yet that same deviant practice is actually a locally superior method for achieving that same outcome. This kind of deviance is particularly interesting because it runs directly counter to norms and sometimes policy, yet is tolerated because it provides superior outcomes to the work processes governed by those norms and policies. 

Bernstein’s study focused on how changes in observability in factory work changed productivity. He found that reducing observability allowed for more productive deviance and learning about productive deviance – and that these in turn produced productivity improvements. Less observability drove more productive deviance which caused better performance. He did not focus his conceptual or empirical gaze on productive deviance itself. In this dissertation, I treat robotic surgery as an opportunity to enrich and extend our understanding of productive deviance – how and why it arises, who is involved, at what places and times and with what consequences for the organization and profession in which it is performed. In the next chapter, I explore the role that productive deviance played in discontinuous change to surgical methods from 1800-2017. In chapter three, I examine how a few medical residents acquired robotic surgical skill through productive deviance, while those who stuck with accepted methods failed to do so. In chapter four, I consider the productive deviance that allowed surgical teams contending with a degraded surgical robot to achieve comparable results to those achieved on a well-resourced model of the same system. Finally, I conclude with the implications of my findings and thoughts on future work.
Chapter 2: A Shady History: Expanding Surgical Practice through Productive Deviance from 1800-2017

Introduction

Surgery’s interesting, in that randomized trials are unnecessary [pause] or not required. If you had to do a randomized double blind trial on connecting the ileum to the stomach you’d never try it. The surgeon has to have room to try new things. The cardiac bypass came about that way. Surgeons just tried that. – Surgical Chair

Getting ahead sometimes requires cutting corners. Yet available historical work on surgery and surgical technologies has not focused on the ways that surgical progress has hinged on such productive deviance. By taking a second careful look at five key discontinuous changes to surgical methods since 1800, I found evidence that strongly suggests productive deviance has been alive and well in surgical progress for at least this length of time. In particular, I show that such progress has hinged on productive deviance that challenges the norms that the surgical community of practice sets for itself. On its face, this is a paradoxical state of affairs – professions persist and enhance their jurisdiction on problems in part by assuring the public they can reduce the harm and uncertainty associated with solving complex problems (Abbott, 1981). Yet as in the other papers in this dissertation, I argue below that it is this very assurance and related community norms that drive the experimentation required for progress into the shadows.

Drawing on Abbott’s characterization of professional work (1988), archival data on technological change to surgical methods and my dissertation data, I suggest here that this dynamic flows from the ways that surgery has been performed. I specifically offer an account of surgery as a “crafty science” (Starzl, 1998; Schlich, 2007; Toledo-Pereyra, 2011) that at key points requires unsafe, inefficient experimentation with new technological means, citing several important examples in the order that they were introduced: anesthesia, antisepsis, surgical gloves and laparoscopic surgery. I end with a deeper examination of robotically-assisted laparoscopic surgery (henceforth “robotic surgery”).

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1 Any direct quotations such as this one are from my own interview informants. Quotations embedded in the text are from secondary sources.
This argument centers on two theoretical themes – one that tilts towards more traditional sociology of professions (Abbott, 1988) and one that tilts towards more recent conceptions of materiality in organizing (Orlikowski, 2010). The sociological theme involves a tension faced by many occupations. On the one hand, in work such as surgery, policing, aviation and lapidary where the cost of failure is extreme and failures are irreversible, occupational norms guarding against risky experimentation will strengthen. But any time such work is actually done, these norms must be challenged: related problems are dynamic and uncertain, and it is often necessary to intervene in them without full information – i.e. to experiment – to produce needed information to guide further action or to avoid catastrophe (Schrock, 1992; Fox, 1996). These responses may be more or less premeditated and occur at varying scales and intensities, but I argue they will happen: practitioners who care about minimizing risk and increasing quality in one-shot, failure-intolerant work on dynamic, uncertain problems will be on the lookout for techniques that do a better job. Thus, while the surgical profession goes to great lengths to minimize the appearance and performance of unsafe experimentation, surgery cannot proceed without it.

The materiality theme addresses an orthogonal dimension of the problem: the ways that surgical practice gets reconfigured as new technologies are introduced. Strictly speaking, it is neither technique nor tool that creates surgical outcomes and change. As performing state-of-the-art methods reveals repeated, unacceptable failure and inadequacy, practitioners and other stakeholders often eventually compensate by designing and building new tools. As these are introduced, surgeons must experiment with them to arrive at techniques that allow them to regularly get good results at reasonable cost. Considering materiality in this case means carefully examining changing surgical work, rather than reifying technique or tool as empirical phenomena or causal agents. On this view, a practice only exists as it is materialized in specific times, places, texts, artifacts, bodies, infrastructure, and so on (Orlikowski and Scott, 2008; Schatzki, 2010), so studying surgical experimentation means studying its material enactment (Introna, 2011). Doing so can illuminate the very specific ways that professions tolerate and extract value from any unsafe experimentation via new technologies.
Drawing on both perspectives, my own data and historical examples, I argue that the surgical profession has improved results by maintaining strong professional norms against unsafe, inefficient technological experimentation while tolerating such experimentation and associated suffering. I begin by describing my data, then I explore the role of productive deviance through accounts of four surgical innovations – ether, antisepsis, surgical gloves and laparoscopy. I complete this chapter with a deeper examination of robotic surgery, and consider the role of productive deviance in surgical change moving forward.

The Demand for Cutting Edge Surgical Technology

"First, do no harm." Though it actually did not include the prior phrase, the 4,000-year-old Hippocratic oath did prohibit injury to patients, and still guides physicians everywhere. On its face, surgery violates this oath: it involves injuring a person to heal them. Yet for longer than the Hippocratic oath has existed (Leonardo, 1943) we have encountered problems so grave that cutting into the unknown seemed less harmful than leaving the body alone. Early examples include trepanation\(^2\) (cutting holes in the skull to relieve intra-cranial pressure), cauterizing and suturing wounds, draining abscesses and performing caesarian sections. Given the sanctity of life and the many ways that cutting into a body can lead to disfigurement, pain and death, these first surgeons were driven to discover better methods. This drive likely intensified as procedures became routine and widespread; significant practice leads to greater skill and insight into a given activity (Bittner, 1983), and communities of practice emerge in even very small societies (Geertz, 1973). To the extent that surgical norms and rules prohibited harm and inefficiency, surgical experimentation violates them in that involves trying new ways of cutting amidst significant uncertainty (Wootton, 2007).

As with many other domains of skilled work (Benner and Tushman, 2002; Poole and Van de Ven, 2004), surgical technique has changed in both incremental and discontinuous ways. In incremental cases,

significant surgical improvement often hinges on new technique with the same tools – there are many
ways to suture a wound shut with the same thread and needle, and some of these stitches will stay in, stay
tight and leave little scarring while others will loosen, allow infection and leave a large reminder of the
original wound. Such expansion can proceed along many dimensions – work sequence, spatial
configuration, task decomposition and reallocation and so on. In discontinuous cases, however, markedly
better results hinge on new techniques and new tools. Wound closure is an exemplar here as well. We
discovered in the mid 20th century that we can much more effectively and efficiently close certain large
wounds with staples (Robicsek, 1980), and recently sutures and staples have been selectively abandoned
in favor of dermabond (medical super glue) or cautery, as neither of these leave an object in the body and
often do not require as much manual skill. Though incremental and discontinuous kinds of surgical
change likely play out in different ways, their reliance on uncertain experimentation in a profession that
claims to put patient safety above all else suggests that productive deviance plays a crucial role in such
change.

In order to investigate the role of productive deviance in changes to surgical methods, I draw on
historical accounts of discontinuous, technological change to surgical methods over the last 200 years.
Given the uncertainty associated with wholesale changes to both technique and technology in failure-
tolerant work, focusing on discontinuity increased the likelihood that studies and secondary sources
would highlight failure, alternative approaches and unilateral experimentation – all potential hallmarks of
any productive deviance that was crucial to a given change. This focus was important because the
historical literature on surgery – often written by physician-historians – focuses overwhelmingly on
structural conditions for discontinuous innovation that are consonant with the norms of the surgical
community. This work identifies how idiosyncratic combinations of expertise, resources and power
enable sufficient learning for new techniques to take hold.

These studies do not focus on the role of productive deviance in such change: they do not cite
ethnographic data such as workplace interactions or interviews with practitioners, let alone training
processes or the performance of actual procedures. The absence of this kind of data also reasonably explains the lack of research focused on incremental changes to surgical methods, given stable technology. At best (Whitfield and Schlich, 2015) we have histories grounded on archives, personal journals, patient records and published documents, identifying how idiosyncratic combinations of expertise, resources and power enable sufficient learning for new techniques to take hold and spread. This is problematic for my purposes in that it greatly limits insight into whether and how these “innovations” involved surgeons deciding to perform surgery in ways that violated/strained standing professional norms. Though counterfactuals would be required to make the point firmly, the following four case studies strongly suggest that productive deviance has played a crucial role in discontinuous change to surgical methods over the years.

First Case: Ether

Western cultures began to treat surgical pain as unacceptable in the early 1800s, and this drove surgeons towards a variety of methods for reducing or eliminating it during procedures. Though it is hard for the modern mind to comprehend, until the late 1800s extreme pain was often a sign of the surgeon’s masterful status and viewed as a crucial and natural part of the healing process. Surgery was often performed in open theaters to a large audience, and surgeons demonstrated technical prowess and status by directing the surgical process while ignoring patients’ suffering. One account of actual surgical work in the early 1800s illustrates this: “During a lithotomy [kidney stone removal] the patient “attempted to close his limbs in a vain attempt to avoid stretching the gaping wound” and thereby suffer even greater pain. His surgeon shouted, “Slack your legs, man; slack your legs – or I won’t go on.” Then he “coolly relinquished the operation” and stated coldly, “No, I won’t go on,... unless he loosens his limbs.” Eventually the patient was able to do so.” (Winter, 2000: 168) Until around this time, any practicing surgeon had been through extensive apprenticeship primarily constituted by participation in live procedures with no sedation. This weeded out anyone who was unwilling and unable to inflict massive
suffering on patients during a procedure and in many cases to ignore patients’ demands to stop operating. Many practicing surgeons therefore did not see extreme pain as a problem. Indeed, the anesthetic effects of ether – and techniques and technologies for administering it - were well known to medical students for at least ten years before it was successfully used in surgery. These students would get together for “ether frolics” – times to drink, relax and dose themselves and each other with ether. Partially through such parties, students and others came to understand that ether dulled or eliminated pain and could remove consciousness (Strickland, 1996).

Of course, they had no choice in the matter, but it is still quite striking that surgery without anesthesia was also accepted by the public at the time. This acceptance had complex roots, but two strong cultural beliefs played an important role: that nothing valuable could come without suffering and that intense pain was an important part of the healing process. These beliefs were reflective of contemporary Christian religious doctrine as well as a “naturalist” medical movement that included groups such as the Grahamites, homeopaths, hydropaths and mesmerists. Generally, these groups held that disease and dysfunction arose as humans lived out of accord with natural law, and that in most cases lifestyle choices were the only right and effective remedy for such disease and dysfunction. When surgery was required, however, such groups saw the human pain response as an obviously natural response to such intense bodily violation, and that this pain and the expression of it needed to be preserved to let nature take its course (Winter, 2000). Both the public and surgeons valued patients’ consciousness during a procedure for another reason: doing so allowed patients to remain aware of a surgeon’s actions, both to guide them and to limit concerns about abuses of power such as rape and mistaken or even gratuitous surgery.

Jurisdictional conflicts and the availability of anesthetics reframed extreme surgical pain as a problem in the early 1800s. Nascent (but ultimately failed) occupational groups such as mesmerists, homeopaths and hydropaths actively sought to redefine pain as a treatable and unnecessary condition. Mesmerism (or animal magnetism) was the most powerful of these – a discipline involving an extensive relationship between a practitioner and a patient in which the patient was put into deeper and deeper
trances over time. Mesmerists and the physicians who supported them claimed to use this technique to heal disease, moderate poor temperament, for exorcism and eliminating surgical pain (Winter, 2000). In some cases, mesmerists and other naturalist practitioners used surgical pain as a wedge to directly seek occupational jurisdiction over the surgical act and the status that came with it. They were generally successful in this, likely in part due to the simultaneous increased availability and popularity of tonics to ease pain for domestic surgical procedures (see figure 2). Mesmerists, for example, wrote and spoke publically about pain as an avoidable failure during surgery, recasting surgeons away from their former “heroic” role and into one associated with chaos and brutality.

---INSERT FIGURE TWO ABOUT HERE---

Surgeons had to respond, and they did so by adopting general anesthetics, beginning with ether. As for how this adoption proceeded through unsafe and inefficient experimentation, it is instructive to examine a very public moment\(^3\) when ether anesthesia was shown to be an effective general anesthetic: a procedure in 1846 involving a minor incision to the jaw and some minor dental work, led by William Morton, a Boston-area dentist. Having observed his partner Horace Wells fail at several public demonstrations of anesthesia involving nitrous oxide – Wells’s patients experienced no dulling of pain – Morton practiced with ether numerous times in private. This practice consisted in sedating the same patient repeatedly, with varying apparatus for administering the ether, various doses and varying titration approaches. Wells – like many physicians and dentists before him – had refused to experiment in this way because ether administration had killed people and was sometimes (accurately) treated as more harmful than the procedures themselves (Pernick, 1985; Winter, 2000). Ironically, Morton’s test patient had requested mesmeric anesthesia, and we have no record of how Morton managed to convince this person to undergo experimentation with ether. Morton arranged for the operation in a crowded open theater, and by most accounts the patient moaned and stirred under the knife, reporting later that he felt some pain.

\(^3\) This was not the first use of surgical anesthesia – merely a very well publicized demonstration in a particularly elite surgical community.
But as the surgery was completed, the audience erupted in applause and cheers. The news of this “great success” spread quickly throughout America and Europe, as did the practice of administering ether (and then chloroform) as an agent for general anesthesia.

Many accounts of early use of ether in surgery have similar characteristics and indicate that neither tool nor technique alone were responsible for outcomes: patients were convinced to try it without explanation of related risks, proper dosage was unknown, proper administration was unclear, the tools for such administration were varied and redesigned (often on the fly) and no consideration was given to side-effects (Pernick, 1985). Experimentation with ether was clearly enacted in dynamic material practice. Relatedly, such research offers little to no empirical data on how these characteristics were made manifest. In many cases we do not know how the ether was administered, how patients were convinced to undergo this experimental and risky procedure, and we have no statistics or process data on failures and death involving this technology (Armstrong Davison, 1958).

But however underemphasized pain may have been in the early 1800s, surgeons of that time treated death, deception, poor technique and complications as evils to be avoided, so this experimentation ran directly counter to the core tenets of the profession. To put a fine point on it: before and after this diffusion, there was evidence that ether killed patients (Calverley, 1989), and techniques for administering it were unknown (Fairbrother, 1847). And alternatives were available: many surgeons at the time advocated strongly for mesmerism, citing a significant body of (now debunked) evidence that mesmerism effective and safe, and techniques for administering it were well understood. Despite all this, experimentation involving ether extended from before this public demonstration well into the late 1800s.

Second Case: Antisepsis

Surgeons began to see surgical infection as a serious problem later in the 1800s. Though ether and other general anesthetics eliminated extreme pain from surgery, allowing surgeons to work more meticulously and greatly reduced psychological trauma for all involved, these technologies did not lead to
a decrease in patient mortality (Pernick, 1985). As had been the case for centuries, surgical fatalities were primarily due to postoperative infection such as gangrene, sepsis, fever and the like. The elimination of pain of course did not eliminate infection; indeed, some now argue that general anesthesia extended operative time, exposing patients to more infectious agents, thus increasing postoperative infection (Schlich, 2015a). Compound fractures skyrocketed in Europe due to the Franco-Prussian war and industrialization, leading to overcrowding in continental hospitals, thus exacerbating the infection problem there. One set of statistics (rarely generated in those days) makes the point: In 1872, across all German hospitals, 37-41% of compound fracture victims treated by surgeons subsequently died from infection. Relatedly, at the country’s best hospital in Munich, 80% of all wounds were infected by hospital gangrene, and no wound was seen to heal in the hospital without first becoming infected in some way. “Horrible was our trade!” a well-known German surgeon later declared (Schlich, 2013a). The imperative for a solution was extreme.

Regardless, the surgical profession had no ready solution to these fatalities, because it did not agree on what caused them. Some held that a chemical process caused infection, others a biological process, others focused on “miasma” (noxious vapors from human waste and decaying flesh) (Worboys, 2000). In the beginning of this period, proponents of any given approach did not have or agree on standards for data to support their claims. Crucially, even where there was local agreement on a theory and the empirics of postoperative infection, there was often incongruity in the practices enacted to address a given root cause – some wards would open windows to the outside for increased ventilation, others would fastidiously clean the walls, floors and sheets, yet others gave patients injections of nucleic acid to stimulate the immune system, and others began using caustic chemicals on wounds (Schlich, 2013a, 2015b). Given the systemic and pervasive nature of the problem, progress required a consistent and coherent set of theories and enacted practices to solve it.

History tends to point to Joseph Lister as the British surgeon who saved the day through antiseptic technique, forever uplifting surgery to the status of an “experimental science” (Schlich, 2007). Lister
came across Swann’s (a German scientist) 1837 “germ theory of putrefaction” between 1860 and 1864, which he claims made sense of an uninfected injury he observed in 1855 (Wootton, 2007). He settled during this period on carbolic acid – a noxious and skin-damaging chemical - as a suitable agent for killing germs on instruments and in wounds. He conducted his first operation using carbolic acid in 1865, washing and draping all wounds with cloths impregnated with the substance. Though his patient’s wounds took four months to heal and involved frequent reapplication of acidified dressings, there was no infection. Antisepsis clearly relied on new technologies: chemical agents (e.g., carbolic acid) and new tools (e.g., foil trays and poultices to apply and contain the acid to a wound site). But Lister insisted that effective antisepsis required new tools and techniques, consistently applied. To the extent that this was the case, antisepsis thus represented a shift in the interconnected practices associated with surgery: the chemical and the apparatus mattered only when they were put into practice in a way that prevented infection until healing was complete (e.g., applying the acid to a wound every single time a dressing was changed without first touching a potentially-contaminated object or person).

One need look no further than Lister himself to find counternormative experimentation with antisepsis. In one of his earliest and most influential works, Lister outlines his failed treatment of “Patrick F”, a patient with a compound leg fracture (one of a number of such failures). Lister applied a carbolic acid solution to the wound in an effort to prevent infection, but Patrick contracted gangrene and his leg had to be amputated. Lister noted that the caustic effects of his own antiseptic measure was a major – if not the sole – cause of Patrick’s gangrene: “While I could not but feel that this case, by its unfortunate issue, might lose much of its value in the minds of others, yet to myself it was perfectly conclusive of the efficacy of carbolic acid for the object in view. At the same time, it suggested some improvement in matters of detail. It showed that the acid may give rise to a serous exudation apt to irritate by its accumulation, and therefore that a warm and moist application would be advantageous to soothe the part, and also ensure the free exit of such exuded fluid.” (Lister, 1867: 338) We have no record of Lister
securing colleagues’ or Patrick’s input and consent for this procedure, and at the time Lister did not have knowledge of proper technique, dosage, tools and methods for assessing progress, given his intervention.

Beyond the antiseptic inner sanctum, others were causing harm as they appropriated Lister’s methods. One surgeon reported that his patients did better without Lister’s antiseptic method: “…in twelve compound fractures, where there existed a probability of union without suppuration [formation of pus], the only cases where suppuration did occur were two in which I employed the acid paste exactly as recommended by Mr. Lister (Tait 1868).” (as quoted in Troher, 2014) Others – especially early adopters in Germany who were particularly desperate for results – appropriated Lister’s methods piecemeal and/or applied them inconsistently (Schlich, 2012). This was at least in part because these Germans had to wade through Lister’s obtuse and excessively-detailed English about his techniques. But it was also because surgeons were used to making discrete changes to improve outcomes – a tool here, a method there, a material here. Antisepsis required wholesale, consistent change to interconnected practices, so had it not been for the advent of aseptic surgical technique (detailed below), it likely would have been quite some time before antisepsis was implemented in a way that routinely eliminated risk and inefficiency.

Third Case: Surgical Gloves

Antisepsis provoked a focus on controlling infectious agents and thus changed the face of surgery forever. Postoperative infection began to decline significantly, making surgery subject to the kinds of expectations of consistency and quality that consumers had for manufacturing and railway operations (Schlich, 2013c). But these very expectations focused surgeons on reducing the risk of surgical infection, independent of how often such infections actually arose. And surgical practice in the late 1800s left much to be desired in this department – surgeons operated in open theaters occupied by dozens of men in their normal clothing, patients were often not cleaned, surgeons wore unclean aprons, no masks or headgear, and operated with their bare hands, for example (Leonardo, 1943). Even practitioners of the day recognized that these practices likely introduced infectious agents into the surgical field, and began
experimenting with various technologies to address this surgical risk. Surgeons thus entered the normatively-interesting territory associated with introducing unproven, potentially risky change into failure-intolerant work in order to hedge hypothesized risk, rather than to treat a known problem.

I focus here on surgical gloves - just one of a dizzying array of technologies, tools and techniques brought to bear on this problem. While the need for sterile surgical gloves is perhaps obvious in hindsight, they were not introduced until 1889 (Lathan, 2010), a full 24 years after the successful deployment of antiseptic technique, and did not see widespread adoption until 1896. Beyond this, surgical gloves were not routinely impermeable until after the First World War. A key contributor to these delays was a tension between surgical goals. On the one hand, surgeons sought perfect manual control of the surgical act: they relied deeply on minute fingertip sensation and fine movements to guide diagnosis and intervention during surgery. On the other hand, surgeons now looked beyond antisepsis (destruction of infectious agents in the field) to asepsis: perfect control over infectious agents (Schlich, 2015b). For approximately 30 years, available technologies for making gloves produced a product that greatly compromised one or both of these goals. This led to a wide array of experimental practices – surgery of the day involved various glove types in different ways, even during the same operation. Numerous alternatives to gloves were also tried during this period, ranging from washing the hands with a series of chemicals to “no touch” operating technique to wearing gloves at all times outside the operating theater.

No matter whether they favored asepsis or manual control, surgeons who tried gloves knew they were placing themselves and patients in harm’s way. All knew that asepsis required complete prevention of infectious agent transfer during surgery. On this view, eliminating almost all infectious agents from a surgeon’s hands was tantamount to deliberate transfer of such agents to the patient. Despite the clear violation of norms core to the profession, early approaches to glove technology and implementation technique sacrificed asepsis for manual control, ensuring such transfer until well into the 20th century.

As with ether and antisepsis, it was the enactment of gloved surgery – and not tools or techniques separately - that mattered for experimentation and the harm it produced. Of course, there were new tools:
strict advocates for asepsis tried sterilized silk gloves, cotton gloves impregnated with paraffin, leather
gloves, leather gloves with one finger removed and rubber gloves, knowing full well that only the last
technology had the potential for completely preventing infectious agent transfer. But surgeons were
simultaneously experimenting with related technique, and it was how the surgery got done that mattered:
many staunch asepsis advocates removed gloves to operate barehanded if they wanted particularly fine
control or sensation (Schlich, 2013b).

Favoring asepsis by wearing sterilized rubber gloves throughout a given procedure produced
surgical risk as well. Early rubber surgical gloves were quite thick and rigid, practically blocking all but
the grossest fingertip sensation – those few surgeons who *did* make early and complete shifts to rubber
gloves went through significant learning curves, ultimately demanding thinner and more flexible gloves
(Rutkow, 1999). But it was nearly two decades before these gloves arrived. During this time surgeons
faced – and made – a devil’s choice between asepsis and surgical effectiveness every time they set foot in
the operating room. Either way, they violated norms core to their profession. Unfortunately, we have no
systematic records of complications associated with surgery during this transitional period, so it is
difficult to assess the impact of this transitional period on patient and surgeon health.

**Fourth Case: Laparoscopic Surgery**

Historically, Urology has been a field that has adopted [minimally-invasive] technologies
because of our use of endoscopes. Cystoscopy started with looking into bladder, then
Ureteroscopy (2nd gen), smaller fiber optics then lasers came by and [kidney] stone work then
work with tumors. Then next step was laparoscopy, general surgeons started using it with the
gall bladder, then once that was figured out, it went to some work with the appendix, hernias,
then Urology, because they were facile using endoscopy. We started off with kidneys then
[moved] to prostates, [but] prostates were hard, they started and they failed. – Robotic Surgeon

Until the late 1980s, doing abdominal surgery meant significant trauma. Whether the practitioner
was a Gynecologist, general surgeon, Urologist or Colorectal surgeon, getting deep into the abdominal
cavity was intense: it typically involved a six-to-twelve inch incision through skin, muscle and internal
tissues, stretching this incision wide with moist towels, clamps and retractors, securing organs to the side
of the operative field with additional moist towels and packs, cauterizing, cutting and suturing focal
tissues, then “closing” by repositioning and reconnecting affected tissues, layer by layer, until the skin could be stapled shut and bandaged. Such procedures often involved week-long stays in the hospital for initial recovery, and were followed by two to three weeks of convalescence at home. Post-operative pain from such “open” procedures was often extreme – patients were typically prescribed powerful opiates or barbiturates to manage it. Patients undergoing significant abdominal surgery thus had to spend a month away from work and normal life and ended up with large scars seen as unattractive (Whitfield, Unpublished; Zetka, 2003; Doyle, 2008). And while many objected to these difficulties, no alternative was accepted on a wide scale, so most accepted them as the price for life-saving surgery.

Though it did not involve surgical manipulation of internal tissues, endoscopic diagnosis began to convince surgeons that there was a reasonable alternative to some open abdominal surgery. Though its origins are murky, German medical journals clearly report very early applications of the technique in 1804 and 1805 (Pogliano, 2011) - essentially peering through a thin tubular scope inserted into the abdomen to make sense of a problem with vague external symptoms. Early endoscopic procedures relied on natural orifices – Urologists and Gynecologists were thus first to demonstrate the value of the technique (Whitfield, Unpublished; Van Dijck, 2005). Given this body of experience manipulating a sticklike instrument for purposes of intracorporeal perception, it is perhaps unsurprising that it was these surgeons who first experimented in the 1930s and 40s with inserting additional sticklike instruments to perform simple procedures such as tubal ligation and lithotomy (removal of a kidney stone from the urethra, bladder or ureter) (Modlin, 2000; Zetka, 2003). But it was many decades after such approaches literally became standard operating procedure that surgeons of any stripe began to consider surgery performed through keyhole incisions – the hallmark of modern laparoscopic surgery.

Though the public did not contribute to the initial push for laparoscopic procedures as it did with ether for general anesthesia, it seems to have contributed to a massive secondary push for widespread adoption by the surgical profession. In contrast to surgeons who focused on surgical risk and outcomes, the public saw also scarring and the month-long recovery window as major problems with open surgical
claim that public advertisements and opinion pieces written by manufacturers (but not competing
occupational groups, as with ether) drove consumers to shift their mindset around what was possible with
respect to surgical technique. Patients therefore rapidly came to demand this new “scarless, painless”
technique for a wide variety of operations (Zetka, 2003).

General surgeons are widely regarded as making the first attempts at laparoscopic surgery through
keyhole incisions. If one could insert a single stick into the abdomen to examine its tissues from the
inside, asked many practitioners, why not insert one or two more in order to manipulate those tissues
instead of using open surgical technique? And while the first well-publicized attempt at such a procedure
—a laparoscopic cholecystectomy (gall bladder removal) — was actually performed in Germany in 1985,
surgeons across many disciplines and geographies were experimenting in this direction both before and
afterwards (Boyce, 1998; Braun, 2015).

As with ether, antisepsis and surgical gloves, we have limited firsthand data on whether and how this
experimentation ran counter to the norms of the surgical profession, but the reasons for the lack of such
data differ. Partially as a result of asepsis and the “experimental science” it permitted, rules, norms and
law surrounding experimentation became far stricter during the middle of the 20th century than they were
for the advent of general anesthesia in the 19th century (Smith, 1941). We thus have fewer surgeons
volunteering firsthand accounts of unsafe and inefficient surgical experimentation. Yet it seems as if the
increased availability of data on the performance of surgical procedures and technological innovation had
little effect on the actual performance of unsafe and inefficient experimentation. Henry Beecher, an
anesthesiologist at Harvard Medical School, published an expose on clinical research during this period
(1966) that greatly influenced public dialogue and federal statute on human experimentation and informed
consent. Inspired in part by the Nuremburg trials, he showed that much unsafe, unethical and inefficient
research had been published in plain view and went unrecognized (Veatch, 2016): known, effective
treatments were withheld from ill patients and dangerous drugs, untested surgical devices and cancerous
tissues were implanted into healthy individuals, all without informing them clearly of the risks involved. Many of the patients in these studies died or suffered permanent loss of health.

Available examples of productive deviance in laparoscopic surgery are similar to those associated with ether, antisepsis and surgical gloves. One that has received some attention (Whitfield, Unpublished; Litynski, 1998; Boyce, 1998) is Kurt Semm’s now lauded introduction of the electronic insufflator in the late 1970s – a crucial enabler of modern-day laparoscopic surgical technique. This device inflated patients’ bellies with carbon dioxide and maintained a near constant pressure, expanding operative space to allow for easier maneuvering and visualization with laparoscopic instruments. Notably, Semm performed his initial experiments with his insufflator – designed by his brother and father – without the knowledge or consent of his surgical chief (direct supervisor). He collaborated instead with Eisenberg, a surgeon with significant expertise in diagnostic laparoscopy. Semm’s chief discovered that they had begun an experimental operation with this technology, proceeded directly to the OR and literally chased them out in the midst of the procedure. We have no data on whether this was Semm’s first attempt at insufflation, whether the patient was aware that this technique was being applied, and whether this patient suffered any complications as a result of the procedure being interrupted. Nor do we have any data on complications caused by Semm’s uninterrupted experimentation with his insufflation machine. Ironically, Semm is now referred to as a brilliant innovator who had to “endure” decades of complaints – both formal and informal – from surgeons and surgical boards that his methods were “unethical,” and “dangerous.” (Litynski, 1998; Mettler and Semm, 2003).

And as in the cases above, the counter-normative risk and inefficiency in experimentation with laparoscopic methods stemmed from its enactment. As a case in point, one of the main objections to laparoscopic surgical experimentation had to do with how hard it was to learn because it so radically reconfigured the surgical act. In these procedures, multiple small incisions are made in the patient’s belly, and both a camera and stiff sticklike instruments are inserted through these holes in order to manipulate tissues inside the patient without seeing them directly. Images captured by the camera are projected onto 34
one or more televisions in the OR. Given the rigidity of the tools and the fulcrum effect associated with operating through small ports, surgeons had to get used to inverting their movements to achieve desired results in the surgical field (i.e. left is right, up is down) (Zetka, 2003; Prentice, 2005, 2013). They likewise had to learn to interact very differently with surgical staff who had in turn to learn to play different roles: retraction was formerly done by a surgeon collaborator via moistened pads, retractors and clamps, whereas retraction was now partly done via an insufflation machine, for example.

The intricate and complex nature of several key surgeries (e.g., prostatectomy) meant that only a very small number of surgeons had (and still have) the levels of talent required to perform these surgeries laparoscopically, let alone the time and motivation to learn such a radically new practice. The ongoing performance of laparoscopy has thus revealed an additional source of harm and inefficiency from experimentation – reducing the number of practitioners who could perform complex procedures with the new technology. This profession-scale outcome challenged norms within the profession associated with adequate training and providing adequate health care capacity for the general populace, yet the practice of laparoscopic surgery saw widespread adoption, particularly for relatively simple procedures (e.g., hernia repair). Robotic surgery was introduced in part to resolve this problem, but as I explore below it has often had the opposite effect.

**On the Surgical Edge: Robotic Surgery**

It’s not the same as doing a weekend course with Intuitive Surgical and then saying you’re a robotic surgeon and now offering it at your hospital [italics indicate heavy emphasis]. I did 300 and something cases as a fellow on the robot and 300 and something cases laparoscopically. So a huuuge difference in the level of skill set since I was operating four days a week as opposed to the guy who’s offering robotic surgery and does it twice a month, okay? The way I was trained, and the way I train my residents, my fellows and the people I train at the national level is that you need to know how to do a procedure laparoscopically first before you’d tackle it robotically. The robot is not, in my opinion, a skip. You don’t jump from open to robot, although that is exactly what has happened in the last five years. For the vast majority, and it’s a marketing, money issue driven by Intuitive. No concern for patient care. And unfortunately, the surgeons who don’t have the laparoscopic training who have been working for 10 to 15 years – panic, because they’re like “I can’t do minimally invasive surgery, maybe I can do it with the robot.” Right? And then that’ll help with marketing and it’s a money thing, so you’re no longer
thinking about patient care it’s now driven by money from Intuitive’s perspective and from the practice perspective. This is all a mistake. This is a huge fucking mistake. – Robotic Surgeon

The Surgical Problem

Practically speaking, patients in need of significant abdominal or thoracic surgeries before 2000 had two options: open or laparoscopic surgery. Though often quite effective, both of these approaches have significant drawbacks. As outlined in the prior section, open procedures require large incisions, stretched open with steel brackets and clamps that perturb and expose significant portions of the internal anatomy to the air. Trauma to important structures such as muscle and bone and adjacent organs is often severe, requiring long recuperation times and inflicting significant pain. The risk of infection in such procedures is also a serious issue, despite OR aseptic protocols. Laparoscopy was often effective but is exceptionally difficult to learn, greatly limiting the available surgeon pool. And my informants uniformly indicated that surgeons who could perform straight stick procedures often ended up with physical complications of their own, further reducing the profession’s ability to serve growing demand.

The medical community became simultaneously convinced of the improvement that laparoscopic surgeries offered over open procedures and frustrated that they couldn’t be performed at higher volume. This was compounded by increases in diagnostic sophistication and a shrinking surgical labor pool overall. The last 20 years have seen rapid advances in diagnostic technologies such as the Prostate-Specific Antigen (PSA) test for prostate cancer. These and similar advances have allowed a greater number of doctors and their patients to detect disease in its earlier phases. When used to detect diseases that are best treated by surgery (such as prostate cancer), these technologies have led to increased demand for surgical intervention (Moyer, 2012). During the same time period, the number of surgeons has slowly declined, and this decline is projected to continue through 2025 (Dill and Salsberg, 2008; Fang et al., 2016). Given this increasing demand for and decreasing supply of Urologic surgeons, relying on straight laparoscopy for complex surgery did not seem tenable to many in the long run, as it would have placed an additional constraint on the number of available surgeons.
The Robot as a (Controversial) Solution

A technological solution emerged to these problems in the late 80s and early 90s. During this time, DARPA (the US Defense Advanced Research Projects Agency) funded the development of a laparoscopic surgical system that would allow surgeons to operate remotely on wounded soldiers. Both policy and technical hurdles prevented its deployment for this purpose, but some involved in this project commercialized their work. After an initial rivalry between competitors (Computer Motion, Inc. and Intuitive Surgical, Inc.) was resolved by acquisition, Intuitive Surgical’s da Vinci system was tested at a number of hospitals and received FDA clearance in 2000. This clearance came via a process called “premarket notification” that has to demonstrate “substantial equivalence” in outcomes contrasted with currently available surgical technologies. The da Vinci system was marketed as offering the benefits of laparoscopic surgery while making the practice easier and safer, and thus accessible to a wider range of surgeons.

Though it was originally intended for use in cardiac procedures, the da Vinci system was first adopted on a broad scale in Urology. Many point to Mani Menon⁴, a Urological surgeon in Dayton, Ohio, as the urological “father” of the da Vinci. With Intuitive Surgical’s support, he convinced his hospital that the technology was a worthy investment, secured a robot, and devised a method of performing robotic prostatectomies (RPs) that took advantage of the system’s features. In the last twelve years, he has performed more than 8,000 robotic RPs⁵, a notable achievement given that high volume surgeons perform approximately 300 per year. Of course, no one person can shift the practices of an entire specialty. Many urological surgeons found the system attractive, given that urological procedures typically focus on fixed structures within the abdomen, and are thus well suited to laparoscopic methods. As more hospitals purchased the da Vinci, urologists began to experiment with it in other procedures such as Nephrectomies (kidney removal), and Gynecological surgeons began to use it to perform hysterectomies.

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⁴ [http://content.time.com/time/specials/packages/article/0,28804,2032747_2033111_2033133,00.html](http://content.time.com/time/specials/packages/article/0,28804,2032747_2033111_2033133,00.html)

⁵ I have no data on Menon’s complication and success rates – this high volume could have come at the expense of either.
By 2003, the system was used in at most 9% of radical prostatectomies (RP). In these early days, Intuitive Surgical focused their deployment at major medical centers. This figure increased to 43% by 2007, and more than 60% in 2009. As of 2013, the da Vinci surgical system was used in approximately 85% of RPs in the US. This explosion in the use of the da Vinci is not limited to RPs; the da Vinci was used in 8,000 procedures globally in 2003, and in 523,000 procedures in 2013 (Figure 2). This change has been highlighted in the media, courts and medical journals as both major progress and stagnation in the cost, safety and effectiveness of surgical practice. This rapid expansion in sales of the Da Vinci surprised many, including Intuitive Surgical: as of 2016, approximately 37% of the 5,723 hospitals in the US had purchased the system.

---INSERT FIGURE THREE ABOUT HERE---

Intuitive’s marketing claims are far from groundless. Compared to straight stick surgery, the da Vinci system allows for an unprecedented amount of precision in the surgical field because the system translates hand movements directly (right is right, down is down), magnifies the surgical view (up to 10x), eliminates surgeon hand tremors, scales down hand movement (up to 5:1) and allows the surgeon to do their own retraction while operating. Additionally, each of the surgical instruments is “wristed”, allowing the surgeon to more easily execute complex maneuvers (e.g., fine suturing and dissection) than they can in straight stick work, and to do these in a way that keeps these maneuvers in the natural field of view. Finally, compared to straight stick work, the ergonomic seat and console greatly reduce the amount of physical strain on the surgeon during each procedure.

\textit{Adopting Robotic Surgery Meant Challenging Surgical Norms}

Despite these features and unprecedented sales (Sukumar et al., 2012), the da Vinci was a controversial technology almost from its introduction – both in the public eye and within the surgical profession. The public controversy has in part arisen because adopting and using robotic surgical methods has run directly counter to cherished norms surrounding surgery, surgeons and the surgical profession.
These norms center on the efficacy, safety, cost of procedures involving the system, and the ways that the system has been marketed and sold. Controversy within the profession has been focused on competence and certification to use the technology – norms for adequate training and practice are strong in surgery, and many see insufficient work on this front for robotic surgical methods. I explore each of these areas of controversy below, linking each back to the themes presented at the beginning of this chapter.

**Efficacy**

The ultimate normative requirement for robotic surgery is that it be at least as effective as other methods (Sauerland et al., 2014), and 2002-2017 saw much disagreement on this point. Initially, few studies compared surgical outcomes achieved with the da Vinci to those achieved with open or straight stick procedures. Only in the last few years, large sample statistical studies have begun to show that patients undergoing robotic procedures suffer less blood loss and pain, leave the hospital faster and return to work sooner than those who have open or straight laparoscopic procedures (Bolenz et al., 2010; Sukumar et al., 2012; Liu et al., 2013). These are precisely the outcomes that Intuitive, hospital administrators, surgeons and patients have cited informally since the early 2000s. These same studies bring a starker message, however, one that is only just now becoming widely known: there seems to be no significant difference in longer term outcomes (e.g., impotence, incontinence, cancer control in the case of prostatectomies) between da Vinci and open/straight laparoscopic procedures (Agarwal et al., 2011; Trinh et al., 2012).

Questions about the relative efficacy of the da Vinci system have recently emerged across surgical disciplines. The American Congress of Obstetricians and Gynecologists issued a statement suggesting that the da Vinci does not produce notable improvements in certain surgical outcomes, and that surgeons exercise more restraint in their use of the system for hysterectomies, for example (Breeden, 2013). Yet others claim that we should expect little *initial* improvement in long-term patient outcomes with the da Vinci because patients who are willing to experiment with new technologies are generally worse off than
most (Sukumar et al., 2012) and it has often taken 10-30 years for best practices with new surgical technologies to emerge. Regardless, recent studies have begun to indicate that the material enactment of robotic surgery is central to efficacy – who is performing the work, what kind of support staff they have, what kind of material support they have, specific patient comorbidities and so on (Leow et al., 2016; Löppenberg et al., 2017).

Safety

Surgeons and the public also insist on safety, and a number of serious questions have been raised about the safety of the da Vinci system. These concerns can be divided into two categories: concerns about underreporting complications and adverse events, concerns about the safety of the system itself. A recent study out of Johns Hopkins (Cooper et al., 2013) exemplifies the underreporting concerns: analysis of available data on the >1 million procedures performed between 2000 and 2012 indicated that only 245 complications (including 71 deaths) were reported to the US FDA. This figure (0.0245%) is implausibly low; 10% is viewed as an acceptable complication frequency for most well-accepted and widely practiced procedures. While intended to reveal shortcomings in the FDA’s process for reporting complications, many claim that this study indicates that previous da Vinci safety studies (Agarwal et al., 2011; Trinh et al., 2012; Liu et al., 2013) draw upon censored data. Some claim that the lack of reporting of complications for robotic procedures indicates that Intuitive Surgical, hospital administrators and surgeons have been selectively underreporting complications with the technology (Parsons et al., 2014; Alemzadeh et al., 2016). Others side with the researchers from Johns Hopkins, claiming that complications are similarly underreported for all surgical technologies (Sauerland et al., 2014). Thus, the normative status of safety reporting practices is not yet clearly established.

Even if it were the case that complications were underreported for all surgical technologies, significant concerns remain about the safety of the da Vinci system itself. Some of the da Vinci’s

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6 These categories are presented for analytical purposes; in practice, concerns in each of these areas seem interdependent.
instruments are designed for cautery (precision burning of tissue), and when a surgeon positions these instruments close to other instruments in the surgical field and activates the cautery feature, electric current can arc from one instrument to the other, causing significant and unpredictable internal burns in some patients. Relatedly, the surgeon can only see the ends of the da Vinci’s surgical instruments in the surgical field. The bulk of each robotic instrument is positioned behind the camera, and these can “clash” with each other (as with the type heads in a manual typewriter). When this happens, the instruments can damage organs and tissues. Surgeons only meet resistance to this at the console when the mechanical limits of the system have been reached (e.g., arms are pressing directly against one another), long after any organs or tissues between the arms have been torn or crushed. Thus, as with prior surgical technologies, it is the way surgery is actually performed that makes these risks manifest, and surgeons have discovered these dangers as they have operated on patients.

There has been a legal outcry on these “product safety” issues. Between 2010 and 2017, many law firms have developed specialized malpractice groups specifically focused on the da Vinci (a Google search for “da Vinci malpractice law firm” yielded 37,500 hits as of February 2014 and 65,700 hits in July of 2017), and a number of firms have emerged that only service da Vinci malpractice cases (e.g., http://badrobotsurgery.com/). Intuitive Surgical initiated a product recall in response to the arcing issue (caused by insufficient insulation in the wristed portion of some instruments), replacing a large number of surgical instruments with newer models which had more robust electrical insulation. This recall is the exception, rather than the rule, however; Intuitive has generally claimed that injuries to patients are the result of poor surgical technique, which is the sole responsibility of hospital administrators and surgeons. The legal system seems to be enacting a similar view. Intuitive has not yet lost a court case, while a number of surgeons have been successfully pursued for malpractice in their use of the system.
Norms for cost containment in the healthcare profession have strengthened as the government has become more involved in the provision of healthcare in the United States, and many have serious concerns about the cost of da Vinci procedures relative to open and laparoscopic alternatives. These concerns are focused on the price tag for the robot itself ($1.2 – 1.9 million), the annual maintenance fee ($125,000 - $250,000), and the disposables required for each procedure ($2,500/procedure). The da Vinci specifically relies on two sets of precision disposables: the sterile drapes for the arms and camera, and the surgical instruments themselves. These instruments can be reused up to 10 times each, and are then sent back to Intuitive Surgical for refurbishment. Though hospitals may lease da Vinci systems, Intuitive has sold most of their systems to hospitals outright.

The cost of the da Vinci thus dwarfs that of the specialized tools required for open and straight laparoscopic procedures: data from two of my sites indicates that a complete set of non-robotic laparoscopic tools costs in the $20-$50,000 range and disposables typically cost $600-1,000/procedure. Hospitals amortize the cost of the robot over the procedures performed. In exchange for their annual maintenance fee, Intuitive supplies 24/7 live customer service and performs routine maintenance on the da Vinci system every quarter. Crucially, Medicare and private insurers do not reimburse hospitals more for robotic operations than they do for their open or laparoscopic equivalent. Leddy et. al. (2010) estimate that this translates into a $1,500 profit for average hospitals on each open procedure and a $4,000 loss on each robotic procedure. There is some disagreement on this question, however; some studies find that robotic procedures have lower complication rates (Lee et al., 2011) and shorter hospital stays (Geller and Matthews, 2013), and therefore involve “hidden” profit that more than makes up for increased equipment cost. These questions of cost and profitability are far from settled, but surgeons settle them provisionally – and against norms and policies for cost-containment – every time they choose to perform robotic surgical work.
As indicated by the quotation at the beginning of this section on robotic surgery, Intuitive Surgical’s extensive investment in marketing and sales is itself another source of controversy. My informants believed patient care and outcomes should drive whether and how new surgical technologies are adopted, and in the case of robotic surgery they felt as if the marketing tail was wagging the dog. This was particularly true as the technology was initially being adopted in the 2005-2008 timeframe. A prior hospital CEO describes the pressures in this period succinctly in his blog:

Notwithstanding the lack of evidence of enhanced clinical efficacy, I have been advised the following by one of our leading doctors: "Due to market forces beyond any of our control, the unfortunate reality is that without a DaVinci robot, BIDMC prostatectomy volume would likely plummet by 2010 and BIDMC would consequently quickly become a non-entity in regional prostate cancer care. This would have dire consequences for BIDMC clinical urology, radiology, radiation oncology, medical oncology, as well as for research in translational oncology. It is unlikely that we can fully gauge the breadth and depth of collateral damage that absence of a daVinci robot would bring to our medical center.” Here you have it folks -- the problem facing every hospital, and especially every academic medical center. Do I spend over $1 million on a machine that has no proven incremental value for patients, so that our doctors can become adept at using it and stay up-to-date with the "state of the art", so that I can then spend more money marketing it, and so that I can protect profitable market share against similar moves by my competitors? (Levy, 2007)

The company has provided free training and information sessions to hospital staff, supported research comparing short term surgical outcomes (e.g., blood loss, pain, length of stay) between open and robotic methods, offered free advertising (e.g., billboards, online) and hired a relatively large number of sales reps who spent considerable time helping hospital staff use the da Vinci. Intuitive has also marketed heavily to the general public in the United States; in the late 2000s, it was not hard to find a fully functional da Vinci system in shopping malls, with an Intuitive sales rep ready to offer a demonstration and a turn at the controls to passers-by. Intuitive sold a large number of systems to hospitals that had either low surgical volume, surgeons with no experience with the robot, or both. For many institutions, this meant that the system went unused, or was used very infrequently by surgeons willing to experiment with it in their practice:

The very first hospital [in Canada] to get one [a surgical robot] was Jewish Hospital in Montreal, and it sat in a room, unused, for years -- it costs about 1mil per year to run the thing at full utilization, and they didn’t have that cash, nor did they have anyone who knew how to use
it, so they got it just to get donors – it’s a public health system, so they’re not trying to attract patients, but it was for donors, but never used. – Robotic Surgeon

At the same time, the financial pressure on hospitals to increase robotic procedure volume has been significant. The more procedures performed, the more the cost of the robot and its service contract could be amortized over these procedures. Additionally, patients in the US generally sought surgeons who have performed the desired surgery many times. Hospitals therefore stood to lose patients (and therefore revenue) if they didn’t encourage their surgeons to perform robotic procedures (Levy, 2008). Several high-profile investigative journalists have examined Intuitive Surgical’s role in these dynamics (Rabin, 2013). Given all of the above, Intuitive had the reputation in some quarters of being too aggressive, putting sales above safety, efficacy and hospital fiscal health (Langreth, 2013).

These controversies about the efficacy, safety, cost and marketing of the da Vinci system were salient largely because hospitals bought so many systems so quickly. For better or for worse, the da Vinci became the de facto standard for an expanding array of surgical procedures in the US, and increasingly across the globe. Patients, hospital administrators, donors and surgeons all demanded the system. Intuitive Surgical had a practical monopoly on this market, the standard of proof for the safety and efficacy of surgical devices was (relatively) low, and regulatory and technical barriers to entry were quite high. These dynamics reveal an interesting and potentially novel dimension of productive deviance: the influence of markets and public opinion on professionals’ engagement with new technological methods. Norms and policies within the surgical profession may well guard against rapid adoption absent strong evidence, but surgeons and hospitals end up accommodating the market in a way that runs counter to these norms.

Competence and Certification

Robotic surgery challenged an additional norm that was not as obvious to the public: “best practice” with the robot allowed surgeons without sufficient skill to operate. As my informant describes below, the profession, hospitals and Intuitive Surgical implemented a certification and training regime to make this possibility manifest on a wide scale. When the technology was introduced, those already in
professional practice could operate minimally invasively after only a few proctored cases on the robot, and without having to learn laparoscopic technique via straight stick procedures. These requirements were tightened as the bulk of practicing surgeons made the transition, but before this was done many of them received questionable training:

The data is not clear about how many cases you’d have to do to get good enough to get good outcomes – some say after 20 cases, one guy says 1500 cases, but the AUA [American Urological Association] says 2 cases – that an experienced surgeon only needs to be proctored for 2 cases before they can go on their own. This is ridiculous, but understandable, given that prostatectomy pays a lot – there are long recovery times – and many are required. So, in the 90s, when the standard approach was radical open prostatectomy, they [surgeons] all built their reputation on this procedure, got very good at it, and got high surgical volumes. The robot made this approach obsolete, and so their volumes went down. For someone who is 65, or even 60, this isn’t a huge problem – they just end up in an administrative role. But if you’re 45? That’s a real problem. What do you do? You lose your power – you can’t retire, you made your name in an obsolete procedure, so what do they do? They have lots of power for the time being, so of course they’re going to ensure that the AUA indicates that you only have to be proctored twice to switch – that way they can get to work on the new procedure. Now this is all done – they’ve all gotten 50 cases under their belt, and they’re fine. Given this, it’s now popular to blame the company and require 2 years training and all the rest of it – these people safely made the transition. – Robotic Surgeon

As this surgeon describes, the chorus of complaints about training in robotic methods rose dramatically once the senior surgical population completed their certification requirements with the technology. Roughly speaking, these requirements were made more stringent as a result, with significant implications for the upcoming generation of surgeons. As above, these dynamics reveal another potential dimension of productive deviance on the level of professions and institutions: the ways in which legitimation regimes are established and enacted. On the one hand, the approach to certification outlined above extended the valuable surgical life of a large number of surgeons, allowing the profession to add more value. Yet the way this extension was done ran counter to norms of transparency and training, leaving many underqualified surgeons in practice. The impact of all this is unclear: we cannot yet separate any harm this has caused patients from the overall complications data.

As for trainees, I document extensively in chapter three of this dissertation that most robotic surgical residents did not develop the skills required to perform robotic surgery safely and efficiently, yet all
graduating residents were granted the legal right to do so. And neither trainees nor legacy practitioners got the on-the-job practice they needed to retain (let alone build) capability with this methodology: as of 2015, the average surgeon who did any robotic surgery at all performed one procedure per year (Chang et al., 2015). As I show in my next chapter, those that did get ahead and maintained their skills do so via productive deviance. Here one AP mentions how his robotic surgical skill development hinged on joint experimentation on patients with his mentor as they both figured out how to use the technology:

Trained up with my teacher at a unique time – when he was learning the tech just as much as I was, and when he said “you know, [X], here’s what I’d do, what do you think – he really really meant it, and we were discovering it together. It was an amazing time. – Robotic Surgeon

These latter points suggest that unsafe and inefficient experimentation will continue to be tolerated as an important mechanism for the adoption and continued use of surgical technology. My own work shows that even in this increasingly rationalized and liability-laden atmosphere, such deviance continues to be crucial for surgical progress. This may not always be the case: as I indicate above, asepsis provided strong structural incentive for the surgical profession to shift towards a risk-management and quality control orientation. This orientation provides a strong drive to narrow the spaces and times where such deviance is practiced and tolerated. Expectations of consistent, safe and effective surgical procedures has produced liability pressures, so modern-day surgical professionals may engage in an interconnected set of practices that greatly decrease the visibility of productive deviance in the adoption of new surgical technologies. It also seems clear that surgeons would not be dissembling – surgical training and practice are much less the “wild west” than they used to be, involving sanctioned, reasonably safe processes that make minor experimentation permissible and public (Gawande, 2001; Prentice, 2013).

Conclusion

The brief histories above suggest that surgeons and the surgical profession have held to norms and policies that guard against harming and deceiving patients, whether through direct action, inaction or inefficient action. Yet these histories also show that surgeons have repeatedly turned to productive deviance as a way to accomplish discontinuous changes in surgical methods. Concretely, this has meant
they have materially performed their work in a way that runs counter to the norms and policies their own community holds dear. Each surgery is an encounter with the unknown, but integrating new tools into surgery is doubly so: in practice, surgeons have had to make uncertain cuts with novel tools to produce better knowledge. Yet just as this productive deviance has enabled progress, the trajectory of western surgical practice over the last 200 years has bent towards risk mitigation and rationalization, with concomitant increases in observability and liability pressures.

If this continues, what will happen to the unsafe and inefficient experimentation inherent in surgical work itself? What of the failure required for learning, and the invention of and adaptation to new technologies? One possibility is that such innovation will shift to countries and geographies – notably India (Rao, 2007; Chaturvedi et al., 2008) and sub-Saharan Africa (Chu et al., 2009; Nthumba, 2010; Grimes et al., 2012) – that allow for markedly different approaches to observability, risk and liability. For example, Cardiac bypass operations are often performed by a stable group with one surgeon and take hours in the United States. The same procedure is often done in 30-45 minutes in India by a rotating group of surgeons who each specialize in a portion of the procedure. Regional differences – whether within the US or global – on other issues such as patient consent, surgeon supervision and training, reporting and standardization requirements and payer-provider models may also allow for more and varying productive deviance in surgical practice.

Another possibility is that productive surgical deviance will die because surgery itself is on the wane. A good number of the senior surgeons I speak with presume that new treatments – nanoparticles, nanobots and the like – will make cutting into patients less and less necessary. But most physicians and researchers expect that surgery isn’t going away for at least several decades, and that if anything, robotic surgery is going to continue to expand in proportion to other methods, given that it allows fewer surgeons to perform surgery with less trauma to the patient. Automation may accelerate this transition; we have recently seen striking progress on automating surgical tasks such as suturing and tumor excision in lab settings (Moustris et al., 2011; Patil, Abbeel, and Goldberg, 2014). When I ask experienced robotic
surgeons about the future of their work, some of them suggest that relatively routine portions of a given procedure might soon be automated. The system may move more slowly than they would, and the surgeon may need to orient the system to the landscape inside the patient, but a semi-autonomous system could assume practical (if not legal or ethical) responsibility for a growing proportion of the experimental interventions required to advance a procedure.

Finally, we may soon be able to allow for some of the benefits typically achieved through unsafe and inefficient surgical experimentation via advanced digital surgical simulation. Simulation has already played an important role in resident education – Intuitive has partnered with a number of organizations to produce relatively advanced software simulations that help build basic surgical competence. If simulations could model the complexity and dynamism associated with human biology – which would necessarily entail models of related chemistry and physics – surgeons might attempt new surgical maneuvers and introduce new surgical technologies digitally to get useful information about their efficacy and safety. The trouble here is that we are all too willing to presume verisimilitude given the latest simulation technology (Bailey, Leonardi, and Barley, 2012), and this contributes to work breakdowns on the ground. Nevertheless, aviators adapted to this problem despite a strong norm for learning in the cockpit and now rely deeply on simulation for risky experimentation, so this seems possible in surgery.
Abstract

How do trainees in a community of practice learn new techniques and technologies when approved practices for learning are insufficient? I explore this question through two studies: a two-year, five-sited, comparative, ethnographic study of learning in robotic and traditional surgical practice, and a blinded interview-based study of surgical learning practices at 13 top-tier teaching hospitals around the United States. I found that learning surgery through increasing participation using approved methods worked well in traditional (open) surgery, as current literature would predict. But, the radically different practice of robotic surgery greatly limited trainees’ role in the work, making approved methods ineffective. Learning surgery in this context required what I call “shadow learning”: an interconnected set of norm- and policy-challenging practices enacted extensively, opportunistically, and in relative isolation that allowed a minority of robotic surgical trainees to come to competence. Shadow learning practices were neither punished nor forbidden by the very community that held them to be problematic, and they contributed to significant and troubling outcomes for the cadre of initiate surgeons and the profession. This research expands our conceptions of learning in communities of practice by detailing how trainees learn new techniques and technologies when approved practices for learning are insufficient.
Introduction

We have known for decades that the world of work is changing, and communities of practice must cultivate new skills in order to stay relevant (Barley, 1996; Anteby, Chan, and DiBenigno, 2016). New business models (Barley and Kunda, 2006), collaborative practices (Leonardi, 2011) and technologies (Bailey, Leonardi, and Barley, 2012) all demand new ways of interpreting and acting skillfully in the midst of a new and shifting set of problems, and those communities that do not adapt to these conditions deliver less value and lose jurisdiction (Susskind and Susskind, 2016). Though this adaptation occurs at the team (Edmondson, Bohmer, and Pisano, 2001) and organizational (Bechky, 2006) levels, communities of practice cannot accomplish it without ensuring an adequate supply of new members capable of performing the work that a changing world requires.

But communities of practice face a dilemma here. Much consequential learning occurs through direct and increasing participation in experts’ work (Lave and Wenger, 1991; Hutchins and Lintern, 1995), yet firmer divisions of labor and increased specialization maximize experts’ quality output (Marshall, 1972; Bailey and Barley, 2011). Prioritizing trainee involvement risks increased costs and decreased quality in the short run as trainees consume resources and make errors, and prioritizing output invokes these same risks in the longer term via a shrinking pool of competent members. Whether via shunting lower-level automotive design work to India (Bailey, Leonardi, and Barley, 2012) or moving car sales support work to a room away from a dealership floor filled with computers (Barley, 2015), available empirical research shows a decisive turn towards the second horn of this dilemma. Trainees must now often make do with decreasing participation in the work that they must ultimately perform.

Technologies that allow experts to work with reduced trainee help intensify this challenge. Communities of practice must incorporate new technologies to improve results and jurisdiction, yet these technologies are often designed in accordance with efficiency pressures. This frequently reconfigures the work in ways that concentrate control in the hands of experts without retaining a meaningful, direct role in that work for trainees (Barley, 1986; Barley and Orr, 1997; Leonardi, 2011). Adopting new
technologies often means shifting “simpler” tasks from professionals to paraprofessionals (Marshall, 1972; Barley, 1996, 2015), limiting trainees’ ability to participate in their mentors’ work. Similar change also often redistributes work across time and space, which likewise limits trainees’ ability to participate directly in a meaningful subset of the work (Kellogg, Orlikowski, and Yates, 2006; Bailey, Leonardi, and Barley, 2012). Generally, such reconfigurations bring new possibilities and new failure modes, and existing research does not show how communities of practice can adjust trainees’ role in the work to ensure their learning. Thus, especially as technologies and related methods allow experts to work with less help from trainees, communities of practice themselves make it hard for these trainees to learn.

So what do trainees do to learn to perform their work in spite of these barriers? Available research on learning in communities of practice focuses elsewhere, in particular on situations in which trainees enjoy ‘legitimate peripheral participation’ in experts’ work – semi-structured and increasing collaboration with experts on real problems involving significant risk, granted via a publically approved role (J. S. Brown and Duguid, 1991; Lave and Wenger, 1991). Legitimate peripheral participation is clearly evident in the socialization (Hughes, 1955; Orr, 1996; Pratt, Rockmann, and Kaufmann, 2006) and learning (Harper, 1987; Lave, 1988; Bailey and Barley, 2011) literatures – after a period of formal initiation and instruction, trainees succeed because they are granted access to increasing opportunities to work near the edge of their capacity alongside experts. This works because the tasks of the next expert up the chain overlap significantly with the trainee below them, allowing for meaningful observation and coaching (Hutchins and Lintern, 1995; Bailey and Barley, 2011). None of these literatures explore how trainees succeed when such participation is constrained, however, let alone how learning plays out during moments of technical transition. Experts face increasing productivity and liability pressures, and “labor saving” technologies that consolidate operational control to experts – such as personal computers and process automation – have become quite common. My study inquires directly here, asking: when efficiency pressures and technological reconfiguration of methods prevent legitimised peripheral
participation, how do trainees into communities of practice learn to perform their work – and what are the consequences?

I find that trainees who successfully learn under these conditions do so via what I call “shadow learning.” If approved means are not sufficient, trainees who succeed must, by definition, learn through practices that run counter to norms and/or policy and to which key stakeholders turn the proverbial blind eye. Though not focused on learning, studies in a variety of literatures offer some insight into the practices I observed in my two-year ethnographic study of the learning of robotic surgical practices in five hospitals. Studies of deviance explore policy-breaking practices (Gouldner, 1954; Anteby, 2008; Paulsen, 2015) while studies of workarounds focus on practices that run counter to norms but do not break rules (Roy, 1952; Gasser, 1986; Bernstein, 2012). Drawing on concepts from these literatures helped me to account for learning practices that were frequently tolerated by key stakeholders as they allowed for mutually desirable outcomes, even though they would have been punished or forbidden if viewed in the bright light of day. My theoretical contribution is to show how trainees learn skills core to a community of practice through such methods.

In my observations and interviews, shadow learning emerged as a salient and important set of practices for skill development. I derived this concept through my analysis of qualitative data derived in a two-study design. The first study was a two-year ethnography of robotic surgical work at five top-tier teaching hospitals and affiliates in the northeastern United States; this study highlighted significant barriers to learning and generated several insights into patterns that allowed particular residents to acquire exceptional robotic surgical skill. Roughly two-thirds of the way through my ethnography I launched the second, interview-based study to further explore these patterns: a blinded, matched-pair (exceptional learners and average learners) study across 13 additional top-tier teaching hospitals distributed throughout the United States. Sampling on these matched cases of learning in technologically-mediated reduction in the legitimized trainee role allowed me to shine a bright light on the practices that constitute shadow learning. Successful trainees engaged extensively in three interdependent, norm and policy-challenging
practices that went unsanctioned: “premature specialization” in robotic surgical technique at the expense of generalist training, “abstract rehearsal” before and during their surgical rotations when concrete, empirically-faithful rehearsal was prized, and “undersupervised struggle”, in which they performed robotic surgical work close to the edge of their capacity with little expert supervision – when norms and policy dictate such supervision.

This study expands our conceptions of learning in communities of practice by showing that when technological change to core methods allow experts to work with less help, successful trainees may learn through norm- and policy-challenging practices that are enacted extensively, opportunistically and in relative isolation. And, unlike known learning practices that function through gradually increasing participation in the work, robust participation during such technical change can be starkly dependent on immediate demonstrations of relatively advanced competence that can only be acquired through norm and policy-challenging practices. I identified several unintended consequences associated with this kind of learning. First, it led to a star-pupil-take-all dynamic – successful learners gained discrete, increasing and disproportionate access to learning opportunities. Thus, the gap between credentials and actual skill widened for most trainees, as they could not participate sufficiently in the work. Second, those trainees who did engage in shadow learning become hyperspecialized in related techniques in a world that has room for only a handful of such hyperspecialists. And, finally, this was particularly problematic in a time of decreasing expert capacity relative to demand – the very situation faced by the surgical profession for the last few decades (Dill and Salsberg, 2008; Decker et al., 2013).

Prior Research on Learning in Communities of Practice

Communities of practice cannot persist without training new members. Competent membership allows them to tackle complex, dynamic problems (Abbott, 1988; Susskind and Susskind, 2016), expand jurisdiction over those problems (Abbott, 1981; Freidson, 1988) and maintain a strong identity and culture (Pratt, Rockmann, and Kaufmann, 2006; Kellogg, 2011). Research has shown that while formal training has
an important role to play in this competence (Glance, Hogg, and Huberman, 1997; Luo, 2007), much consequential learning occurs through legitimized peripheral participation in the work core to the community (Van Maanen and Schein, 1978; Lave and Wenger, 1991). Legitimated access lets trainees “get it” by “being there” with old hands during the work, and helping out on risky tasks in ways that bring them close to the edge of their expertise. In some cases, this occurs via canonical (i.e. formal, codified) channels such as corporate training and via noncanonical (i.e. informal, tacit) channels such as telling “war stories” in others (J. S. Brown and Duguid, 1991). Regardless, the trouble here for trainees and the communities they aspire to join is that economic and efficiency pressures, coupled with technologies that allow experts to perform more of the work without assistance often mean dividing the work (Berg, 1997; Hinds and Bailey, 2003) such that trainees get less meaningful exposure to experts in action. Especially as these dynamics become more prominent, successful learners must find alternate routes forward.

Studies of learning in communities of practice have not focused on this problem; it has rather treated legitimate peripheral participation as a given. The socialization literature is an exemplar. Van Maanen (1975, 1978; Van Maanen and Schein, 1978) shows that once they emerged from the academy, all expected police recruits to go “on the beat” with more senior cops where they would really “learn the ropes.” This was an essential and legitimized semi-structured partnership in which they drove their own learning as they helped their more senior counterpart with failure-intolerant policing – from paperwork to castigating “assholes” via physical violence. Bosk (2003), in his study of trainees’ relationship with medical errors, shows that learning how to avoid errors of comportment was more important than learning how to avoid technical or diagnostic mistakes – even those that lead to death. Whether it was learning the “no surprises” rule or senior doctors’ idiosyncratic preferences for treatment of ambiguous conditions, residents learned these lessons through a legitimized role that gave them direct, collaborative and increasing involvement in a stable body of professional work. Again, these findings depicted trainees as enjoying a legitimized role that provides consistent, increasing and direct involvement in experts’ work, and the authors do not focus on technologies that allow experts to work with less help from trainees.
Studies of apprenticeship generally take the same approach. In a study of distributed cognition in the operations of a naval vessel, Hutchins (Hutchins and Lintern, 1995) articulates how navigation trainees learn first how to take a bearing on a distant object, then to record these from someone else taking those bearings, and then to plot position and heading based on someone else’s records. Hutchins shows how this overlapping responsibility ensures that anyone at any organizational level has deep expertise in the work all the way out to the empirical interface, and can therefore coach these individuals, detect and correct errors. In a ten-year study of working knowledge in a community mechanic’s shop, Harper (1987) illustrates his own learning as an apprentice to Willy, a master mechanical tinkerer. Through a legitimized role that gave access to collaborative performance of the work, Harper learned a hierarchically-ordered set of skills: how to use basic tools (e.g., an acetylene torch), then how basic materials (e.g., metal, wood, plastic) respond to modification attempts, then techniques (e.g., a blacksmith’s weld), then elegant problem solving (e.g., learning to heat a metal chimney from the roof to induce a draft rather than punch a new hole in the roof). At each phase, Harper worked close to the edge of his current capabilities with Willy’s guidance. As with the socialization literature, we gain little insight from these studies into how trainees build professional grade skill when methodological change radically limits legitimate peripheral participation.

Two studies of apprenticeship buck this trend, but do not illustrate how learners succeed despite these barriers. The first, a study of butchers and their apprentices in urban England (Marshall, 1972) shows apprentices taking jobs in hopes of learning the trade, only to find themselves shrink-wrapping prime cuts of meat without much hope of observing master butchers making these cuts. The cost of trainee mistakes while butchering livestock was high, and the gains of dividing labor into cutting and wrapping rooms was high, so most trainees worked for years and built no appreciable butchering skill. The second shows North American medical personnel introducing standard western training methods to midwives on the Yucatan peninsula (Jordan, 1989). Ironically, these methods impeded learning, as they contradicted situated historical methods for performing midwifery in the region, and interfered with apprentices’ and midwives’ efforts to simply spend time with one another as they worked. While offering limited insight into successful
learning in these conditions, these studies illustrate that technological change and limited legitimate peripheral participation do indeed impede trainee learning.

As with studies of many organizational phenomena, the learning literature has considered learning as a process that unfolds in the light of day: practices and methods are known and approved, learners enjoy regular, shared, and increasing access to participation in experts’ work and this has wide-ranging implications for how learning occurs and key learning outcomes. I suggest here that we stand to gain a great deal by examining learning that occurs through norm and policy-challenging practices that go unsanctioned because they allow for productive ends. Studies of deviance and workarounds in organizations focus on such practices, and therefore offer key insights into the shadowy territory that trainees likely traverse when approved means for learning are not enough. Studies in these literatures clearly show that organizational phenomena such as identity incentives and organizational control (Anteby, 2008), collaborative efficiency (Bernstein, 2012) and technology implementation (Gasser, 1986) unfold in qualitatively different ways when enacted outside the bounds of legitimized practice, with consequential and different implications for organizations and the workers who inhabit them.

Learning the skills of a given community of practice has traditionally been theorized as involving increasingly substantial participation in experts’ work, granted via a legitimized role. This view has implied learners are openly offered predictable and collective access to norm- and policy-consonant learning opportunities and that these can be flexibly sequenced to accommodate differences in aptitude and risk. Considering robotic surgical training revealed a set of practices in the shadows outside legitimate peripheral participation: learning was opportunistically seized via norm- and policy-challenging practices enacted by otherwise unconnected learners away from experts’ watchful eyes, and meaningful access to collocated work with those experts on real problems was heavily dependent on this extensive preparation. These marked differences led me to frame successful learners’ process as shadow learning. While the implicated practices allowed a few learners to reach competence in the face of significant barriers, I show below how these same practices had significant negative consequences for their cohort and their community of practice.
Research Setting

This research draws upon data derived from two interleaved studies: a multi-sited ethnography and an interview-based study. The ethnography was a two-year comparative study of urologic surgical procedures performed by interdependent surgical professionals at five hospitals in the northeastern United States. Three of these were world-renowned teaching institutions and the other two allowed for training rotations from these institutions. The teaching institutions each had capacity for hundreds of patients, included every major western medical specialty, employed hundreds of physicians and thousands of nurses and support staff to deliver cutting-edge treatment involving the latest technologies. Each surgical discipline within these institutions also supported 5 or 6-year medical residencies – viewed by many as a crucial training period that allows generalists to achieve professional-grade skill (Becker et al., 1976; Conrad, 1988; Pratt, Rockmann, and Kaufmann, 2006; Kellogg, 2010). The interview study included Urological surgeons and medical residents at 13 additional top-tier teaching institutions distributed around the United States.

Residents arrive at their institution knowing they will train in a discipline such as Urology, and expect to leave their programs with professionally-sufficient capability in key Urological diagnostic frames and procedures. Generally, apprentices spend a year or two rotating across disciplines and functional areas of their institution, with only minor formal opportunities to specialize. These are the scutwork years. Residents then progress to one or two years of rotation through the various areas in their discipline, performing apprentice-type functions during procedures and in the clinic. In the final year or two of residency, trainees engage in similar work but take a more senior role and handle more complex cases. It is standard practice for residents to rotate through nearby institutions at least once (typically two times) during their residency, thus gaining exposure to different people, problems and surgical methods.

This study encompassed two such surgical methodologies, each with distinct technological accoutrements: open and robotic. The technologies involved in open surgery are inscribed in modern western culture: scalpels, drapes, sponges, retractors, clamps, sutures and so on. The da Vinci robotic
surgical system\(^7\) consists of three basic components: “the console” (an immersive control apparatus), “the brains” (a computing tower), and “the robot” (a 1,000 pound, four-armed surgical device). Three arms on the robot hold interchangeable, sticklike equivalents of traditional surgical instruments such as scissors or graspers, while one arm holds a stereoscopic camera. The console has foot pedals and two multi-jointed “masters” for hand control – smooth surgery requires coordinated, complex foot and hand movement by a seated surgeon. The tower both translates the surgeon’s manipulations of the console to the robot and transmits a magnified, 3-dimensional video signal from the robot to the binocular console display and magnified 2-dimensional video from one of the camera’s “eyes” to screens around the OR.

Two aspects of the da Vinci technology were particularly relevant to resident learning. Due to feedback from surgeons that prior robots made it difficult to train residents in situ, Intuitive designed a dual console version of their system. Essentially this added an additional console to a given da Vinci setup in the OR, and control of the robot could be digitally delegated by the senior surgeon via a few taps on a touch screen embedded in the armrest on their console. Every training institution in my study rapidly purchased this dual console setup, and used it preferentially whenever residents were involved in a procedure. Additionally, Intuitive offered a suite of simulator software that was either installed directly on a console in the OR or on mock consoles elsewhere in a given hospital. Either way, these simulators allowed individuals to practice via the console to perform simplified, very basic surgical actions (e.g., moving instruments in space, shifting a view, passing sutures through rings) in a digital environment. Performance on these simulations was scored and rated, and could be saved.

**Doing Robotic and Open Surgery: Key Differences for Surgical Trainees**

Open surgery is accomplished in practices involving an attending physician (AP), medical resident(s), a scrub technician, a nurse, and inanimate, general purpose tools (e.g., sterile garb, retractors, sponges, tables, drapes, scalpels, sutures, cautery devices). All but the nurse stand within inches of each

other and the patient, looking down into an incision, performing highly interdependent activities with handheld tools and without much talk. As the years go by, residents do more and more of what the lay public thinks of as surgery (e.g., cutting, suturing) while the AP holds and dissects tissues with their gloved hands inside the patient, sets clamps and retractors and issues directives. When there is talk amongst the surgical team, most of it is so quiet that it is barely audible from two feet away, given the noise from devices throughout the OR. In many institutions, the AP regularly arrives well into the procedure and leaves before it is complete – senior residents lead the processes leading up to through “opening” the patient, and the AP is paged when the surgical stage is set for complex or dangerous phases of the procedure. Once that phase is over (e.g., a tumor is removed and related damage remediated), the AP will back away from the patient to fill out paperwork and depart as the residents “close.”

In robotic surgery, all (including the AP) immobilize the patient, attach a four-armed surgical robot to them through keyhole incisions, then inflate their belly with CO₂. The surgeon then sits in an immersive control console 15 feet or so away, viewing and operating inside the patient through “wristed” instruments at the end of each robotic arm. The resident may be at the bedside or at the console. If at the bedside (a role referred to as “the sucker”), the resident uses a laparoscopic (sticklike instruments inserted through trocars) suctioning device to keep the field clear of blood, smoke and other fluids, uses the tip of this instrument to retract tissues, and passes sutures, instruments and tissues in and out of the patient. If at the console, the resident either sits on a chair next to the AP, waiting for a turn to sit and operate with the surgeon sitting in the resident’s chair, or sits at a second “trainee” console, seeing what the surgeon sees through the robotic camera and “taking over” when the surgeon digitally delegates control to them. When the surgical work is done, all again cooperate to “undock” the robot (i.e. remove instruments, detach the robot from the patient and back it away) and close the patient. Unlike in open procedures, the AP stays in the OR and participates directly in all of these activities. The nurse, scrub tech and medical resident are much less active and interdependent with the surgeon than in traditional procedures, though all can see the procedure unfolding on multiple monitors throughout the OR.

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Research Methods

Data Collection

Study 1: Multi-sited Ethnography. My ethnographic work involved site visits and observation of surgical work in the OR nearly every week at five hospitals from 2013 to 2015, as well as recurrent formal and informal interviews with hospital staff. Specifically, this study draws upon 4772 pages of data gathered during 94 surgical procedures, encompassing 478 hours of direct observation. I took time-stamped notes documenting staff interactions and the flow of work before, during and after each procedure, noting technology configuration and use and the roles and responsibilities of each participant. In each of these procedures I engaged in participant observation, regularly helping with scutwork in the OR (e.g., dealing with trash, running for supplies, turning lights on and off, helping people scrub in), training on a daVinci simulator for six sessions, getting trained to move the robot’s arms around for sterile draping, and sitting in the trainee console during procedures. I also spent informal time with staff before and after procedures. This study also included 62 formal interviews conducted in private, involving 18 surgeons, ten scrubs, 12 circulators and 16 residents. These typically lasted 30 minutes and were recorded for transcription. Towards the end of my study, I solicited feedback on my findings at all levels in private interviews. After incorporating responses, I presented this and a draft summary of my findings to a large group of staff in all roles at one institution for the same purpose.

Study 2. “Blinded Snowball” Interviews. In order to sample heavily on relatively rare “successful learners”, I launched study two, a “blinded snowball” interview study across 13 additional world-renowned teaching institutions throughout the United States. Each AP I interviewed at my ethnographic sites supplied two sets of interview subjects: two or more colleagues with comparable experience and roles at other institutions and two residents from their own institution. One of these residents had, in their view, learned to do robotic surgery very rapidly, while the other was average or below average in that regard. I was blinded to the senior surgeon’s evaluation of their learning success until after I had interviewed them.
Enacting this protocol connected me with 33 APs and 33 medical residents. Nine of these residents were assessed as average or below average, 12 were assessed as exceptional. For semi-independent assessment of my emerging findings, I interspersed an additional 12 interviews with residents on this topic without seeking an assessment of their capabilities.

**Data Analysis**

Though the motivation for this study preceded its implementation, the obstacles to learning robotic surgery were not clear until study one began. As these became apparent, so did the reality that a few residents were managing to acquire a surprising amount of robotic skill – and concomitant time on the console – in spite of these obstacles. These obstacles and successes were only apparent as I gathered data on medical residents’ (and APs’) entire education – from well before residency until its conclusion. I thus settled on the period between residents’ initial introduction to the daVinci system through their legitimized acquisition of professional-grade skill as my unit of observation for the study. A year’s worth of time at my five ethnographic sites presented only three individuals who had managed to make exceptional progress in learning robotic surgical technique, and while these individuals differed greatly, the practices that they had engaged in to learn seemed quite consistent. Study two confirmed and deepened my initial findings – a particular set of particularly-sequenced activities and settings were associated with successful learners. Practices are therefore the unit of analysis for this study.

My analytical work iterated across data derived in both studies. This involved multiple readings of field notes and interview transcripts from my ethnographic sites as well as multiple readings of transcripts from my blinded snowball interviews. Both of these relied on consideration of a variety of literatures and discussion of exploratory memos with colleagues (Glaser and Strauss 1967) and focusing on surprises and contrast (Abbott 2004) as a way of inducing meaningful and novel perspectives that could powerfully explain the work under study. My initial analysis during study one yielded a number of themes related to contrasts between learning robotic surgery and learning open surgery. Some of these centered on
legitimized methods for learning and teaching (e.g., time in the OR, AP feedback), some on challenges (e.g., dramatic reductions in residents’ time on task from open to robotic surgery) and others on rare productive responses (e.g., abstract rehearsal). These themes shifted over time given additional, more focused data collection, and in response to interim findings. One of the most important methods for producing findings – whether manifest in the first or second study – was regularly soliciting reactions to my interim findings from participants in informal conversation, private interviews and group presentations. Overall it became clear that legitimized and well-understood practices for training and learning surgical skill were quite insufficient for rapid and extensive progress learning robotic surgery.

In my second study and later analysis, I focused on how residents made exceptional progress acquiring robotic skill despite quite dramatic and widespread barriers to legitimate peripheral participation in robotic surgical work. It became evident in this analysis that the norm- and policy-challenging yet tolerated practices I observed in study one were indeed crucial to residents’ success. This led me to draw on the deviance and workaround literatures for interpretive grounding. These literatures suggest that when approved means are not available for locally-preferred outcomes, norm- and policy-challenging means are enacted. While these means are observed by some, they are generally performed out of the limelight, and are tacitly endorsed by the broader organizational system for the results they allow. By taking these literatures seriously and through close examination of my empirical data, I derived the concept of shadow learning: the norm- and policy-challenging, tolerated practices enacted out of the limelight that allow apprentices to learn when norm- and policy-consonant means in the limelight are insufficient. This frame was an excellent match for my phenomenon and with a practice theoretic lens (Feldman and Orlikowski, 2011), as it was the enactment of these activities in a particular sequence that counted for learning. Below I argue that residents had to engage in shadow learning to gain professional-grade robotic surgical skill, and that a robust understanding of expert skill development should take shadow learning into account.

**Barriers to Learning Urological Robotic Surgical Skill**
Surgical residency has no purpose if not to produce new members of the surgical community: individuals who may legitimately perform surgery by dint of the skills to do so. To achieve both aims – legitimacy and skill – students undergo years of costly training, beginning with pre-medical undergraduate education, proceeding through four years of medical school and culminating in five to six years of residency. This system explicitly begins at the generalist level, and presumes that trainees will become increasingly specialized. Beyond addressing the critical need for extensive side-by-side practice with experts, these activities are portrayed as and presumed to be effective (Abbott, 1981; Freidson, 1988) and therefore legitimize the outcome to trainees, surgeons and ultimately the public. Pressures to adhere to legitimized methods for building surgical skill are growing. For example, the shift from a 120-hour workweek to an 80-hour workweek for residents (Kellogg, 2010) means that residents and APs must make even more of the decreased practice opportunity available.

But the reality of professional work – and surgery in particular – is that pressures to innovate via new technologies and methods are also growing, and experimentation is required in order to make progress:

The history of surgery is always that you’re trying to move things forward, to find the next best thing. And you’re not going to know in the beginning whether or how a new approach is more effective. It was the same with laparoscopy. What, that started in ’92, and there were similar calls [as with robotic surgery today] – you should lose your license, you’re killing patients, it was crazy. Now, if you don’t do a bowel resection laparoscopically, people look at you with a little suspicion. – AP

Beyond this, technical change to methods such as the shift to “straight stick” laparoscopy (operating through small incisions instead of large incisions) has allowed for finer-grained division of surgical work in which APs do more of what they are best at and that imply potential reconfigurations of residents’ roles in the work. Surgeons and residents at all of my sites therefore faced a dilemma on a daily basis: find a way to ensure meaningful, legitimate role for residents in the work while taking full advantage of the cost-reducing and skill-extending benefits offered by new technologies. By definition the APs that I interviewed had discovered a way to succeed on this front with respect to robotic surgery, but it became clear that most residents had not.
Legitimized Learning Opportunities in Surgery

From well before they arrived until they left, residents built surgical skill – the ability to use one’s body to execute appropriate surgical maneuvers effectively – in a hierarchically-ordered fashion. After an initial phase focused on building conceptual knowledge (e.g., anatomy, organ system function), they moved on to building embodied capability with basic materials and tools (e.g., learning to tie certain kinds of knots). More complex skills (e.g., making an initial incision, resecting a tumor) were constituted by more basic skills. The key with any skill – whether complex or basic – was that the resident had to be able to perform them smoothly in the midst of real work. Just as with many embodied skills, this required extensive repetition: I frequently observed medical students – visiting for summer rotations – tying knots in the air or on a post, for example. Complex surgical skills could not be acquired through solitary rehearsal, however – this required increasing involvement in live procedures in the OR.

For many decades, surgeons have referred to the requirement for legitimate peripheral participation as “dwell time” (Holmboe, Ginsburg, and Bernabeo, 2011), and treated it as foundational to their legitimacy and skill: you couldn’t become a surgeon if you haven’t logged many, many hours in the OR. Within this requirement, everyone involved in surgery - APs, nurses, scrubs and residents – understood the appropriate way to convert dwell time into surgical skill: “see one, do one, teach one.” In other words, watch a procedure a number of times, participate in it a number of times and then teach others how to do the procedure a number of times. As illustrated in other studies of legitimate peripheral participation, these activities were not distinct – as time went on, the emphasis of a resident’s experience shifted gradually from observation to performance to coaching new hands. The structure of medical residency was tailored to this learning pathway: everyone expected junior residents to primarily observe procedures, mid-cycle residents to perform ever-more complex portions of these procedures, and senior residents to teach and guide junior residents in surgical work (even as they continue to practice complex skills themselves).
Legitimate peripheral participation and “see one, do one, teach one” in particular were deeply disrupted in the practices of robotic surgery at my field sites, as the daVinci surgical system allowed experts to proceed without trainee help:

...Say you were in upper Maine or something, and you needed to do a hysterectomy and you didn’t have a partner to operate with... you have a scrub tech. You could use the robot and get your surgery done. So the robot allows people to operate without other surgeons in the room, that’s the bottom line. – AP

APs have ultimate responsibility for safety and efficacy, and therefore did what the technology allowed, with extensive, negative implications for resident learning.

**Legitimate Peripheral Participation in Open Surgery**

Standard open surgical technique at my field sites dictated residents’ legitimate peripheral participation in the work, allowing them an effective means of achieving open surgical skill. During the beginning and end of many traditional procedures, the AP was not in the OR. Alternatively, they stood back from the surgical field. During this time, a mid-level or senior resident led the prep and initial opening of the patient and led more junior residents and paraprofessionals through the surgical procedure until it approached a point of where risk and implications for downstream action were high. This is the point which the nurse called the AP to tell them that he or she should participate in the procedure. After the AP arrived, they then worked with the resident(s) to do this part of the procedure, the AP generally showing the way and the resident doing what the lay public sees as actual surgical work: cutting, cauterizing and suturing. Within this arrangement, APs delivered feedback through touch and gesture or spoke it quite quietly. They likewise regularly, easily and quickly redirected the resident’s focus to suit the intensity of the task and the resident’s skill:

There’s more going on [in open surgery than in robotic], it’s not apparent to everyone in the room, and it’s easier for the attending to also move in a different direction if you’re not doing something right, they can take... instead of 50-50, it can be a 75-25 sort of thing, basically instead of letting you get into the appropriate plane of a dissection, they’re getting into the planes of the dissection and you’re basically just cutting. But you still feel like you’re part of the procedure and the attention is not pointed in a negative way. - Resident
The junior resident, if present, did supportive work of some kind but was in some minor way involved in the procedure (e.g., holding a retractor, minor suturing). Then, once the risky or formative portions of the surgery that actually required the AP were complete (e.g., tumor removal), the AP said something like “okay that’s it,” broke scrub and left the room (or began to fill out paperwork and chat with the nurse, away from the surgical site). After this point, the senior resident was in charge of “closing”, which involved suturing a variety of tissues together in order to reconstitute the patient as whole and stable. They worked interdependently with the junior resident to accomplish this goal. Once the patient was closed and clean, the team moved the patient to a gurney and the residents took them out of the OR to the recovery unit. APs sometimes arrived at the beginning of open procedures. When they did so, they played very minor roles and/or consulted scans at a PC away from the surgical site.

Thus, in open procedures, “see one, do one, teach one” provided an effective learning pathway: the barriers to progression from the periphery to the core of the work were many, continuous and low, and these were routinely crossed as work could not proceed without residents’ extensive participation. Junior residents got to “see one” initially, but were easily and flexibly invited away from the periphery: they closely observed entire procedures from the bedside while doing minor surgical work. Only medical students (generally present in the summertime) were allowed to simply watch entire procedures. Mid-level and senior residents were generally in “do one” mode – they performed a fair amount of independent work and the AP could not work without these residents’ ongoing complementary action:

[In open surgery] you’re cutting, you know they’re [AP] showing you something to cut and you cut, or you’re showing them something to cut and they cut it. All four hands are working together and you kind of find the ureter, you go down to the bladder, you know. - Resident

These residents also “taught one”, however: in almost all cases in which a senior and junior resident worked without an AP present, the senior resident was quite verbose and demonstrative in explaining what they were doing and coached the junior resident through the relatively more active portions of opening and closing. Generally, the more residents did, the more they were allowed to stretch
and do more complex/risky work. Past a certain point, they were implicitly granted the authority to run early and late portions of procedures, and they thus shifted to teaching before they left their residency.

Residents were expected to learn things like anatomy off-line, and practice things like suturing off-line, and even laparoscopic technique off-line, but they reported doing essentially no off-line practice for open procedures. They occasionally debriefed procedures and talked through how to perform complex maneuvers, and some circulated relatively detailed typed outlines of a given procedure. But everyone – residents, APs, nurses, scrubs – assumed that almost all of the important learning happened through increasingly consequential work in the OR, and that this was right and proper.

**Failure of Legitimate Peripheral Participation in Robotic Surgery**

Robotically, yes, you can learn a little bit from watching, especially in the beginning, but until you have your hands in there, moving tissue around – those are robotic hands – I think you’re only learning 5% of your full potential. And for that 10 minutes where you’re doing the steps [robotically], that’s when the other 90% of the learning comes in, but you’re only doing it for a very short time. - Resident

One of the main reasons APs relied on residents to perform open surgery is that these residents had several years of embodied practice with basic techniques such as establishing and maintaining a sterile field, suturing, retracting and making incisions, and could therefore perform these fluidly under pressure. Given that most residents – at best – practiced robotic surgical technique a few hours a year, they were far less fluent with basic robotic technique:

In robotic surgery if you get into the same scenario [nicking an artery], the actual process of tying a knot [to remediate it] is not instinctive. It’s different, because it’s not your own hand, it’s not your own wrist, it’s not your own fingers. Even if you were able to throw a stitch across that bleeding vessel, you have to think how to tie a knot when you’re doing it robotically. - Resident

Beyond this limitation associated with basic robotic skill, standard robotic surgical technique at my field sites made it practically impossible for residents to effectively learn robotic surgical skill through peripheral participation. The medical resident, at best, got the patient onto the surgical bed before the AP arrived in the OR. The AP led the activity of positioning the patient, marking initial surgical sites, making small incisions in the patient, and attaching the robot. They likewise stayed after the core of the procedure
was done to lead the undocking of the robot and all but the final rousing of the patient (perhaps 10 minutes of work). Attaching and detaching the robot were seen as critical opportunities for failure - if workers didn’t position the patient appropriately, the risk of catastrophic injury was high. Metal trocars (tubes with sharp tips that were inserted into the belly to allow for instruments to be attached) could puncture or tear blood vessels or organs if inserted improperly, and strongly determined the ease and range of surgical action once the robot was attached, for example. As with takeoff and landing in aviation, the riskiest phases of a procedure were the beginning and the end. And as illustrated above, this was inverted in open surgery – the danger was in the middle (of the procedure and the patient).

This meant the practical elimination of the AP-free portions of a procedure. For the resident, this meant a dramatic reduction in opportunities to “do” parts of the procedure without significant supervision, and a near elimination of opportunities to “teach” other more junior residents. These issues alone presented a significant threat to resident acquisition of robotic surgical skill through legitimate peripheral participation, but this was not the end of the story. These dynamics were compounded by the way that APs supervised and taught residents during robotic surgical work.

*Helicopter Teaching in Robotic Surgery*

In significant contrast to open procedures, handing off control to a resident in robotic procedures was, for practical purposes, a binary choice. The AP was either at the console, in control and doing all the operating, or they delegated complete control to the resident with a light tap on their armrest touchscreen. They also regularly used this feature to pause the work: if safely positioned and left alone, the robotic apparatus held patients’ viscera fixed – something that took great cooperative effort and skill in open procedures. Many surgeons and residents used a driver’s education analogy to describe instruction in all types of robotic surgery: the surgeon essentially put the resident in the driver’s seat for practice, but retained the ability to hit the brakes at any time.

It’s like driver’s ed. It’s harder than you think. [You’re] Sitting side-by-side and surgeon’s doing something, swaps the controls [for you] to try to do the same thing. There’s a lot more to
learn, and it’s not like you have someone behind you showing you how to, like you do during an open case. Even with the dual console. - Resident

And just as in driver’s education, surgeons relied almost exclusively on verbal feedback and coaching in order to help the functionally independent resident navigate the surgical field. Unlike in open procedures, this “help” came in great volume and intensity. The da Vinci system magnified the surgical field by up to ten times actual size, allowing risk-intolerant APs to perceive a new class of surgical errors. Though typically very minor, they appeared large on screen, and APs were compelled to intervene:

2:24 PM

C (AP, at primary console, just after giving up control): You can see why you’re dissecting, between the sv [seminal vesicles] and vas [deferens] earlier, and now you’re slowly beginning the process of making hamburger meat, that’s where the resident chops up the vas deferens to the point where it’s a mess. And I have to grab it. If you’re going to grab it, grab it like you mean it, none of this little baby shit, take a big grab. Bipolar, aaaaah [making sound effects], now, eeeeh bipolar eeeeh, you’re not going to even... cut to the left, cut to the left, cut to the left, cut to the left, cut to the left. [resident cuts] Does that make sense [referring sarcastically to the resident’s cut]? So we don’t care about backbleeding?

K (resident, operating at second console): Okay.

C: Okay, now go to the top, spread it a little, not like an animal, just a little, there is no law that you must spread maximally, cut to the left, cut to the left, cut to the left, you’re always cutting behind what you burned. Good. Now, tip to the left. K, I promised you two cases ago that I wouldn’t walk you through this anymore. Get that bleeder to the right. Get that bleeder, that’s where you’re going to get the nerves. Bzzzzzz. That’s it, right there, good.

C: Good job, that’s nice, stay right on top of the sv. Stay right on top of it. Nice, cut.

C: Alright, you’re done for now [takes control] 2:27 PM

Field notes, 1/14/2015

As this extract illustrates, APs verbal coaching was audible to everyone in the room. Further, in a dual console situation, the surgeon could make “digital instruments” appear in the resident’s view of the surgical field. They then could point to certain structures and indicate directions and speed of potential motion, but in every case this was done to accentuate a point that the surgeon was making verbally.

Residents experienced this kind of learning environment very differently from open procedures: “If you’re on the robot and it’s [control] taken away, it’s completely taken away and you’re just left to think about exactly what you did wrong, like a kid sitting in the corner with a dunce cap. Whereas in open surgery, you’re still working, so you have less time to focus on that negative time, you’re sort of working into a new area, you’re still doing something, you have to continue to focus, because you’re still operating, you’re not completely out of the game at that point. You’re sitting on the corner of the bench rather than in open surgery you’re swimming at one end of the pool or treading water in the shallow end, but you’re still swimming.” – Resident
And as the elapsed time in the above extract also illustrates, this translated to a dramatic drop in time on surgical task unless the resident demonstrated extreme competence right out of the gate. The irony was that achieving such competence required significant console time. To begin with, most residents spent the bulk of their residency only “seeing one”:

You also have this hate relationship with it because for the last four years you’ve been watching other people do it. For me [by my chief year], I had been on the robot a few times, very scattered and not very long lasting. And you really don’t get a good sense of it when you’re doing it intermittently. – Resident

For the procedures I observed (4.5 hours on average), residents performed surgical work for essentially the entirety of each open procedure, whereas they saw 10 to 20 times less time on surgical task for robotic procedures. Beyond this, the few minutes that residents were allowed on the console were closely supervised and critiqued by an AP. APs were highly skilled and bore ultimate legal and moral responsibility for surgical safety and efficacy, and major mistakes were much harder to correct quickly than in open procedures:

In open [surgery], if you put a hole in the iliac vein, yeah, it’s a big problem, but you can put your finger there, compose yourself and get control. If you cause that in a robotic procedure, the patient could hemorrhage before you regain visualization. If they [surgeons] think they can do it by themselves safely, they’re not going to want to take that risk [letting the resident operate].
- Resident

It’s not going to be bloodless every time, but some faculty, as soon as they see you off course, they say “I got to get you back on” and when they sit down at the console, it’s never just to get you back on course. - Resident

All of these pressures translated into APs intervening frequently in residents’ attempts to operate, both verbally and by taking and granting control:

Q (AP, at primary console observing): Do you think I was happy about that move or no?
J (Resident, operating at second console): No.

Q: Do you know why? Because you’re taking your bipolar [cautery instrument] and ramming it into the bowel. If you’re going to do some blunt dissection, pretend like you’ve done it before. STOP, STOP doing that! Take a break [takes control]. I say don’t do that, you do it, don’t do that, you do it, I don’t know how I’m not supposed to get frustrated. This isn’t a bladder. No more using this hand for anything except to pull things down. [gives control back, resident begins operating]

8:55 AM [closest timestamp to extract start]
Q keeps head in console
Q: Back up the camera for perspective, back it up. Good.
Q: Back up the camera for perspective. I want you to start going the other way for perspective, no, no, no, don’t do that again please. You start going there and you go to the left [takes control] it’s like painting a wall, you go left to right, then right to left, you go like this [demonstrating], you want to try it? [gives control back]

Q: God, stop [stands, out of console] I just can’t stand to watch that. I’ll give you one last chance on this, Dr. J. It doesn’t look good to shove your instrument into the bowel. If you take over, why don’t you pull up, do anything that doesn’t put you on top of the bowel this is your fifth warning.

J: It’s alright.

Q: That’s the line, right there, see where the elbow ends.
Q: now you’re going in the wrong plane. [takes control] Take a break.

8:59 AM
Field Notes, 03/28/2014

Thus, in robotic procedures, the barriers to progression from the periphery to the core of the work were few, discrete and high, and were infrequently crossed as work could proceed without residents’ help and it was exceptionally difficult to recover from residents’ errors. As a consequence, well-intended surgeons relying on new technology that allowed for increased supervision and control ended up micromanaging apprentices away from legitimate peripheral participation in the work. This and standard approaches to performing robotic surgical procedures outlined above prevented resident learning via legitimate peripheral participation. Opportunities to actually do and teach surgery were reduced by an order of magnitude or more, and (largely critical and imperative) AP coaching was both public and far more frequent, greatly decreasing opportunities for residents to struggle near the edge of their capabilities.

Problematic Implications for Resident Learning and the Surgical Profession

Most residents did not overcome these barriers enough to acquire professional-grade robotic skill, though they left residency having been legitimized in this regard: completing residency confers a license to perform any Urologic surgical procedure. Everyone expected them to acquire the bulk of their skill by watching, doing and teaching robotic surgical work alongside experts, and trying to fulfill these expectations within the bounds of legitimized robotic surgical practice did not produce sufficient opportunity for practice, independent struggle and instruction. As a result, all but a few residents felt less competent at the console than they did in traditional procedures:
There’s a different level of confidence [between open and robotic work]. I know that the outgoing chief feels very comfortable doing a nephrectomy [kidney removal] open, but I’ve heard them say that “I don’t know if I’ll do robotic or laparoscopic nephrectomies” because the level of confidence is not there for that modality. And I know that they won’t be doing robotic prostatectomies – they said that they won’t – but they said they would do open prostatectomies if the situation would arise. – Resident

Yet everyone who completes a residency was legally and professionally legitimized to independently perform surgical work in their discipline, including robotic surgical work. And so, confident or not, many new surgeons performed such work, but at very low volume: the average Urologic surgeon in the United States performs one robotic prostatectomy in any given year (Chang et al., 2015). So, most surgeons do not do the work they need to do in order to keep skills fresh (Jenison et al., 2012), nor have they undergone the requisite amount of training to cement their competence in the first place. These dynamics had negative implications for the development of surgical skill in both open and robotic techniques:

It [robotics] has the opposite effect [for learning]. If you take a look at X who trained in Oregon, and Y who trained at Ohio state [top robotics programs], they are not good robotic surgeons. As a result, they have to come here and do them with B [robotics expert]. They trained in [top] programs that teach robotic surgery. And they suck now. I mean these guys can’t do it. They haven’t had any experience doing it. They watched it happen. Watching a movie doesn’t make you an actor, you know what I’m saying?

In addition, their [residents’] exposure to open surgery has been altered by the presence of robotic surgery. The younger guys become deficient because they watch a lot and do nothing on the robot, and they’re becoming deficient in open because most surgery’s going robotic and less and less is open. So that’s shit and bad luck. I mean you stink in robotic and you now you’re stinking in open because you’re not doing enough. - Chair, Urology

Residents were aware of this problem, but had very little influence on the structure of their residency – they were focused on fulfilling its requirements so that they could move on to professional practice:

Sometimes the attending’s don’t feel comfortable doing that given the fact that they cannot interact with you directly or cannot show you or also intervene if it’s indicated. So that’s the thing that limits your education in terms of case numbers and time on the robot.

[Interviewer: What do you do to compensate for that?]

(silent blank stare at interviewer) What choices do I have? I have no choices. - Resident

Further, the deep differences between robotic and open surgery made it very difficult to fulfill the requirement to reach competence in both. Surgeons specialized in one of the other and then ended up performing procedures in that modality almost exclusively. They could not, in good conscience, select a modality in which they had not specialized, even if that approach were indicated for a patient. APs and
department chairs were also often aware of this problem, but the liability and efficacy concerns outlined above presented a strong barrier to change:

We’re trying to deal with this, it’s not like we don’t understand it. But how as a department chair do you go to R and P [top surgeons] and say “Hey, you guys are not teaching, you gotta let them do more surgery.” And they say “Well, what if they fuck up my patients? I can’t do that.” I don’t have the right then to say “You must do it.” Because they’re right too, because their nuts are in a noose, and they have a patient to worry about, and they got malpractice to worry about, and they have outcomes to worry about. – Chair, Urology

Residents thus faced a significant double-bind: they were obligated to visibly comply with legitimized “see one, do one, teach one” methods of peripheral participation to learn, yet standard robotic surgical practice and AP approaches to teaching during live procedures greatly delimited and reconfigured their access to the practice field. It was therefore extremely difficult to engage in legitimate peripheral participation in a way that led to sufficient robotic surgical skill. Given these barriers, a small minority of residents found a way to competence through a different and novel set of practices that stood in significant tension with the norms and policies of the surgical profession and hospitals.

Shadow Learning as a Critical Pathway to Robotic Surgical Skill

We have a fourth year resident here now who happened to do research time in a robotics lab before she started residency, so she’s like way on this side of the curve. I can already tell, she’s great, she’s better than most chiefs, so but she spent significant amount of her life, like one to two years, in the robot lab at [hospital X] doing research, so it’s like cheating, you know? - Senior Robotic Surgeon

Just as they demonstrated effort in legitimized (yet ineffective) learning modalities, the relatively small proportion of medical residents who were exceptionally successful in acquiring robotic surgical skill found alternative ways forward via shadow learning. Three specific, interdependent practices constituted shadow learning in my study: premature specialization, abstract rehearsal and undersupervised struggle. This learning process differed from legitimate peripheral participation in four key ways: its constituent practices ran counter to norms and policy, and these were enacted extensively, opportunistically and in relative isolation.

Shadow Learning: Premature Specialization

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In the United States, almost all residents ultimately went on to jobs that required them to perform a wide variety of surgical and nonsurgical work in their discipline, so everyone insisted on an early generalist education. The right and proper time for prolonged and intensive exposure to any specialized surgical technique was therefore late in surgical residency. By contrast, trainees who acquired notable robotic surgical skill began specializing in this technique years before they arrived at their residency:

The very first time I was on the robot – the University of X had a robot, and a guy who was a robotic surgeon was one of my [medical school] research mentors, and when they were done with the case, he would let me move around the robot arms around inside [the patient], move the camera and clutch pedal and different things like that, I wouldn’t really pull or push on any of the tissues at all, or cut anything, but I got at least a little bit of the muscle memory involved. [Also] they would use children’s toys, so you would play the game operation with the robot in your offtime. So even when I started as an intern, it wasn’t like I was sitting down at it for the first time. – Resident

This quotation outlines three key – and often overlapping – practices for premature specialization: participating in related research, receiving specialist mentorship and participating in the work itself. Medical students typically spent between six months to a year learning and applying research methods in a standing project via a research assistantship. When focused on operative technologies such as the daVinci, such projects required medical students to develop deep familiarity with such technologies, including how they were operated, users’ opinions about them, related outcomes research, and differences in the profession as to how to use them to achieve key outcomes. Successful learners cited this kind of premature, intensive exposure to robotic surgery as crucial to their learning.

Second, successful learners specialized prematurely by matching with a mentor focused on Urologic robotic surgery. While successful residents all reported such matching, this was not typical: medical students tended to find mentors who work in areas of interest (e.g., Urology), but by design they were not yet focused enough to find mentors focused on a particular subspecialty (e.g., Urologic oncology), let alone a method for performing related procedures. Finally, as evidenced by the quotation above, premature specialization involved extensive direct observation of robotic surgical work, often including use of the da Vinci system itself during live procedures and/or in simulated exercises. This extremely
early access to robotic surgical work was typically granted through participation in related research or by a specialist mentor.

These practices violated norms and policy on two fronts. Residency and medical school – and to a certain degree undergraduate education – were zero-sum games in terms of the time available for learning. So, the amount of focus outlined above came at the expense of generalist learning, personal life, or both. Generalist learning was a more likely target for this subtraction, given recent restrictions on residents’ working hours. Second, given the premium put on a generalist education, many presumed that students were not far enough along in their education to extract meaningful skill from premature specialization in robotic surgery, let alone participate in a way that was safe and helpful. According to this logic, successful learners of robotic surgical technique begin “seeing one” (and sometimes “doing one”) years before they should have, wasting resources and slowing their progress.

**Shadow Learning: Abstract Rehearsal**

Abstract rehearsal was the second practice that allowed residents to learn robotic surgery. This was comprised of three activities: practicing basic skills in rudimentary computerized simulation, analyzing recorded procedures for general familiarity, and analyzing challenging segments of recordings just before related work. The first of these – practicing via simulation – was particularly crucial:

The difference [between me and all the other residents] is that I used that simulator pack every day for a while before I actually started operating that much, and that should be required for everyone honestly, because it made my transition a lot easier. Most everyone is learning what they’re learning in the OR, during live procedures. – Resident

Successful learners used available simulator technology extensively for gaining basic familiarity with the new, disembodied control modality presented by the da Vinci system. Until exposed to the da Vinci, residents had learned to use their bodies to control precise professional activity directly. A move of the finger corresponded immediately and directly to a move of the finger in their work, directly generating change in the world with direct tactile and visual feedback. Not so with the da Vinci. Before they could operate on a patient, trainees had to master a new bodily grammar for their professional work:
You hand a kid that plays Xbox all the time any game, he’s come to be good at it because he doesn’t have to think about where the buttons are. Then he figures out how to be good at a game not how to operate the controller. And that’s what it is with the da Vinci too. Once you know how to operate the controller, that becomes mindless and then it’s the surgery which is like any other surgery. - Resident

Most programs required residents to practice on the simulator, but these requirements were scant (two to four hours per year was common) and only occasionally performance based. This was grossly insufficient for fluency with robotic grammar. Those who were successful often invested many tens and sometimes over a hundred hours of discretionary time on the simulator early in their residencies, and this gave them the basic fluency required to earn console time:

I specifically said [to a new resident] “You have to use the simulator. You must use it. When you get on, you want to be there because otherwise they’re [the AP] going to pass you up.” So, if you’ve had hours in the simulator, you’re going to look like you know what you’re doing, and they’ll let you do more. Well I let her get on one, one of these cases, and she looked like she knew what she was doing, and the attending let her go, and she did well. - Resident

While most residents had to use OR console time to simultaneously work on basic robotic fluency and the sequence of activities associated with a procedure, successful learners could devote much more of their attention to higher-order activities such as transitioning from one portion of a procedure to another, asking the AP questions or directing bedside assistants. It was impossible to undertake such activities without a strong command of robotic control grammar, and they were therefore particularly valuable for earning extended console time: making transitions and asking good questions provided insight that facilitated next steps and impressed APs, and a well-guided bedside assistant provided good exposure, making the resident’s work easier and therefore also more impressive to an AP.

Beyond practice via simulators, successful residents analyzed video of previous procedures. In the beginning of their learning, they scrutinized these extensively to get a holistic sense of a given procedure:

You can watch videos on YouTube. The guys that operated there had a video, so I watched that video, I probably watched it, I don’t know, 200 times for an hour-long video. A lot, a lot, a lot of hours watching it. It lets you see his moves and where his hands were going, and how he did things, how he was retracting things. - Resident

This practice ultimately hit limits – recordings were often made public because they were pristine, best-in-class work that involved relatively little uncertainty or struggle. As their skill and need for
nuanced insight deepened, successful learners focused their analysis on portions of a procedure that they wanted to improve on, and did so to prepare for an upcoming procedure:

I think there’s good value in watching other people do surgeries online, and even watching it before you do a procedure, kind of like doing a pregame kind of thing. - Resident

In contrast to those who successfully acquired substantial robotic skill, most residents indicated that simulation and online video were neither a useful nor appropriate means of preparing for real surgical work, as they were too abstracted from the actual work:

They would like us to have more familiarity with the robot, with all this simulated time and time outside the operating room, and there are these, I don’t know if they’re... they’re exercises, they’re not operative simulations. They’re kind of silly. And I don’t think they translate as well as the senior guys think they would. - Resident

People sort of downplay it [simulator experience], like “you have to do it on a live patient!” - Resident

APs had mixed but generally negative views on simulation and video analysis. On the one hand, these are the individuals who built in the requirements mentioned above – so on some level they were committed to the idea that simulation could aid in the acquisition of foundational skill. On the other, APs indicated that “real” learning occurred in the OR, and that any hopes of acquiring substantial skill via simulation were doomed to failure because they weren’t close enough to reality:

There is a simulator that allows for guided surgery in reverse. An expert case, a prostatectomy, goes through the whole thing, fingers, and feet. I think it’s bullshit. I think I could have my kid do that, and I’m not sure how many neurons would be developed. Every case is different. It’s impossible – very difficult to program all the different layers to make it realistic, so many layers, so many chances for bleeding, injury. – AP

Interestingly, APs reported watching videos in the 1990s – recorded at great expense and only available via DVD and VHS – extensively as they navigated the transition from strictly open surgical technique to laparoscopic technique:

I’ve got bins, look at this [gets box]. VHS tapes! I can’t even play them anymore if I wanted to. How many times did I watch them? They’re like treasures to me now. - AP

Beyond the negative normative tinge to learning through simulation and video, residents’ daily responsibilities and the DaVinci technology were configured in ways that made practice on simulators and watching videos impractical:

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I don’t think anyone uses the simulator – we have simulator packs on all of these robots, and I don’t think a lot of people use them. Even though we were supposed to. It’s just crazy that they have these 65-thousand-dollar simulator packs, like the one here, I tried to get on it, and no one knows the password. [Also,] they’re in the OR, so the OR has to be open to use them [i.e. at night]. They do have that sim center [a quarter mile from residents’ normal work area], but I don’t ever really go back there. – Resident

As this resident describes, most simulator practice required access to an empty OR, a da Vinci console that was plugged in and a “simulator pack”: a high-end computer with simulation software, attached to the back of the console. Generally, ORs were only empty in the evenings, so simulation time required residents to stay after hours or take time away from “above and beyond” duty on night rounds (e.g., checking on patients at the bedside). Alternatively, some elite institutions had simulation centers to allow for a variety of kinds of practice. These sometimes included a separate training console with simulation capabilities. These were often physically remote, however, and gaining access required jumping through a number of administrative hurdles. In most cases residents did not rely on such centers any more than they had to in order to fulfill (minimal) mandates for simulation practice.

**Shadow Learning: Undersupervised Struggle**

Through premature specialization and abstract rehearsal, successful residents gained the skill required to get access to a third shadow learning practice: struggling near the edge of their capacity with limited supervision by expert APs. As evidenced above, helicopter teaching was one of the main – if not the main – barriers to legitimate peripheral participation as a means to develop robotic skill. Though no resident reported deliberately attempting to dodge such “help” in their surgical work, the most successful amongst them indicated that they performed robotic surgical work with limited supervision from expert APs for lengthy periods. Ironically, while expert APs were the very perpetrators of helicopter teaching, they also cited undersupervised struggle as crucial to their skill development:

P (resident, sitting next to console): I don’t think I could see this (tissue plane), you could show me this ten times...
R (head in console, operating): some of it was when I was learning this and I struggled, and I tell you my solutions... When I was a fellow, they were doing their cases in Mexico, they asked for someone, everyone said no, and they ended up with me. They said can you go to Mexico

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and I said sure (stops operating, removes head from console, turns to resident). Did I tell you this?
P: No.
R: There were 3 [senior Mexican] surgeons doing 13 surgeries in 8 days, so I was there in the OR teaching these surgeons and a couple things made it hard. When we ran out of instruments, that was it. And I tried the American thing where you complain and you get what you want, and they were like “no no no,” so we were having to manually override the system so we could use expired instruments, we didn’t have rv sutures and we had to use sh needles… Out of that week and out of necessity I had to get people out of cutting the prostate in half, cutting the gastric, all but the most major snafus, upper gastric injury, it was a crash course of how to get people out of trouble, and so for each step I had to take them out of the console and walk them through it verbally, it was like the wild west, so that week I learned so much.
P: I can imagine.
-Field Notes, 06.03.2015, 12:55 PM

Successful residents engaged in undersupervised struggle in three ways: working for superstars, working with lower-skill experts, and working at institutions with less cost strain. In each case, successful residents did far more surgical work near the edge of their capability with little supervision than other residents. This forced them to independently recover from non-catastrophic errors far more frequently than those who did not engage in undersupervised struggle, driving them harder to practice for each procedure. Both of these activities had significant positive implications for their robotic surgical skill.

**Undersupervised Struggle: Working for Superstars**

Some successful residents worked for one of a very few superstar robotic APs (not the more numerous “excellent” APs). As with superstars in other professions, these APs were responsible for wildly disproportionate number of procedures per year in comparison to most other APs. A typical high-quality prostatectomy took 3.5-4 hours, for example, allowing merely “excellent” institutions to perform, at most, three prostatectomies in two shifts. Superstar robotic surgeons completed between six and seven such operations in the same timeframe. They achieved such volumes by running multiple concurrent surgeries, relying on residents to perform and supervise the bulk of each procedure. Residents so unusually entrusted with life-and-death responsibilities reaped significant dividends in terms of learning:

You would do simple parts of the procedure first. Our goal was to do that portion of the procedure independent – meaning no one else was in the room, you start the case, you dock the robot, and you get to that point then you call the boss [AP], and the boss finishes it off. 4th year
we did more. Chief year, pretty much do the whole thing, the boss would maybe come in and
look at it. A lot of it was autonomous. And we were very good about not going rogue and all
that stuff. And whenever you got stuck, the boss would come in and show you how to get out of
it, or you’d call an upper-level resident and they’d show you how to get out of it. So it was more
a directed apprenticeship model with independent time to kind of figure things out, you know?
There’s no one telling you where to cut. You’ve got to manage bleeding on your own, and you
figure it out. By the end of it you’re doing it all yourself. We had high volume and that’s what
really helped you out. - Resident

It is key to note that this resident’s experience was typical at his institution. At institutions with
merely “excellent” robotic APs, such autonomy was never granted intentionally, and would be impossible
to achieve accidentally, as each AP was responsible for the entirely of each procedure. Superstar APs
simply did not engage in helicopter teaching with much frequency. To the contrary, direct AP supervision
of resident surgical work was minimized to allow for high throughput. This dramatic difference in
undersupervised struggle during surgical work greatly accelerated residents’ robotic surgical skill.

Beyond the structural implications of residency in superstar-led robotic surgical programs, this
quotation encapsulates several important aspects of unsupervised struggle. First, many of my informants
indicated unease with the practice, and nearly all acknowledged that it broke policies for AP supervision
during surgical work. Speech dysfluencies were most common during these portions of my interviews.
Second, this was not unsupervised struggle: expert help and accountability were never far away, and
residents sought them when they got into surgical trouble. Third and nevertheless, actual struggle was
intense: residents bore life-and-death responsibility for their patients during these periods of work:

Having nobody in the room and you’re in the hot seat, I mean I’ve had times where you’re
sweating, you’re leaning on the console, the boss [AP] comes in after you and is like “Whoa,
whoa, whoa, you’ve been nervous here on that bleeder, huh?” And I was like “Yeah but how’d
you tell?”, and he’s like “’Cause this is all sweaty.” I think, having some time to flounder a bit
and get yourself out of it in a safe manner, I think that that helped me out a lot. That’s how you
learn stuff, really. Versus having someone show you, you don’t even realize that you don’t get
to do it, you know? – Resident

Given that they were working near the edge of their capacity, patient anatomy and next steps were
somewhat ambiguous to these residents, and they had imperfect embodied capacity to execute next moves
safely and elegantly. They were rarely relaxed and jocular while operating, as APs sometimes were; more
often than not they were tense, focused and reasonably silent.

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Most of the successful residents in my study secured residencies at top-tier institutions with merely “expert” AP robotic surgeons, and so found undersupervised practice opportunity by collaborating with APs at their institution with less-than-expert level skill in robotic surgical methods. These APs were less able to detect quality deviations in residents’ surgical work, and were aware that these residents were being trained by true experts. They were therefore far less likely to engage in helicopter teaching:

What has really influenced my training is by having other attendings within our own institution that are not as experienced or proficient as he [X, true expert AP] is. The attending that’s on that service I think probably feels that I do the case as well as he can so he’ll allow me to do much, much more and he’ll actually defer to me a lot of times, and say “Well oh what does X do, what do you want to do?” And I can do it, and he allows me to do a lot more of the case, and that builds a lot of confidence and experience in a way that I would never do operating solely with X. - Resident

It was relatively rare for residents to find such a gap in AP robotic expertise within their own department. Rather they found APs with less robotic expertise as they rotated through other departments during their first, second and third years of residency. Because Urology had a nearly ten-year robotic head start on every other surgical discipline, APs in these other departments almost always were relatively new to the system, and therefore allowed Urological residents to operate early and often:

I had even been on the console multiple times before with Colorectal, when I was an intern. P [new Colorectal robotic surgeon] had just started and was just doing his first robotic cases, and I was on his service at that time, so I ended up bedside assisting for him on multiple cases. And while I was there, I asked him [for console time], and at that point I had just used the simulator. And he let me do some steps, and it went well, so in future times he let me do it as well.  
- Resident

As in the two quotations above, successful residents indicated that such rotations went beyond the absence of helicopter teaching. APs on these services realized that they themselves were learning and could stand to gain something from residents who had more direct contact with expert APs and who demonstrated solid basic robotic capability.

Undersupervised Struggle: Working at Institutions with Less Cost Strain
Successful residents also got ahead by working at institutions with lower cost strain. Top-tier surgical training programs required residents to spend a number of months in their fourth, fifth and sometimes sixth years at nearby institutions with lower cost pressures and/or quality standards. These rotations allowed residents demonstrating aptitude and interest to perform robotic surgical work with far less supervision than for extensive practice for those demonstrating aptitude and interest.

I think especially the [X hospital] rotation, they get a little more hands-on experience, I think unfortunately – not unfortunately – fortunately for them, but maybe unfortunately for the patient, because the competency level of the attending’s not very good. - AP

As in non-Urological departments within residents’ home institutions, APs in these institutions were less skilled with the da Vinci system, and knew these residents were being trained by APs who were far more capable and productive than they were. When successful residents demonstrated significant basic capabilities garnered from premature specialization, abstract rehearsal and prior undersupervised struggle, these APs granted these residents significant autonomy. Successful residents therefore got extensive undersupervised time to build their robotic surgical skill near the edge of their capabilities:

Then I went to [hospital new to the robot] and got a lot of experience on the robot and I think it was there where I think my learning curve, I think it was there where it kind of like clicked, and I stopped having to think about what am I doing with my hands and clutching and moving the camera and stuff like that and I started thinking about the surgery. So then I got a lot more exposure, and then coming back and in my chief year, so I did a lot. – Resident

These institutions experienced less cost pressure than elite institutions. This meant less urgency to perform procedures quickly, and in turn greater willingness to allow (slower) residents to practice during surgery. Beyond this, such hospitals and their patients imposed less pressure with respect to liability, commitment to top quality and requirements for AP involvement in procedures, and these aspects of such institutions also increased the opportunity for residents to engage in undersupervised struggle:

There’s just an understanding for the attendings that these aren’t their private patients who have sought them out. It’s just kind of a tradition for residents to do a lot more there, without much supervision. Also, at a lot of [elite] hospitals the attending is required to be in the room the entire time, whereas at [non-elite institutions] the attendings don’t have to be physically in the operating room. I think [non-elite] surgeons in general, if they’re there, they’ll do something, but if they’re not there, they’ll trust the resident to proceed safely. – Resident
This reduction in supervision and increase in proactive extension of autonomy allowed skilled
residents to “teach one” to junior residents as well:

The first time I did that case at [a non-elite institution], I did the whole thing, and the attending
was obviously there, and the case went beautifully, you know, every now and then it goes like
butter, and the whole case took three hours, it was very nice, beautiful dissection, and he was
like “okay, I trust you.” He saw I could do it, I didn’t need more practice taking the bladder
down, so he was okay with me delegating that part of the case [to the junior resident]. –
Resident

When junior residents were present and APs were not, senior residents taught the junior residents
almost by necessity – they needed these junior residents’ help at the bedside. While this occurred
regularly during the beginning and ends of open procedures, when APs were present such resident-to-
resident teaching essentially ceased. Robotic surgical work at non-elite institutions allowed residents to
perpetuate this practice. Teaching while operating was no simple task – this required the presence of mind
to note when a junior resident might get involved, performing the surgery in a slightly exaggerated way to
make certain points clear, and leaving the surgical field in abnormally pristine and obvious condition for a
junior resident as they sat at the console. So, this teaching burden added a new layer of undersupervised
struggle both for the senior and junior resident, offering important skill development possibilities.

**Unintended Consequences of Shadow Learning for Surgeons and Surgery**

Engaging extensively in shadow learning led to one clear consequence for robotic surgical trainees:
they got unusually quick and deep access to risky work, and became unusually skilled. These residents
therefore “succeeded” in that they were ready by the end of their residency to competently and
confidently perform robotic surgical work on their own. Beyond this, the routine enactment of shadow
learning also led to three outcomes that were quite problematic for residents’ cohort and their profession.

**Limited Professional Learning**

Shadow learning was characterized by a culture of silence and plausible deniability, and this
limited the profession’s ability to incorporate related practices into approved learning methods. On the
one hand, shadow learning saw no negative attention. Despite the fact that engaging in related practices
clearly bent norms and violated policy, I have no data that shows residents facing consequences for engaging in them, and I have no data that shows any AP (or other authority figure) enacting policy to explicitly prohibit them. Yet on the other, shadow learning garnered very little positive attention: beyond APs occasionally making passing reference to somewhat analogous practices as instrumental to their learning, I have no data showing residents or APs sharing knowledge of these practices or suggesting them to each other, let alone indicating that they had personally relied on them. This was part of what allowed it to function – if everyone engaged in it, this star-pupil-take-all learning pathway would likely break down. But a lack of broader, more public discourse on the failures of legitimate peripheral participation and the effectiveness of shadow learning for robotic surgical technique essentially prevented the profession from adjusting work practice and educational processes to keep pace with technological change to methods.

**Matthew Effect for Skill**

All residents in my study were required to participate extensively in open procedures, and APs routinely and fluidly granted them access to increasingly complex and risky opportunities to practice and meaningfully advance each procedure. Situated practice therefore had to be meaningfully granted in advance of the skill required to execute the work skillfully. The opposite was true with respect to robotic surgery: APs had no drive to involve residents in this work other than to give them an opportunity to practice, and the only way that residents gained meaningful access to such situated robotic practice was to demonstrate the skill required to execute the work without much coaching or intervention. If they did not do so – within moments of sitting down at the console – they were promptly publicly censured and/or ejected:

So all right now it’s time for the DVT (dorsal vein) stitch, go, do it. He steps off, you’re on, then you run that play well and then you get to take the next snap [referencing American football]. That’s how you get the maximum amount of time out of the console. Because it’s limited, you know? We’re only doing two or three cases a day, you know a couple times a week over those four months that’s really not that much when you think about it. So if you screw up early on and you get kicked off the console, that’s it. - Resident
Those who engaged in shadow learning gained exclusive access to extensive collocated practice alongside an expert. This dynamic led to a self-reinforcing cycle in which those who extensively engaged in shadow learning gained discrete, increasing and disproportionate access to the best learning opportunities while the opposite was true for “average” learners:

Yeah, our system [gives] high performers get more opportunities to do more, and by that become better, whereas the people who underperform probably get fewer opportunities, less time on the console, and they are sort of stuck in that rut. - AP

Thus, as shadow learning became increasingly crucial to developing adequate robotic skill, the gap between credentials and actual skill widened for most trainees, as they could not participate sufficiently in the work.

**Hyperspecialization**

In the states, [superstar robotics hospital] is a boutique situation – you have a five-star hotel for robotic prostatectomies, run like a factory, with extra doctors just standing around because [head surgeon] wants to show he’s the king, and you get a silk robe as a patient, and the rest of the disciplines are like hostels. Hyperspecialized, that’s what people want in the States, not like that in Europe, you have to be able to do a bit of everything. But people here want to know “how many of these have you done”? – AP, former resident and fellow at this institution

There are at least six and perhaps as many as 15 superstar robotic Urologic surgeons on the planet. Beyond these slots, every surgical resident, no matter how specialized in robotic surgical technique, lands in a job that requires a diverse Urologic surgical skill set. After graduating, most successful residents will find themselves doing procedures such as open partial nephrectomies, TURBTs, laser lithotripsy and vasectomies, all of which require significant nonrobotic skill. Yet residents who engaged in shadow learning for robotic skills – premature specialization, abstract rehearsal and undersupervised struggle – ended up sacrificing opportunities to broaden their skill set to match their desired future jobs:

When I did my rotation through the clinic, you can choose the cases you do, so I just decided that since this is basically the mecca of robotic prostates, I was just going to do as many robotic prostates as I could and really didn’t see a lot else. – Resident

Beyond this generalist-hyperspecialist mismatch problem, residents know on some level that they are playing a winner-take-all game with respect to skill – the returns to superstar-level capability are wildly disproportionate to those at the merely top-tier level. In response, many of the successful residents in this
study indicated that they felt they needed a fellowship – one or two more years of training beyond their residency – in order to enter professional practice.

And that’s why most people, if you really want to do robots in your practice, you’re really forced to do a fellowship for a year or two. I’m going to do it [robotic cases] probably but I’m not going to do complex cases because I really don’t have the experience. - Resident

Finally, successful residents face strong pressures to perform robotic surgery on their patients, even when it is unclear whether robotic surgery is the best course of treatment. Patients demand the robot because it is novel and “high tech” and hospitals demand that the robots get used to garner a reasonable return on their multi-million-dollar investment. These pressures and residents’ success through shadow learning therefore contribute to the ongoing and highly controversial trend of performing robotic surgery on patients where there is no strong evidence that robotic surgery is superior to open surgery (Breeden, 2013; Liu et al., 2013). Additionally, this hyperspecialization and the Matthew effect cited above exert downward pressure on the already dwindling supply of skilled Urologic robotic surgeons, just as demand for the technique is increasing (Dill and Salsberg, 2008; Decker et al., 2013; Fang et al., 2016).

Discussion

To date, learning has been theorized as occurring through legitimate peripheral participation (Lave and Wenger, 1991), a process involving increasing participation in experts’ work through a legitimized role. In the open surgery I observed, trainee learning proceeded according to current theory. Doing robotic surgery presented a different set of conditions: perceiving trainee mistakes was easy, managing the risk of trainee participation was hard, participation was unnecessary, and barriers to delegating work to trainees were high. I found that, under these conditions, shadow learning was necessary for trainees to come to competence. Table 4 shows work characteristics conducive to legitimate peripheral participation versus shadow learning. Table 5 shows differences between the ways these processes were enacted in the hospitals I studied.

---INSERT TABLES 4 AND 5 ABOUT HERE---
Shadow Learning

The literature on legitimate peripheral participation demonstrates that it functions through three key practices: granting individuals access to the work via a legitimized role (e.g., trainee, apprentice), relying on their help in ways that slightly exceed their current capabilities, and moving them ever-closer to the parts of the work requiring peak expertise. In robotic surgery, trainee mistakes were magnified and made public, remediating trainee mistakes was very difficult, the work could proceed entirely without trainee help, and giving trainees control of the work was an all-or-nothing choice. So, while APs gave trainees legitimate access to the work site, APs greatly limited residents’ increasing participation in the work. And when APs did grant such access, they helicopter taught most residents, preventing significant learning opportunities. Legitimate peripheral participation thus broke down, leaving most residents certified to do life-critical robotic surgical work but with limited robotic skill. In addition, time sunk into failed attempts to learn robotic surgical work compromised many residents’ ability to learn open surgical technique through legitimate peripheral participation.

A small minority of residents in my study relied on shadow learning to build appropriate levels of skill. Figure 4 shows how shadow learning functioned in my setting, how it differed from legitimate peripheral participation, and with what consequences. Three interdependent norm- and policy-challenging practices constituted shadow learning in this setting: Premature Specialization, in which trainees traded early generalist education for building specialized robotic surgical capability, Abstract Rehearsal in which trainees practiced basic skills via rudimentary computerized simulation and repeated analysis of video recordings of surgical procedures, and Undersupervised Struggle, in which residents struggled near the edge of their capacity with limited supervision by expert APs. Only residents who engaged in all three of these practices extensively built notable robotic surgical capability. While effective for the residents who engaged in it, shadow learning produced four unintended consequences: limited professional learning because the culture of silence around shadow learning inhibited the profession from adapting its apprenticeship practices, a Matthew effect for skill in which shadow learners got rapid, unequal and
exclusive access to the work, hyperspecialization, in which most shadow learners were unprepared for the
generalist positions they would ultimately occupy, and limits to professional capacity because shadow
learning took longer and produced a smaller number of true experts.

---INSERT FIGURE FOUR ABOUT HERE---

Scholars who have studied learning in communities of practice have examined it in the light of day:
集体和连续序列的实践，涉及稳步增加和一定程度的风险
involvement of trainees in experts’ work, granted slightly in advance of requisite skill via a legitimized
role. It was only through comparative analysis of resident involvement in open and robotic surgical work
and sampling heavily on rare successes in robotic surgical training that I uncovered the practices through
which a few residents managed to achieve high levels of robotic surgical skill in spite of formidable
barriers to legitimate peripheral participation. What emerged was a picture of shadow learning as a norm-
and policy-challenging, isolated, opportunistic process that built requisite skill in advance of participation
in risky work. Relatedly, this study suggests that as work methods expand the deployment of expertise
and reduce trainee involvement, premature specialization and abstract rehearsal will play an increasingly
central role in trainees’ progression towards skill. In prior research, trainee learning hinged on legitimate
access. Once given the title “trainee,” “apprentice,” or “resident,” individuals could expect to participate
and learn, even though they weren’t quite ready to do so. In contrast, for the trainees in robotic surgery in
my setting, this legitimate access was necessary but not sufficient for successful skill development;
trainees essentially had to pre-specialize for years so they could show they didn’t need basic practice in-
situ. My findings further indicate that this may increasingly be the case as technology enables experts to
perform failure-intolerant work with less help from trainees; accountable experts will have strong
incentives to decrease trainee involvement, and a limited imperative to increase it. My findings direct us
to pay close attention to how work is actually performed (Barley and Kunda, 2001; Feldman and
Orlikowski, 2011) – and specifically to the ways in which trainees participate in the work – to ensure we
build learning theory that accounts for empirical reality.
Further, in an age where power-law type distributions of talent are increasingly evident (Rosen, 1981; J. Brown, 2011), this study raises important questions about the distribution of learning gains amongst a cohort of trainees. Prior studies have not focused on whether and how different trainees may learn at different rates, and the implications of an individual’s learning for that of their compatriots. This may well be because studies that draw on legitimate peripheral participation show or presume equifinality: once granted legitimate access, all trainees get equal opportunity to participate in the work, and for the work’s sake, experts must flex this opportunity in many ways to help all learners get what they need as they go. Additionally, trainees and experts share stories and experiences (Orr, 1996) and this communal tide raises all learners’ boats. My study offers a stark contrast – much of the successful residents’ shadow learning occurred years before they set foot in an OR during their residency, these advantageous practices were not discussed or formalized amongst their cohort, and as a result these successful learners were rapidly granted disproportionate access to work opportunities just as their peers were rapidly deprived of them.

Finally, this study shows that well intended experts may inhibit trainee learning through their attempts to facilitate it. Prior research shows experts and higher status individuals facilitating learning as they adopt participative and encouraging interaction styles, and shows that learning fails when experts fail to help appropriately (Edmondson, Bohmer, and Pisano, 2001; Bunderson and Reagans, 2011). By illuminating the dynamics of helicopter teaching, this study shows how higher status actors can do this to excess, and so block learning. This outcome is most likely to occur when – as was the case with robotic surgery – it is easy for experts to see trainee mistakes, difficult for experts to remediate them and easy for experts to take control of the work. In such cases, I show that lower status actors may need to engage in shadow learning to secure time away from experts who are compelled to “help” (Perlow and Weeks, 2002) with intensity and regularity.

Practical Implications
This study was limited to data derived through observation of open and robotic surgical performance at five hospitals in the northeastern US and to interview data collected from APs and residents at an additional thirteen—all within the 2013-2015 timeframe. While these conditions bound its contributions, several practical implications stand out.

First, this study raises important questions about the supply of skilled professionals as technologies make it possible for masters to perform work with less assistance. From a technical perspective, the dual console configuration of the DaVinci surgical robot allows two surgeons to simultaneously control different parts of the robotic apparatus. This kind of shared control allows for residents and APs to assume roles quite like those that they adopt in open procedures: the AP could make next moves apparent with one arm while the resident used the other two to do direct surgical work. Yet I never observed this, my informants said they never saw it, and sales representatives from Intuitive surgical told me that this practice is exceptionally rare. This turn towards expert control at the expense of trainee involvement offers strong evidence that efficiency and liability pressures may win the day at the expense of maintaining legitimate peripheral participation in skilled work. This and related dynamics outlined in this paper may contribute to shifting the talent distribution away from a normal-type distribution towards one that more resembles a power-law type distribution. On the other hand, as in aviation, abstract rehearsal may become an increasingly-accepted mode of acquiring basic competence with technologies involving the translation of embodied movement for control purposes, allowing a wider range of trainees to more than make up for lost time learning on the job, expanding and enriching the talent pool. Such questions clearly warrant subsequent study.

Second, this study raises important questions about the costs and benefits associated with superstar-type markets for talent, especially as shadow learning becomes more salient. On the one hand, those residents who made exceptional progress through shadow learning did so to some degree at the expense of their fellow “average” students’ learning and on the backs of patients, experts and institutions who could least afford to insist on higher quality standards. Injuries, death and lawsuits may be more common.
in such circumstances, and those patients and institutions who can pay the most may face these risks far less frequently. Such dynamics raise serious questions of equity, especially in a profession so committed to health for all who are in need. On the other hand, it was also clear that residents who succeeded through shadow learning may have minimized risk to patients in situations where the AP had less robotic skill than they did. Thus, shadow learning may actually ensure quality for the patients and institutions who could least afford to insist on it. These compelling questions should be addressed in subsequent study.

Finally, in a world of work characterized by technologies that allow experts to work with less trainee help, shadow learning may play an increasingly central role in trainees’ progression to skill. This would have far-reaching implications. If lawyers, electricians, pilots, accountants, filmmakers, clergy and police officers in training need to engage in increasingly premature specialization, abstract rehearsal and undersupervised struggle, successful members of these professions may increasingly treat rules and norms as optional reading, learning as an opportunistic, isolated experience directed by the trainee, cohort members as competing against each other, and access to the work as a privilege granted to a small trainee minority. These and other professions have heretofore built knowledge, added value and extended jurisdiction through roughly the opposite orientation. Consequences for skilled labor may mirror those outlined in this study – a small and shrinking hyperspecialized minority that cannot possibly serve the needs of a broader population, a majority that is losing the skill to do the work effectively, and communities of practice that don’t know what they don’t know about how learning is actually occurring on the ground.
Chapter 4: Coping with Degraded Technology: Coordination Tension and Compensatory Work in Robotic Surgery

Abstract

Using technology means degrading it. This leaves us with the frustrating task of coordinating through technology that is unreliable and difficult to use. How do we do this? I explore this question via qualitative and quantitative longitudinal comparison of robotic surgeries performed via two surgical robots at a teaching hospital. One robot was a newer, well-resourced model, the other was an older, under-resourced model of the same system. Coordination with the former was relatively untroubled, and could reasonably be explained via the current literature. This was not the case with the degraded model: its material arrangements deeply challenged valued methods, moods and goals for the work, producing a practical-affective stress I call “coordination tension.” To cope and keep work coordinated, workers engaged in a set of activities that I call “compensatory work.” Ironically, these added to coordination tension, just as they mitigated it, though statistical analysis of outcomes data shows that patients did just as well with the degraded system. I account for these results by showing how compensatory work swaps tension for risk, concentrates relevant expertise, and disperses tension in space and time. In contrast to prior theories of coordination that do not integrate affect, I account for coordination by adopting a lens that treats work methods, moods and goals as co-constitutive in practice – and as reciprocally-interdependent with the material arrangements through which that work is performed.
Introduction

P (surgeon): Why do you think that’s happening, N? (said as scrub withdraws partially fogged binocular camera from the patient for a third cleaning)

N (scrub): Cause this robot sucks.

P laughs, resumes suturing kidney to ureter when camera is reinserted

(The same eye of the camera fogs again within two minutes)

P (stops operating, takes head out of control console, squeezes forehead with one hand, closes his eyes and leans forward): Clean the camera again (to all). Fuck (slowly, under his breath).

– Field Notes, 1:14 PM, 7/01/2015

Skilled workers are often stuck coordinating through degraded technology. After an initial investment to integrate increasingly complex technology into practices that are core to the firm, organizations often minimize support and maintenance in order to extract a satisfactory return (Orr, 1996; Barley, 1996). Additionally, as economic disparities increase, the resources to upgrade technology are becoming increasingly scarce in many parts of the global economy. These forces align to keep technologies in service just as lack of attention makes them increasingly unreliable and difficult to use. Skilled workers therefore routinely have to contend with degraded technology for extended periods – often with the growing realization that better technologies and technological support are available. This challenge increases to the extent that the work at hand is tightly coordinated and methods and outcomes matter to workers. Insofar as the cost of switching technologies and related work practices is high and resources are limited, skilled workers will find themselves stuck with degraded technology that makes coordinating quality work a particularly difficult, charged affair.

So what do workers do? This is unclear, as degraded technology does not figure in studies of coordination. Such studies have examined the ways in which workers rely on information technologies (Hinds and Mortensen, 2005), boundary objects (Carlile, 2004; Bailey, Leonardi, and Barley, 2012) and common spaces (Bechky, 2003; Kellogg, Orlikowski, and Yates, 2006) to bridge coordination boundaries such as geographic dispersion (Hinds and Kiesler, 2002; Hinds and Bailey, 2003) and differences in occupation, roles and status (Faraj and Xiao, 2006; DiBenigno and Kellogg, 2014). Although they offer a range of findings with respect to technology’s implications for coordination, these studies are alike in that
they focus on how new interaction possibilities arise in work involving fully-functional technologies. This is somewhat surprising as these studies also show that satisfactory explanations require rich data on materiality — configurations of physical spaces, objects, and technologies have a great deal to do with how coordination is achieved (Okhuysen and Bechky, 2009; Beane and Orlikowski, 2015). We are therefore left with limited insight into coordination when technology is degraded. My study inquires directly here, asking how workers coordinate routine work through degraded technology — and with what consequences.

Despite the fact that many studies of technology and organizing show stressful misunderstandings, conflict and failure (Gouldner, 1954; Orr, 1996; Barley, 2015), such studies have not explicitly theorized affect. Studying coordination via degraded technology offers an excellent opportunity to do so, and would capitalize on a broad research tradition that accounts for the added, often unnoticed affective work done to find productive ways forward in contexts that provoke emotional responses (B. E. Ashforth and Humphrey, 1995; Hochschild, 2003). These studies show how workers moderate their emotional displays to fit with organizational norms and to produce desired outcomes (Blake E. Ashforth and Humphrey, 1993; Rafaeli, 2013), but do not focus on coordination. The coordination and affect in organizing literatures are well-matched, in that they find that contingent responses arise when abstract rules do not mesh well with the socially-embedded, uncertain working conditions that unfold on the ground (Hutchins, 1991; Weick, 1993; Barsade and Gibson, 2007).

Treating affect as integral to goal-directed work allowed me to explain safe and efficient surgery involving a degraded robot at my research site. Specifically, coordination tension and compensatory work emerged through my analysis of qualitative and quantitative data derived in my two-year ethnographic study of robotic surgical work at Fairtown, a top-tier teaching hospital. Coordination tension is the practical-affective stress experienced when valued methods, moods and goals become difficult to achieve in collaborative work, given local material arrangements. Such tension became evident as I compared the performance of surgical procedures involving an older, under-resourced surgical system — known locally

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*To retain confidentiality, the hospital name and additional identifying information have been changed.*
as “the shitty robot” – to those performed through a newer, well-resourced model of the same system. Doing surgery safely and efficiently with the degraded robot was very difficult, both practically and emotionally: it involved regular, significant trouble with setting up, breaking down, supplying, staffing and performing surgical work. To manage the resulting coordination tension and keep work on track, workers engaged extensively in a range of activities during each procedure that I refer to as 

compensatory work. While effective, this also created coordination tension as it required compromises to valued methods, moods and goals for surgical work. Coordination tension and compensatory work were evident with the newer robot but much less so as it was far easier to use and more reliable.

I explore coordination tension and compensatory work through a lens that treats valued work methods, moods and goals as co-constituted in practice and as reciprocally interdependent with the material arrangements for that work (Schatzki, 2002, 2010). Much research on collaborative work treats goal-directed behavior and affect as empirically and analytically separable. This paper challenges that view, holding that any given practice involves a valued set of intertwined methods, moods and goals, and this guides participants through uncertainty. Further, material realities mean there is always some tension between what is valued and what can be done. In particular, the lens I adopt holds that differing material arrangements – configurations of people, artifacts and natural objects that have local meaning – make fulfilling valued methods, moods and goals more or less difficult. I find that when certain material arrangements – such as a degraded surgical robot in a spare OR, far from needed supplies – make valued methods, moods and goals harder to achieve, a practical-affective tension arises that is stressful, interferes with coordination and motivates responses that allow coordinated work to continue.

Viewed one way, compensatory work was remarkably effective at Fairtown: coordination was relatively smooth throughout procedures involving the degraded robot, coordination tension was curbed and procedures on both robots were of comparable quality on traditional measures. Yet viewed another way, compensatory work was itself frustrating and difficult to implement, and led to problems such as handler’s traps - those who accumulated experience on the degraded robot received more assignments
with it and decreasing amounts of supplementary help. Compensatory work also led to *temporal shifting* of tension from particularly intense times and places in the work to times and places that would otherwise be relatively quiescent and energizing. Thus, compensatory work perpetuated coordination tension in the work, just as it addressed it. Through my analysis, I highlight the interdependence of valued work methods, moods and goals with material arrangements in coordination and detail the compensatory work performed to coordinate such work, particularly as technologies degrade.

**Research on Coping with Technological Constraint in Collaborative Work**

Despite its promise, we have long known that technology can get in the way of coordinated work (Taylor, 1911; Rice, 1953; Orlikowski, 1992). For example, work involving technology can impede the flow of important information (Berg, 1997a; Bailey, Leonardi, and Barley, 2012), impose disorienting role reconfigurations (Barley, 2015), introduce burdensome formalization (Berg, 1997b), decrease motivation and cohesion (Trist and Bamforth, 1951), slow adaptation (Tyre and Orlikowski, 1994), confuse users without advanced technical knowledge (Barley, 1996), and add counterproductive performance pressure (Nardi et al., 1995; Bernstein, 2012). Beyond this, complex technologies themselves often behave erratically (Barley, 1986), interface poorly with other technologies (Perrow, 1985; Kraut, Dumais, and Koch, 1989), and become harder to repair and supply as new versions arrive (Orr, 1996; Tucker, Heisler, and Janisse, 2014). Coordination studies show workers coping with these constraints by inventing new interaction possibilities, with the materiality of their work situation playing a crucial role in such invention.

Broadly, studies that show successful coordination in the face of technical constraint have focused on overcoming interpretation difficulties that arise from diverse information (Cramton, 2001; Kellogg, Orlikowski, and Yates, 2006; Espinosa et al., 2007; Cummings, Espinosa, and Pickering, 2009; O’Leary and Mortensen, 2010). In a study of a mandated reorganization within a FTSE 100 firm, Jarzabkowski et al. (2012) explore how Distribution and Wholesale groups invented new coordination mechanisms as legacy mechanisms had to be retired. Engineering appointment book software that gave Wholesale customer advisors preferred access to engineering help was taken offline, for example, and engineers
rejected requests driven through remaining paper records and telephony. In response, Distribution and Wholesale built new IT, external relationships and processes to allow internal and external customers the same, legitimized access to engineering help. Likewise, in their study of globally-distributed automotive design and test work, Bailey et. al. (2012) show engineers from globally-distributed functional groups relying on digital models and crash simulations to share information. These models and simulations often relied on incomplete designs with impossible “penetrations” (one part of a vehicle protruding through another) and given that only the test group had intimate knowledge of and access to actual vehicles, it was challenging for simulation modelers in India to choose which penetrations to correct. They often simply guessed conservatively, creating significant rework for their US counterparts.

As far back as Trist and Bamforth’s study of the longwall coal-mining method (1951), research has shown that physical realities of putting technology to use can constrain coordination effectiveness. For example in his study of naval navigation, Hutchins (1995) showed that as distributed workers collaborated to take bearings and set courses, communicating via telephone contributed to misunderstandings and errors, limiting coordination effectiveness. They resolved these issues through multiparty calls and relocating some workers to the bridge of the ship behind the map table, allowing for gesture, simpler language and joint, simultaneous visual reference to the map and the ocean. Recent scholarship on materiality has brought such issues into sharper theoretical focus (Leonardi, 2013; Orlikowski and Scott, 2014). Beane and Orlikowski’s (2015) study in an ICU compares robotic telepresence to the telephone, and shows that performing night rounds (remote checking on patients) with each technology enabled and constrained coordination in different ways. Residents brought inaccurate and incomplete patient information to night rounds discussions when they hadn’t prepared at the bedside, for example, but when using robotic telepresence, nurses and senior doctors compensated by communicating directly and examining the patient and medical monitors. Generally, the specific material enactments of the work led to key exclusions and inclusions – who could see what objects, who could see and hear who, who could take what actions – and these enabled and constrained coordination.
We know from our experience and data in these papers that coordinating work through technology is often frustrating. Yet studies of coordination involving technology have not theorized affect. Inspired by Hochschild’s seminal examination of flight attendants’ emotional labor to preserve the customer experience (1979, 2003), the literature on affect in organizations shows us that work is an emotional affair, and that emotions must be regulated in order to keep things moving smoothly (Gross, 1998; Barsade and Gibson, 2007; Gooty, Gavin, and Ashkanasy, 2009; Thompson and Willmott, 2016). For example, Bolton and Boyd (2003) find that flight crews engage in four kinds of emotion management in their work: “pecuniary” in which they modify their emotional displays to provide a positive experience for customers, “presentational,” in which they hewed to pan-organizational conventions of feeling such as using humor to manage boredom and to let off steam, “philanthropic” in which they gave positive displays of emotion as a gift, and “prescriptive” in which they followed professional feeling rules to gain status amongst their peers. Rafaeli and Sutton (1991) show that bill collectors and criminal interrogators could elicit compliance through strong emotional contrast – specifically through variations of the “good cop, bad cop” technique.

Whether enacted sequentially, simultaneously, through reference to hypothetical counterparts or by a single individual, producing these artificially-heightened, contrasting emotional displays increased compliance with desired behaviors, thus reinforcing key organizational outcomes. Affect clearly matters for organizing – and thus coordination.

So, treating affect as empirically and theoretically separable from coordination under technical constraint has limited potential insight. Practice theory, especially as recently conceived of by the philosopher Schatzki (2002, 2003, 2010) offers a way forward. Schatzki makes explicit what is often implied in much practice-theoretic work: that the preferred goals and methods of a practice are inseparable from concomitant preferred moods – goal-directed, skilled work is an affective process, through in and throughout. As he examines horse-breeding practices in rural Kentucky, Schatzki further suggests that such “teleoaffective structures” bear a strong, reciprocally-interdependent relation with the material arrangements amidst which work is performed: if the ranch pond is full, guiding a foal to drink from open
water is easy and relaxed – as the pond dries, guiding will become harder, open water harder to find and the mood poorer. Taking such a view is useful for studies of coordination, as it both retains a tight focus on the moment-by-moment performance of work practices (Barley and Kunda, 2001; Bechky, 2006) but also allows us to examine whether and how certain configurations of people, artifacts and natural objects can make work harder or easier, stressful or pleasurable and the like, with significant consequences for the way the work is done and related outcomes.

I build on Schatzki’s formulation through my comparative exploration of surgery involving both well-resourced and degraded robots, exploring how workers coordinate as material arrangements for the work make it difficult to fulfill valued methods, moods and goals. I specifically find that significant coordination tension arises when coordinating through a degraded surgical robot, and workers perform compensatory work to keep things on track. In some cases, this meant reconfiguring material arrangements, in others the work, and in yet others it meant reconfiguring compensatory work itself. Beyond directing attention to an underexplored and common organizational phenomenon – work involving degraded technology – this study contributes to the coordination literature by suggesting that affect and goal-oriented work constitute one another and that it is this “lived experience” of work that drives us to keep things on track.

Research Setting

This project involved a two-year ethnographic comparative study of Urologic surgical procedures performed through the daVinci surgical robot by interdependent surgical professionals at Fairtown, a mid-sized nonprofit teaching hospital. Fairtown included over 400 patient beds, 500 physicians and 4,000 nurses, technicians and support staff. Efficiency and quality pressures were high in robotic Urologic surgeries at Fairtown. All valued patient well-being and cost-efficiency in their surgical work (Bosk, 2003; Kellogg, 2010). They likewise understood that surgical patients tended to do better and Fairtown would gain financially when procedures did not run “long,” and that the price of failure was extreme:

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9 http://www.intuitivesurgical.com/products/davinci_surgical_system/davinci_surgical_system_si/
patients could see extended hospital stays, disease-recurrence, permanent impairment, or even death as a result, and ensuing treatment and legal costs could be great. Everyone involved in robotic Urologic surgeries engaged in careful preparation and skilled, coordinated adjustment to dynamic surgical conditions to avoid such outcomes; the threat of any of these outcomes caused significant stress.

The da Vinci surgical system consists of three basic components: a control console, a computing tower and what most refer to as “the robot”: a 1,000 pound, four-armed surgical device. Three arms on the robot hold interchangeable surgical instruments such as scissors or graspers, while one arm holds a stereoscopic camera. The console has foot pedals and two multi-jointed “masters” for hand control – smooth surgery requires coordinated, complex foot and hand movement. The tower both translates the surgeon’s manipulations of the console to the robot and transmits a 3-dimensional video signal from the robot to the binocular console display and 2-dimensional video from one of the camera’s “eyes” to screens around the OR.

Da Vinci surgical procedures were performed in two ORs at Fairtown; OR 4 and OR 15. These ORs measured approximately 30’ x 40’ and were equipped with movable, ceiling-mounted lights, equipment “booms” and monitors, a highly-adjustable surgical bed, a nurse’s desk with a networked pc, a mobile anesthesiologist’s cart, a glass-walled supply closet for frequently used items, a number of mobile chairs, trash bins, trays and tables, and three large, HD displays mounted on three different walls. These ORs contained an array of standard surgical devices such as a “bovie” (for electrocautery), an insufflator (for inflation of the abdomen), and suctioning system (for removal of bodily fluids), connected daily to each other and to the ceiling and walls with myriad hoses and cords. Much of this equipment was repeatedly moved from well before “wheels in” (when the patient was brought into the room) until well after “wheels out” (when the patient was moved to a recovery room). These ORs were spacious enough to allow for this reconfiguration, but cramped enough that hasty or ill-planned moves could create great inconvenience and stress.
Robotic surgical procedures were performed at Fairtown by members of five occupational groups: surgeons, anesthesiologists, nurses, medical residents and scrub technicians. Robotic surgeons were senior specialists in the treatment of Urological cancers (e.g., kidney, prostate), having performed each procedure many hundreds – often thousands – of times. Surgeons bore ultimate responsibility for the quality of each surgical procedure, and for developing residents’ surgical capacity in the process. Anesthesiologists managed patients’ consciousness, and only rarely had substantive interactions with other surgical staff during a procedure. Residents had recently received their medical degrees and were at least two years into their six years of specialized training as Urologic surgeons. After their second year at Fairtown, residents were dedicated to Urology, and spent much of their time assisting surgeons in their work. Nurses had specialized degrees, training and certifications, and were known as “circulators”, given that they worked outside the sterile field, moving around frequently and doing what was necessary to ensure the overall smooth flow and documentation of each procedure. Scrub technicians or “scrubs” established and worked in the sterile field, facilitated safe and efficient access to equipment and disposables and operated sterile equipment.

Performing Robotic Surgical Procedures at Fairtown

To begin a da Vinci procedure, the scrub and/or circulator prepared the OR, organized surgical supplies, and configured the robot. First, they configured movable equipment and checked the supplies in a mobile case cart delivered by central supply. After donning sterile garb (referred to as “scrubbing in”), the scrub then laid sterile supplies out on covered tables – this included things like sutures, sponges, syringes, scalpels, robotic instruments, gowns, masks, gloves and so on. The circulator and scrub then “counted”, running through a call-and-response check of all required supplies. The scrub and circulator then checked the da Vinci was positioned appropriately, the scrub draped each arm with disposable, sterile, transparent sleeves, then calibrated the camera’s color sensitivity and stereoscopic vision. Together, the scrub and nurse draped the camera and its cord, and laid this on a small table near the bedside. Ideally, a “third person” (a circulator designated to float between ORs) helped at key points.
during this process. Staff had approximately 45 minutes to perform this highly interdependent preparatory work for any given procedure.

After wheels in, an anesthesiologist asked the patient to slide off their gurney to the surgical bed and put them under general anesthesia. The surgeon and residents arrived, scrubbed in, and all positioned, immobilized and draped the patient, attached or “docked” the robot to the patient’s belly via trocars (hollow metal cylinders) inserted into keyhole incisions, and inflated the patient’s abdomen with CO2. The surgeon then “scrubbed out” to sit at the console 15 feet or so away, looking and operating inside the patient on a minute scale; their view was shown on many monitors in the OR. The scrub and one resident stood next to the patient, swapping robotic instruments as requested by the surgeon, adjusting the robot’s arms, cleaning the camera when it becomes dirty and reporting trouble to the surgeon. The circulator communicated with everyone, moved around the OR to secure and offered needed supplies and dealing with nonsterile equipment (e.g., lights) as necessary or requested. After the surgeon was done, the scrub and resident detached the robot from the patient, the circulator backed it away, and the surgeon, scrub and resident “closed,” which involved removing bagged tissues, suturing incisions, and removing drapes. Then the anesthesiologist roused the patient, all staff moved the patient to the bed they were wheeled in on, and the resident wheeled the patient out of the OR. The scrub and circulator undraped the robot, disposed of a variety of materials, and then left as the room was cleaned by support staff who arrived for that purpose. All of these tasks were highly interdependent in space and time, requiring an ongoing stream of observation, talk, gesturing and interactions with objects to keep the work flowing smoothly.

**The Difference between Robotic Surgery in OR 15 and OR 4**

In January of 2013, Fairtown’s OR operating committee purchased, and staff installed a da Vinci “Si” robotic surgical system. This system offered significant improvements on Fairtown’s “S” model. Amongst OR staff, the Si became known as the “new robot”, whereas the previously-prized, well-resourced S became the “shitty robot” (or rarely, in polite company, the “old” robot). As with many large prior technological investments in a variety of organizations, the OR committee elected to keep the older
model in order to extract greater returns. Staff diverted surgical cases to the new model whenever possible. The large majority of cases were soon performed through the new robot (see Table 1). It included a higher resolution camera, a more ergonomic and intuitive console, a second console that allowed for greatly expanded teaching, and a set of hardware and software capabilities that allowed for new surgical applications. The new robot’s camera, cables, console and tower were incompatible with the older model.

--- INSERT TABLE 1 ABOUT HERE ---

Just as the new system offered new capabilities, reduced maintenance of the older system progressively stripped it of capability: the lamp that illuminated the inside of the patient failed with increasing frequency, one of the two lenses in one of these cameras became incurably “foggy,” instruments (e.g., scissors) failed to load or stay in place because the components that held them in place had weakened, and diverse faults with aging fiber optic cables led to dramatic surprise degradation of the video signal captured by the robot’s camera. Repairs to basic components such as actuators became increasingly frequent. And compared to the newer model, the older robot was difficult to use: the foot pedals were more awkward, the console put more strain on surgeons’ necks, and setting up and making changes to the system during procedures required more parts and steps.

Technical differences aside, Fairtown moved the new robot into OR 15, which had been dedicated to procedures using the older system. OR 15 was well stocked with supplies for robotic procedures, was close to central supply and was also directly adjacent to the hospital’s main pyxis (automated dispensary for surgical supplies and medications). Fairtown moved the older robot to a closet a tenth of a mile away from OR 4. As this OR was also used for non-robotic procedures, each robotic procedure required several non-surgical staff to move the ~2500-pound system into and out of OR 4. These staff likewise connected and disconnected all of the components of the system. OR 4 was several hundred feet and three double doors away from central supply and the pyxis, and central supply routinely packed case carts with robotic drapes and cameras only suitable for the newer robot when procedures involved the older model.
Research Methods

Data Collection

As part of a larger, five-hospital project, I conducted a two-year field study of Urologic da Vinci procedures at Fairtown from 2013 to 2015. This involved site visits and observation of the OR work environment nearly every week, as well as recurrent interviews with surgical staff.

Participant Observation. This study draws upon observational data gathered during 30 procedures involving the degraded robot and 20 procedures involving the newer robot at Fairtown. I took time-stamped notes documenting staff interactions and the flow of work before, during and after each procedure, noting technology configuration and use and the roles and responsibilities of each participant. In each of these procedures and for numerous others, I did participant observation, regularly helping with scutwork in the OR (e.g., dealing with trash, running for supplies, turning lights on and off, helping people scrub in), training on a daVinci simulator for six sessions, getting trained to move the robot’s arms around for sterile draping, and sitting in the trainee console during procedures. Aside from this, I also spent informal time with staff before and after procedures.

Interviews. This study draws on 40 formal interviews conducted in private, involving six surgeons, four scrubs, five circulators and nine residents. These typically lasted 30 minutes and were recorded for transcription. Towards the end of my study, I solicited feedback on a draft list of difficulties, responses and consequences associated with procedures in OR 4 from individual staff at all levels in private interviews. After incorporating their responses, I presented this and a draft summary of my findings to a large group of staff in all roles for the same purpose. I then presented revised findings to top hospital executives.

Archival Data. I secured, cleaned and combined several sets of medical records pertaining to each robotic procedure performed from January 2006 – July 2015. In aggregate, these records contain a number of indicators of efficiency (e.g., time under anesthesia) and effectiveness (e.g., length of stay), and detail a wide variety of data that can be used as controls in statistical analysis (e.g., date, staff present, procedure, body mass index, age, OR number).
Although the motivation for this study crystallized when a surgeon speculated on compromised patient outcomes while struggling to operate in the corner of his field of vision, workers at all levels had been regularly expressing and exhibiting a great deal of frustration during robotic procedures in OR 4 since I arrived at Fairtown. Safety and efficiency were clearly and persistently under threat in such procedures, and the full scope of the responses to these threats was apparent only upon consideration of an entire procedure, including preparation and breakdown. As in other studies of coordination, responses to trouble were themselves coordinated work. I thus settled upon a surgical procedure as the unit of observation for this study. My focus on the moment-by-moment activities of each procedure was driven by a desire for theory informed by high-fidelity empirical data on actual work performance (Barley and Kunda, 2001).

This study involved two interdependent and iterative analytical streams, enacted through two rounds of analysis. The first stream involved multiple readings of field notes and interview transcripts, consideration of a variety of literatures and discussion of exploratory memos with colleagues (Glaser and Strauss, 1967), focusing on surprises and contrast (Abbott, 2004) as a way of inducing meaningful and novel perspectives that could powerfully explain the work under study. My initial analysis yielded a number of themes related to contrasts between robotic procedures performed in OR 4 and OR 15. Some of these centered on valued methods and goals (e.g., safety and efficiency, reducing stress), some on challenges (e.g., unexpected shifts to 2D vision for surgeons) and others on responses (e.g., stocking and then drawing from a mobile cart dedicated to the degraded robot). These themes shifted over time given additional, more focused data collection, and in response to interim findings from the second stream of analytical work.

The second stream involved requesting, aggregating, cleaning and performing statistical analysis on data collected at Fairtown on various aspects of robotic surgical work (e.g., staffing, patient age, length of stay, time under anesthesia, OR number). I produced descriptive statistics for and performed simple correlation checks, exploratory classical hypothesis tests (e.g., t-tests) and linear regressions on these data. This analysis allowed for additional insights that would likely not otherwise have become apparent. Initial
consideration of these data showed, for example, that surgeons with most experience in OR 4 performed an increasing percentage of their procedures in OR 4 over time. This was a puzzling discovery, given how much these top-performing surgeons detested such work. One of the most important methods for addressing such puzzles was regularly soliciting reactions to my interim findings from participants in informal conversation, private interviews and group presentations throughout the study period. Interestingly, a significant proportion of key themes were not evident in my interview data. These became evident through analysis of my field notes on the actual performance of work and records regarding such work.

In my second round of analysis, I focused on how workers coordinated their work safely and effectively despite dramatic difficulty with the degraded robot in OR 4. This led me to draw on Schatzki’s (2002) work on teleoaffective structures as a sensitizing framework. As Schatzki highlights, we can confound analysis of work when we treat affect as separable from goal-directed action. He proposes their union through the concept of “teleoaffective structures,” seeing these as reproduced through and shaping local practices. He further suggests that analysis of work is likewise incomplete without consideration of the mutual shaping of teleoaffective structures and the material arrangements amidst which work is performed. These dynamics are not an inherent property of technologies, spaces, artifacts or tools, but rather are manifest only through the performance of the work. This frame was well-matched with my phenomenon and with a practice theoretic lens (Feldman and Orlikowski, 2011), as it was not the chronological age of the S robot per se that challenged coordination, but the ongoing ways in which it was degraded through the enactment of related organizational practices such as maintenance, supply, surgery and so on.

Taking this tack made it clear that doing robotic procedures in OR 4 involved significant emotional energy, for example both stress and motivation to perform the work well. Specifically, the material arrangements for the work made valued methods, moods and goals for the work particularly difficult to fulfill, engendering significant practical-affective tension. I returned in this round of analysis to my empirical data, exploring the very specific ways in which this coordination tension was evident in robotic surgery in OR 4, and categorizing the activities through which workers responded to this tension. It became
evident in this grounded analysis that these activities – which I call compensatory work – were crucial to safe and efficient performance of procedures involving the degraded robot in OR 4. Below I draw on this analysis to argue that coordinating work that relies on degraded technology involves coordination tension and compensatory work, and that a robust understanding of such work must take these into account.

Valued Methods, Moods and Goals for Robotic Surgical Procedures at Fairtown

As with all major surgery across the globe, robotic surgery was dangerous and costly at Fairtown, and given the value placed on human health and cost-containment, all worked to set up for and execute surgical procedures safely and efficiently. While patients’ conditions were exceptionally well understood before they were wheeled into the OR, surgical tools and knowledge were advanced, and surgical methods were generally highly routinized, procedures were unavoidably an act of wounding individuals in an effort to improve their health. Increasingly complex and expensive technologies, staff and methods were brought to bear to reduce this harm. And while the risk of catastrophic injury or death in a procedure such as a robotic radical prostatectomy (removal of the prostate) was exceptionally low at Fairtown and at most hospitals around the United States (Agarwal et al., 2011), everyone knew that this outcome came at a high cost per surgical minute and sought to minimize this cost.

The threat of potentially unsafe situations and delays caused significant stress in robotic procedures, as these involved many more tasks and materials than non-robotic surgery. This stress motivated staff to work towards valued methods, moods and goals:

Emotionally I think most of us have this negative feeling because of the volume of work. [If] you have three people setting up the case you can do it in 45 minutes, but it really takes an hour, because you have to do all the other work that you would do to set up a case. You have to interview the patient and get the room ready. But because the robot needs so many things, you have to focus on that. You get on this treadmill and there’s so much to do and there’s a lot to forget, too. The more tasks people have, the easier it is to forget something, and then there are idiosyncrasies for each surgeon, you know, do they like this pedal or they don’t like this pedal. It sounds sort of ridiculous, but it can ruin their day, just for five seconds, they’re like “reahh!” I want to make everyone happy. — Circulator
Coordinating safe and effective robotic surgical procedures required a keen understanding of the robot, the configuration of the OR, who was in the room and how they were feeling about the task – and adjusting material arrangements and work methods to fulfill these valued methods, moods and goals.

Coordination Tension in Surgery with the “Shitty” Robot in OR 4

Though robotic procedures in OR 15 involved notable challenges to safety and efficiency, procedures performed with the degraded system in OR 4 were exceptionally fraught in this regard. In particular, standard material arrangements in OR 4 presented widespread challenges to valued methods, moods and goals for the work – specifically for setting up for and breaking down from procedures, supplying, staffing, and actual performance of surgical work through the robot during procedures:

Let’s take [ORs] 15 and 4. New robot, easier to drape and coordinate. Older shitty robot, harder to manage, breaks down, so it causes some stress to begin with. So routinely, we use room 15. So that stuff [new robot supplies] still comes up [from central processing] even if the robot’s in 4, but now we can’t use three of those things. So, we have to have that old stuff hanging around, so that equipment has to come in. So, there’s already redundancies, got to move that stuff. And then, people aren’t as happy because it’s the older shitty robot, surgeons are on edge, room’s on edge, and then we go from there (italics spoken a sing-songy voice). And always, it’s inevitable, something happens, you know. – Circulator

As in the quote above, all experienced staff referred to the degraded system as “the shitty robot,” neatly encapsulating the intertwined methodological, affective and teleological challenges presented by material arrangements associated with procedures involving the system. Table 2 outlines the sources of this coordination tension by categorizing the challenges associated with procedures involving “the shitty robot” in OR 4. Some of these challenges – e.g., a fiber-optic cord plugged in wrong – were practically resolvable during the work and others – e.g., a fatigued fiber-optic cord – were not. And as one surgeon stated, no one aspect of the material arrangements in OR 4 was a severe threat; aggregated, however, they presented a formidable challenge:

[Referring to the last in a list of six difficulties] It’s not a big deal, but it’s just one more thing to do. So, you know, these are all subtleties, but if you do it [handle all difficulties together] using the old one is a pain. – Surgeon

--- INSERT TABLE 2 ABOUT HERE ---
If left unaddressed, even a few of the challenges associated with material arrangements in OR 4 would prevent safe, efficient and satisfying performance of any given procedure. Yet robotic procedures were routinely performed in OR 4, and an independent-samples t-test shows comparable indicators of quality: when surgeons were experienced with the degraded robot, patients in OR 4 were under anesthesia for comparable amounts of time (M=233.08 minutes, SD=55.69) as in OR 15 (M = 238.15 minutes, SD = 62.08) (t(449) = 0.32, p = 0.7488), and stayed at Fairtown for comparable recovery periods (M = 1.51 days, SD = 0.89) as did those operated on in OR 15 (M = 1.45 days, SD = 0.87) (t(449) = 0.4138, p = 0.6792). In what follows, I detail the compensatory work that allowed for these outcomes in OR 4, then turn to important consequences of this compensatory work for staff and the work itself.

As the data in Table 1 suggest, when the new robot was installed in OR 15, all staff did what they could to avoid doing surgical work in OR 4 with the degraded robot – the material arrangements implicated in OR 15 made working there easier and less stressful for everyone. Excess surgical demand regularly led to a situation in which scheduling a procedure in OR 4 was the best option, however:

It clearly is a competition to have the new one, and nobody wants to use the old one. Most of the time the old one is used if I have a case that I can’t get into room 15. If I have to wait three or four months [for 15], I will ask if there is some time to use the other robot in order to get the case [done]. – Surgeon

The pressures to serve cancer patients more quickly through robotic procedures and secure a satisfactory return on the OR committee’s investment in the degraded robot put everyone in the unfortunate position of having to perform procedures in OR 4 through a degraded robot – with the realization that performing surgery in this way might not be necessary given increased investment:

I think it’s an unfair thing to ask surgeons to go back and forth from one that functions really nicely to one that doesn’t. I know it makes them kind of nuts. I don’t understand why Fairtown doesn’t get another robot. But money is always at the source for everything. And if it’s really that important, then they shouldn’t do their cases with that robot. But that will never happen, because they have to operate – they’re forced to operate. – Circulator

Why was the degraded robot still in use at Fairtown, given the broad-sweeping challenges to safe, effective and satisfying robotic procedures in OR 4? No patients had yet been injured in professionally significant ways through procedures involving the degraded robot, and after it was designated for use only
Compensatory Work in Robotic Surgery in OR 4

Work had to proceed amidst the challenging material arrangements for robotic surgery in OR 4, and major compromises to professional methods, procedure goals and a focused, good mood were not acceptable. Doing these procedures thus involved significant coordination tension, manifest in feelings such as time pressure, frustration and motivation to pursue key goals. As outlined below, everyone threw themselves into the breach, performing compensatory activities. Notably, this compensatory work deviated significantly from valued methods and goals for robotic surgery and had to be completed within the time restrictions associated with robotic surgical procedures performed in OR 15. Thus more – and more varied – work had to be done in OR 4 to equal standards in the same time. All of this compensatory work thus ironically increased coordination tension, just as it decreased it. When material challenges were resolvable, compensatory work was generally focused on reconfiguring the material arrangements for surgery. When these challenges were not resolvable, compensatory work generally focused on reconfiguring methods for surgical work. Regardless, additional compensatory work was focused on reconfiguring compensatory work itself to reduce its negative impact on coordination.

**Compensatory Work – Reconfiguring Material Arrangements**

Staff began to reconfigure the material arrangements implicated in OR 4 well before wheels in. Four categories of work were salient here, which I refer to as *Stashing, Fishing, Propping* and *Tweaking*. These reconfigured substandard material arrangements into ones that hedged against likely trouble unique to performing surgery in OR 4 through the degraded robot. Given that these kinds of compensatory work were focused on logistics and support, the burden for enacting them largely fell on circulators and scrubs.

*Stashing*
Stashing involved creating a readily accessible cache of backup resources. Scrubs and circulators cooperated to maintain a mobile cart stacked with supplies unique to the degraded robot – including several cameras, monitor drapes and sets of camera cords – to avoid getting stuck with the new robot supplies inevitably sent to the OR as part of the prepared case cart:

We take the old stuff… there’s like a different tray of instruments, there’s a different drape pack, you need an extra monitor drape and camera cover, so it’s like four or five things. So, we all know that now - it’s all outside of 15 on a rollaway cart type thing, so they just roll the cart outside 4. – Scrub

In the morning and after each procedure, the circulator or the scrub for the case examined this backup cart to see if any of the supplies specific to the degraded robot needed to be replaced. If so, nurses would either call down to central supply to request missing materials or engage in Fishing, described below. In the morning, this practice also involved walking by OR 15, where the cart was kept overnight. The circulator or scrub would then wheel this cart approximately 300 feet to OR 4, leaving it outside the main door. Beyond this mobile cart, however, everyone recognized that OR 4 was far from robotic supplies in general, and stashed generic robotic supplies individually:

I bring extra everything [to OR 4]. With a partial [removal of a kidney tumor] if he says to put in a needle driver to start sewing, and I put it in and the needle drivers expired, then that’s waiting time, then that’s bleeding, bleeding, so I always bring a needle driver, and an extra scissors, and an extra clip applier, because N is running down there [to OR 15], and we’re bleeding, and N is not always good to know where to look for things. – Scrub

Thus, the improper supplies regularly sent to OR 4 for robotic procedures and the physical distance between OR 4 and generic supplies produced significant coordination tension, given that staff valued safety, efficiency and a good work mood. Stashing compensated for this by making needed supplies ready at hand, though this also added coordination tension as related activities took extra time and effort, ran counter to preferred methods for surgical preparation, and added complexity to the physical environment.

**Fishing**

Fishing involved securing rarely used supplies from uncertain remote locations. Robotic procedures in OR 4 inevitably involved unexpected demands for surgical supplies, instruments and tools, and
Stashing could only hedge against this so much. It was therefore a matter of routine to duck out of the OR in the midst of the normal flow of work to find needed supplies and tools:

We have to go fishing to get positioning equipment. Doing a kidney, there are certain lateral supports we use, certain devices for the flank, depending on the patient and somebody didn’t pick it, and you’re searching the whole OR to get it, because we’re in OR 4 and they don’t have the positioning equipment there, and I have to go find it because there’s only one set in OR 15. Sometimes there’s extra equipment in B’s area, sometimes instead of leaving it in OR 15, they move it [there]. That takes a few minutes in the morning.  — Circulator

Unlike Stashing, Fishing was done both before wheels in and then as needed throughout a given procedure. More often than not, Fishing targeted supplies and tools that were used infrequently and stored in multiple and/or uncertain locations. Success on Fishing trips therefore depended a great deal on working knowledge of the storage processes and spaces in the entire OR suite. Thus, although Fishing ensured similar outcomes to Stashing, these activities compensated for and created a different form of coordination tension – one rooted in costly, ostensibly inappropriate exploration for uncertain resources.

**Propping**

Propping involved using general purpose supplies to recreate familiar, temporary tools to solve known problems. Circulators and scrubs coopted a generic wheeled cart and added labels and an additional tray for stashing supplies unique to the degraded robot as part of Propping, for example. But surgeons also did this to make operating less painful and more efficient – one surgeon was well known for constructing a “crown” out of positioning foam before each procedure in OR 4 to reduce strain on his neck. He likewise wrapped the wheel of his console chair with medical tape to prevent the chair from moving, so that he could push more forcefully on the sticky console pedals. Doing this kind of Propping typically required multiple staff:

N (scrub): Oh, he forgot it [his crown]?
K (surgeon): Yeah (walking away from docking procedure, ripping off gown and gloves)
R (circulator): Where’s some foam? Some extra pink foam?
Anesthesiologist hands this to R across the patient, R walks foam to a spare chair next to console. K gets a big piece of blue foam off of mobile supply stand, walks over to console, wraps it around head, rips it to length, R hands him tape from the stand, K wraps foam in cylinder on his head, tapes it, R returns pink foam to Anesthesiologist. K gets on his hands and knees to immobilize back wheel on console chair with tape.
R: So, you are the one who tapes the wheels on these chairs!
K: Did I ever tell you the story about how this robot sucks?
– Field notes, 9:52 AM, 7/22/2015

Propping compensated for numerous, ongoing challenges to preferred methods, moods and goals for robotic surgical work produced by the material arrangement of the degraded robot in OR 4. While some of these might be viewed as inherent in the design of the system itself, this was not the case. Each of these could have been eliminated with minor yet durable changes to the routines and material arrangements surrounding the system (e.g., constructing an insert for the console faceplate). As it stood, Propping added time, effort and stress as it ran counter to preferred methods for setup and performance of surgery, but compensated for coordination tension by preventing a range of problematic outcomes.

**Tweaking**

Tweaking involved small, interdependent adjustments to material arrangements that shaped perspectives on the work. For example, surgeons’ visual acuity often got so bad that no standard set of adjustments would resolve the problem. In such cases, surgeons, circulators and residents cooperated to tweak the light settings on the degraded robot to get a “least worst” illumination of the surgical field. After watching the surgeon struggle for a period of time, the circulator would sometimes suggest such tweaking. Surgeons also regularly initiated tweaking, having worked to the edge of their capacity:

P (surgeon, operating): D, would you mind turning the light intensity down to 40 please?
D (circulator): (moves to tower from desk, adjusts setting) 40. So basically, has it fixed anything?
P: Yeah, it looks better. There’s a way to reduce the contrast, one on each eye. And with the contrast issue, it’s hard to see contrast, so if you’re [a] rookie, you might cut right through the artery here, because you can’t tell.
D: Want me to turn down the main light?
P: Sure, that couldn’t hurt, you know.
– Field Notes, 10:15 AM, 6/18/2014

In this case, successful tweaking involved the circulator moving to the tower to make subtle, interdependent changes in the light that each eye picks up as well as the light emitted by the bulb, responding to the surgeon’s requests, then returning to the nurse’s desk. Tweaking was also evident as
surgeons asked residents and scrubs to advance trocars a bit further in or out of the body to allow for a slightly different view and/or reach inside the patient. Thus, reduced and irregular maintenance practices for the degraded robot – such as regular assessment and replacement of defective actuators, lamps and cords – produced a material arrangement that made standard professional surgical moves much more difficult and stressful in OR 4, threatening valued methods, moods and goals. Tweaking compensated for this coordination tension and allowed work to proceed, though it also increased such tension as it involved uncertainty, activities that ran counter to preferred methods and took precious time and effort.

Compensatory Work – Reconfiguring Methods

When reconfiguring the material arrangements during a procedure in OR 4 was extremely difficult (e.g., a weakened spring or sticky pedal), compensatory work involved three activities focused on coaxing adequate functionality out of the degraded robot by reconfiguring valued work methods, which I refer to as Making-sure, Bending and Handholding. These activities were focused around the surgical act, and were a key focus until the robot was undocked from the patient. Surgeons therefore bore the brunt of the burden for performing them.

Making-sure

Making-sure involved checking technological components that were explicitly designed to be completely reliable. A number of the more technically-oriented difficulties listed in Table 2 were both expected and surprising. This was the case because experienced staff knew these problems would arise eventually, but were unsure as to when they might do so. In order to compensate, all staff checked a variety of the components of the degraded robot – such as the camera lenses – that were never supposed to fail. Much of this Making-sure work was performed before wheels in by circulators and scrubs. Beyond checking for these failures, staff regularly had to assess whether the robot had been set up properly in OR 4. They shouldn’t have had to do this work as the overnight staff was supposed to know how to make the
14 connections required to make the degraded robot functional. In practice, these connections were almost never correct, nor was there a single, predictable point of failure in this regard:

When you come in and you’re doing a robot in 4, you know the only thing that happened is that the night shift moved pieces into the room, but you know nothing is hooked up correctly, so you’re kind of behind the eight ball, you don’t really have that extra time that you’d like to have, so you’re trying to rush and make sure everything’s connected properly, turn everything on, double check that the bovie’s [cautery device] connected. — Scrub

As with Fishing, Making-sure was occasionally done after wheels in. Ironically, this often involved addressing potential safety threats that emerged in response to Tweaking:

I check the arms [during a procedure in OR 4], because I don’t know what it is with the old robot but the arms just don’t move as easily as the newer robot, so they [residents and scrubs] are always finagling the trocars up and down, moving the arms and I’ll get up to make sure it’s not pressing on the patient’s feet or any part of the body. Because I don’t want my patient to get hurt. And if you move the robot — if you’re pushing something in or readjusting it when the patient is already positioned, you can’t tell if you’re scrubbed in if you’re putting pressure on the patient anywhere, you just can’t. I get up and make sure that it’s not putting any more or any less pressure than what they should be. This just doesn’t happen as often in [OR] 15. I don’t know why, but it just doesn’t. — Circulator

Thus, significant and recurrent coordination tension was produced as support staff kept defective “failsafe” components in service and set up the robot improperly, and as staff engaged in Tweaking during the procedure. Making-sure compensated for this tension by screening for extremely unlikely failures, though it added coordination tension as it took precious time and effort and ran counter to preferred professional methods for preparing for robotic surgery.

**Bending**

Bending involved adopting awkward postures, views and techniques. The compromised visual and lighting capabilities of the degraded robot meant that valued operating techniques (i.e. keeping the focal surgical activity zoomed reasonably close in the center of the field of vision) often “washed out” the visual field. This was especially true as the amount of blood in the field shifted, as hemoglobin absorbs quite a bit of light. This led to a situation in which the surgeon could not distinguish key anatomical differences. To compensate and keep the surgery moving, surgeons frequently ceded the ideal operating
distance and viewing angle, working at the corner of their field of vision or zoomed very far out from the focal surgical activity:

K (surgeon): (operating in the lower left corner of his field of vision) Shit robot. K: It’s all I have to operate on this ridiculousness, in the corner of my vision, so I can see what I’m doing. Otherwise, if I put it in the center of my vision, it lights up, see (does so, surgical site glares, detail washes out)?

T (resident): Yeah.

K: But do the hospital administrators care?

— Field Notes, 10:57 AM, 7/22/2015

Beyond acuity issues, surgeons routinely lost vision in one eye in OR 4 because of the faulty camera. They would continue to operate in this way for limited periods, then request the camera to be cleaned several times to see if the camera was simply dirty or fogged. Each cleaning took two or three minutes and involved the resident unclipping it from the robot, sliding it out of the housing, bathing it in warm saline, wiping it with a microfiber cloth, cleaning the camera trocar and reinserting and reattaching it. The surgeon would continue to operate with vision in only one eye in between cleanings, and once it was determined that the camera was faulty, it was removed and replaced with a spare from the stash cart.

The under-maintained visual and lighting systems on the degraded robot engendered striking coordination tension given the value placed on safe and effective surgical practice during robotic procedures in OR 4. Bending meshed surgeons’ actions with the degraded system to produce safe and effective surgical maneuvers inside the patient, though these activities took extra time and effort, and were quite awkward compared to standard surgical technique. They were therefore a source of considerable coordination tension for everyone.

**Handholding**

So, when I train new staff, I train them on the Si, because that’s the prevalent one, then if they come in here [OR 4] I have to work extra hard to get them up to speed. — Circulator

Handholding involved attending to those inexperienced with the degraded technology. Most staff did not have significant experience doing robotic surgery in OR 4 with the degraded robot, and those with experience had to keep an eye on them. Related activities included watching those with less experience to
be sure they didn’t make mistakes, helping them perform tasks only relevant to the degraded robot such as calibrating the camera, covering for them when they couldn’t perform tasks smoothly or quickly enough, teaching them about key differences between procedures with the new robot and the degraded robot, and giving them instructions as to how to assist in key portions of the procedure:

N (scrub): This old one, it is... you have to attach the light cords here, not like the new one. It makes zero sense. Someone has got to deal with this.
W (second scrub): Okay.
N: So that button to the right is not on yet, and needs to be pushed (T does), good, then connect that cord. (T does)
W: And then what next?
N: Can you turn that screen (on the tower) towards me? And all you have to do is press and hold that white balance button. So, put your finger right there (glances, T does), yep. That one, hold that down. Okay, perfect.

– Field Notes, 9:00 AM, 7/01/2015

Handholding was particularly prevalent with medical residents, as they often had even less experience with the degraded robot in OR 4 than inexperienced scrubs and circulators. These differences in knowledge regarding the material arrangements and compensatory work specific to robotic procedures in OR 4 were a regular and significant source of coordination tension in these procedures. As with all the compensatory work described above, Handholding both compensated for this tension and contributed to it by introducing more work into the flow of a procedure, and this ran counter to preferred methods.

Compensatory Work – Reconfiguring Compensatory Work Itself

Compensatory work that reconfigured material arrangements and methods did not eliminate coordination tension associated with robotic surgery in OR 4. Indeed, in many cases, compensatory work itself created more coordination tension. Fishing for a lumbar support took precious time. Tweaking trocars met with physical resistance from degraded robotic arms. Bending to operate with monocular vision was stressful. None of these activities was seen as normal. To the contrary, participants saw them as compromises. These activities thus challenged valued methods, moods and goals, just as they helped to achieve them. Three forms of compensatory work helped address these challenges. I refer to these as
Rushing, Forcing and Venting. The first two of these were not activities, per se, but rather shifts in the pace and effort for various activities:

Five or seven minutes is a lot of time for a nurse who only has half an hour to get things going. You just run faster and harder to make up the time. – Circulator

**Rushing**

Rushing involved accelerating the pace of work. Everyone rushed in OR 4. Crucially, they almost always did so in times, spaces and with work where doing so was reasonably safe, thus minimizing additional coordination tension. Before wheels in, scrubs and nurses walked very quickly to another OR (15) to get the stash cart, draped the robot much more quickly, and opened basic supplies much more rapidly, for example. This also occurred during breakdown activities, especially if there was another non-robotic case to follow, as the entire robot had to be disassembled and removed from the OR. Scrubs and circulators routinely moved fast enough in preparation and breakdown for procedures with the degraded robot to sweat through their clothing. This did not occur in procedures involving the new robot in OR 15.

Yet aside from the occasional dropped sterile item, Rushing these practices was not risky:

- R (circulator) literally running over to the tower to get the cord to hook it up with N (scrub), who had the camera ready.
- R moving quickly to slide drape down the camera cables with rapid arm motions.
- R: If I hear anything about expired instruments today, I’m going to be bullshit.
  – Field Notes, 7:20:48 AM, 6/11/2015

Rushing was also evident once the robot was docked to the patient: surgeons would operate much more rapidly, circulators would move much more quickly to the tower to tweak light settings, and scrubs made and handed off sutures faster. Yet again, everyone knew the portions of these activities that could safely be rushed. Surgeons, for example, knew that detaching the bladder and prostate from the abdominal wall did not implicate major blood vessels or nerves, and could therefore either be safely performed by a relative novice or rushed by an expert. Rushing during such times avoided potentially unsafe and highly inefficient – and therefore extremely stressful – surgical work. As evidenced by the excerpt just above,
however, Rushing contributed to coordination tension by challenging the preferred pace for the work, and this tension was produced in times that would have been relatively tranquil in OR 15.

**Forcing**

Forcing involved applying ostensibly excessive effort. Sticky pedals had to be pressed to activate cautery, sluggish masters in the control console had to be moved in order to execute surgical maneuvers, and sluggish robotic arms needed to be advanced further towards the patient to allow surgeons to see and reach farther into the patient’s abdomen. The answer in these cases was exerting notably greater force to get components to perform as needed. This was primarily evident through more rapid motions involving more of the body than in similar tasks in OR 15. Forcing was only the object of discussion as those with experience with the degraded robot in OR 4 coached those with relatively little such experience:

R (surgeon, standing out of console, speaking to resident operating at the console): stomp on that pedal.

S (resident) hits it lightly, takes his head out of the console, looks down at his feet

R: Put your head in. Now stomp on it.

S puts head back into console, taps pedal with his foot

R: The left pedal, stomp on it!

S stomps hard, activating clutch, allowing for vision shift

Field Notes, 11:11 AM, 6/17/2015

And while Forcing was most often evident after the robot was docked to the patient, it was also occasionally evident during particularly challenging preparatory or breakdown work, such as draping the robot’s monitor:

D (Circulator): I’m going to scrub in and drape this thing.

D moves over to robot before scrubbing in, spreads arms out to receive drapes. D then grabs the monitor on her tiptoes and begins pulling and pushing hard to move it down between two arms

D (sweating through her clothing): Stupid old piece of shit robot. Get that [points at me]?

Field Notes, 8:33 AM, 6/17/2015

As with Bending and Tweaking, Forcing tasks reduced coordination tension by meshing staff efforts with the material arrangement of the degraded system to produce safe and effective actions. And as with Rushing, Forcing surgical work caused significant coordination tension as it involved extra work that violated valued professional standards for this failure-intolerant and precision work setting.
Venting

Venting involved expressing and being responsive to stress. Whatever else they highlight, many of the empirical extracts presented in this paper show the significant coordination tension that workers experienced while performing robotic surgery with the degraded robot in OR 4. Everyone did what they could to avoid having to set foot in OR 4, so even arriving there to start a procedure was cause for such tension. This mounted as difficulties arose and as compensatory activities reconfigured material arrangements and valued methods. And while Rushing and Forcing helped keep the work on track and were done in spaces and moments of low risk, they were departures from valued professional standards and therefore stressful to implement. Thus, nearly all roads led to coordination tension in procedures involving the “shitty” robot. Importantly, this tension was a key source of motivation for the compensatory work detailed above. Beyond this, workers engaged in Venting to compensate for this significant, accumulated tension. Jokes and profanity were common, for example, often went hand in hand, and ranged from quite overt to nearly private:

K (surgeon, looks in console): (quietly) Oh sweet Jesus fix this. (loudly) Oh my god its awful!
D (circulator): We just recalibrated.
M: It’s not even calibrated!
N (scrub): What are you aligning it on?
M: This is old school, baby (manually recalibrates 3D vision)!
K (resident): What are you doing there? You were aligning [it] on your own?
M: Thank you lord for myself (group laughter).
Field Notes, 8:52:24 AM, 2/6/2015

Beyond expressing their frustration about a difficult activity involving the robot, workers occasionally resorted to vilifying the robot directly, especially if they continued to struggle with it:

N (scrub): Crap (struggling with monitor drape). Fucking annoyed (as she tries to get it on at the edge of her reach). Oh my GOD! I just want this fucking robot to die. Can’t make it any harder. No fucking love for this shit. Can you make this any more fucking difficult?! (straining on tiptoe, jumping, bending around to drape monitor throughout)
– Field Notes, 8:49 AM, 7/01/2015
When they detected that their colleagues were particularly stressed, workers made it a priority to attend to related requests or trouble more quickly than normal. Alternatively, they gave their colleagues a wide berth for a while:

Even if I’m pissed off, [for example] I try not to let it, or if the surgeon’s pissed off, I compensate for that and I don’t bug him. We all do that, I hope we’re all attuned to each other enough so we just get the job done. - Circulator

Given the intensity and regularity of the coordination tension associated with performing robotic surgical procedures in OR 4, Venting was a common and important way to smooth out the work and keep it flowing. Failure and delay were to be avoided almost at all cost, and Venting helped everyone maintain focus on the work, though it also created coordination tension as it sometimes violated preferred moods for this professional work environment. Unlike Rushing and Forcing, Venting was done in almost all portions of each procedure as coordination tension arose.

Compensatory Work in Procedures Involving the Robot in OR 15

Most robotic surgical procedures at Fairtown were performed in OR 15, not OR 4. Everyone who did robotic surgical work greatly preferred doing robotic procedures in this robot-dedicated setting: appropriate supplies were ready at hand, preparing the robot required fewer, simpler steps and only one person, the robot was always positioned and connected and never needed to be broken down, components rarely failed, and robotic-trained staff were reasonably familiar with the system. Doing surgery through the system was also notably less difficult than in OR 4: the console was easier to manipulate, was more ergonomic and components and functionality were extremely reliable. Despite the relative lack of coordination tension during robotic surgery in OR 15, compensatory work was still done to manage it – albeit far less frequently, with less intensity and with a more diffuse focus.

Reconfiguring Material Arrangements

Stashing and fishing were evident in OR 15. Everyone knew that different surgeons had different preferences for how a procedure should be performed, and that different supplies would be needed in order to enact their preferred approach. One surgeon, P, occasionally used a “hook” robotic instrument for
electrocautery of certain vascular and lymphatic tissues. No other surgeon used this instrument. Surgeons all had “preference cards” to specify their particular supplies for a given procedure, but P used the hook infrequently, so it was never added to his card. Most surgical staff knew this and stashed a hook in the supply tower just outside OR 15 to avoid having to run down to central supply. On rare occasions, P also asked to use a fenestrated bipolar – a blunt-tipped cautery and grasping device. This was never stashed, and so staff had to fish for it – either down to central supply or out the OR door to the supply tower.

Propping and making-sure were also evident in OR 15. Staff occasionally bumped the robot after it had been draped. Unless they were in sterile garb, this was a clear contamination of the sterility of the system, and demanded an immediate response. If the bump was on a relatively small patch of the drape, a staff member regularly suggested that someone “tegi that”, meaning engage in propping by opening and applying a sterile, adhesive transparent patch to the contaminated area. Making-sure was evident as staff opened robotic instruments from the case cart. This involved removing a taped, sterile outer towel-like wrapper on a steel box before opening it with sterile gloves. During many procedures, staff examined this towel from all sides before opening it, as they were occasionally torn. This shouldn’t have been necessary, as these towels were single-use and were barely handled in transit from central supply, but they were torn at the corners every once in a great while, preventing the use of any of the box’s contents.

Reconfiguring Methods

Difficulties were subtle and rare during the performance of robotic procedures in OR 15, so workers did not often or extensively reconfigure methods. Surgeons occasionally engaged in bending after nicking arteries or veins in their work. Some of these sprayed blood on the tip of the camera, and while such bleeding was often quickly controlled, surgeons routinely continued to operate with compromised vision, especially if only one eye of the camera was obscured. Tweaking was evident towards the end of many procedures in OR 15. For most of the operation, the insufflation pressure was similar to the patient’s blood pressure, thus preventing bleeding from small arteries and veins. In order to check for such injuries, the surgeon would ask for the pressure to be brought down by the circulator from
controls at the boom just as the resident suctioned air and fluids through a trocar. The resident and
circulator thus subtly tweaked the intra-abdominal pressure in a highly interdependent way, allowing the
surgeon to scan for injuries. Handholding was far more prevalent in July in OR 15; this was when a new
group of medical residents rotated in to robotic surgical practice for the first time. Surgeons, circulators
and scrubs alike had to devote significant extra time and effort to these residents.

Reconfiguring Compensatory Work

Reconfiguring compensatory work was even less frequent and notable in OR 15 than reconfiguring
methods was. Extra staff were available to help with tasks, supplies were easy to find, components
functioned reliably. It was therefore rarely necessary to rush, force or vent about the work or the
technology. To the contrary, many took their time to do their work, exerted less effort than normal, and
spontaneously expressed enthusiasm as procedures got underway:

K (surgeon): I love you, you little robot, I’ve missed you.
- Field Notes, 11:20 AM, 6/18/2014

Procedures in OR 15 were not a bed of roses, of course. Rushing, forcing and venting were done on
rare occasions in the face of unexpected difficulties. Supply mistakes did rarely occur, for example, and
were sometimes discovered only well into the procedure. If a surgeon asked for a sterile laparoscopic bag
to contain an excised tumor inside the abdomen, and it was discovered that the wrong size bag had been
packed in the case cart, the circulator would have to scramble to fish for one outside the OR, as leaving
excised cancerous tissue resting inside the abdomen posed significant risk. As in robotic procedures in
OR 4, residents were sometimes asked to advance robotic instruments further into a trocar, and this
sometimes required more force if the angle of the arm required an awkward reach.

Finally and ironically, coordination tension became somewhat more prominent when Intuitive
Surgical began marketing a new model – the daVinci Xi – in March of 2014. This model promised
significant improvements upon the Si. Notably, instruments would be longer, eliminating the need to
advance them down a trocar during surgical work, the camera could be attached to any arm and the arms
were mounted on a rotating boom, which would allow for surgery and views from any direction, and the
camera was sterilizable, eliminating the need to drape it for each procedure. These and other changes promised significant quality improvements, including savings in time and effort for all staff. The Si capabilities that were formerly ideal now occasionally seemed to limit work in irritating ways:

R (circulator) calibrating camera [on her own].
R: That’s why I want the Xi, so we wouldn’t have to DO this!
D (scrub): Yeah, that’ll never happen.

- Field Notes, OR 15, 2:10 PM, 6/18/2014

**Consequences of Compensatory Work in Robotic Surgery**

As evidenced above, doing surgery with the degraded robot in OR 4 involved significant coordination tension, as the default material arrangements for such work presented significant challenges to valued methods, moods and goals. This was due in large part to material arrangements produced through deprioritized organizational practices involving this system such as maintenance, storage, setup and supply. This tension motivated everyone to engage in compensatory work as it was a source of significant practical-affective stress. Beyond allowing for effective coordination of the work, the various forms of compensatory work contributed to three notable outcomes related to these procedures.

**Tension-Risk Swaps**

You can’t put a metric on my pain and suffering, you know, the psychological damage it does to me. The inferior quality of visualization, the operating in 2D instead of 3D, the neck strain, I may be able to compensate for all of those things [so] that maybe the case time won’t be longer, blood loss won’t be more, patient outcomes won’t change. Because I have to change my ways to make the shortcomings... [irrelevant]. I tend to lose my cool more in [OR] 4, meltdowns are more likely to occur more there. It’s just a very bad place. – Surgeon

Coordinating safe and effective surgical procedures with the degraded robot in OR 4 came at significant cost to the subjective quality of the work experience. Compensatory work greatly reduced coordination tension that threatened key outcomes, allowing for comparable surgical outcomes and process metrics, but such work often extended and contributed to coordination tension as it added to the list of tasks to be done in the same amount of time, and many of these tasks had to be done in ways that were inconsistent with valued methods. People suffered doing this work, emotionally and physically.
Ironically, the coordination tension remaining after performing compensatory work was never so extreme as to warrant complete work stoppage or broader organizational change related to the work. In a sense the patient was protected at the expense of the staff experience.

**Qualitative Filtering**

Those with the power to replace or adequately resource the degraded robot did not get key information on the impact of work in OR 4, and this contributed to their decision to keep it in service. Experienced surgical staff contributed to this dynamic. When presented with a list of the difficulties involved in robotic procedures in OR 4, most expressed surprise at their scope and intensity:

> Wow, I’ve never really thought about all of the things that go wrong. I would agree that this is very accurate. – Scrub with the most experience working with the degraded robot in OR 4, email correspondence, 7/8/2015

Staff did not maintain and withhold a well-theorized repository of empirical data on trouble with the “shitty” robot. They were focused on their patients, their jobs and each other, and drew on frustration and scattered examples as indicators of trouble. They therefore did not marshal accounts that showed executives unacceptable decreases in patient care or other quality metrics. Executives contributed as well by not inquiring deeply into what they saw as “whining” about working in OR 4:

> It’s a poor surgeon who blames his tools, right? – Fairtown Surgical Chair

Additionally, these executives did not spend time in OR 4 observing work involving the degraded robot. They therefore did not have access to qualitative data – in this case on compensatory work and its negative consequences – that they would have considered relevant to their ongoing ROI assessment. Their reaction near the end of my private presentation of findings to them was telling in this regard:

H (Fairtown COO): This is probably my mistake. I have not done any real financial work with this [the degraded robot] in the last year. I mean at some point in time you gotta stop and say, okay, we’re at 150,000 on a service contract, the net gain on the number of cases just because [we keep it in service]... and then you’re [researcher] adding enough variables, that we would... I mean we’re currently having staffing challenges within nursing...

C (Fairtown Surgical Chair): Right...

H: And if you accept the challenges...

C: The work and the rework and things like that...

H: It's amazing.
C: [long pause] It's [keeping this S] a long run for a short slide.

Thus, by filtering out qualitative data, executives and surgical staff cooperated to keep the degraded robot in service – an outcome that no one would have preferred, given more complete information.

**Handler’s Traps**

Who can handle that robot, the new guy or the gal you already know who knows how to do it really well. It is true, I can handle room 4 and so can P, better than, I mean, we can muscle our way through [procedures], it is true. – Surgeon

The more time that surgeons, circulators and scrubs spent in OR 4 with the degraded robot, the more they ended up doing so in the future. This occurred for different reasons, as people in different roles had more or less discretion in the matter. Between 2013 and 2015, for example, the two most prolific robotic surgeons at Fairtown performed a disproportionate and increasing percentage of their procedures on the degraded robot in OR 4, while the 16 other robotic surgeons at Fairtown secured preferred and expanding access to the new robot in OR 15 over time (Table 3). Primarily, this occurred because most of the 16 other surgeons simply refused to use the degraded system, claiming that they couldn’t use it safely and/or efficiently. Those who could handle the system did, and as they demonstrated their willingness and ability to do so, surgical administrators incrementally reallocated these surgeons’ default “robot time” to the degraded robot. Experience thus reinforced the pattern. Notably, neither of the highest volume surgeons were aware that their share of cases on the degraded robot was increasing over time.

---INSERT TABLE 3 ABOUT HERE---

In important ways, Handler’s Traps were more challenging for scrubs and circulators experienced with the degraded robot in OR 4. First, those scrubs and circulators with the most experience with the degraded robot in OR 4 were almost always formally staffed to those procedures when they occurred. Everyone – including the experienced scrubs and circulators – agreed that experience mattered a great deal for the integrity of valued goals and methods in these procedures. Second, supplementary staffing
help – in the form of the “third person” – was preferentially diverted to OR 15, both by explicit staffing
decisions and in practice, thus amplifying the difficulty for experienced scrubs and circulators:

N (scrub, working to set up in OR 4): how come everyone gets a third person except for me?
Just want to know.
J (scrub, in to help unexpectedly): Cause you’re good, that’s why.
N: Fucking bullshit. Cause we’re tripled, on our work. You don’t need a third person in 15, you
need a third person in this room, cause you have to move everything around, this is the shitty
old one that has 50 extra steps.
J: Yeah.
N: But I never get a fucking third person.
— Field Notes, 8:54 AM, 7/01/2015

Those scrubs and circulators involved only in procedures in OR 15 often had less experience
robotically than those staffed to procedures in OR 4, and therefore ironically often required more help
preserving valued methods, moods and goals given the material arrangements in OR 15 than a lone
experienced scrub or circulator did with the degraded robot in OR 4.

Finally, a single circulator bore primary operational responsibility for both robots at Fairtown.
Whenver either unit needed repairs or troubleshooting, she became involved, whether on her own or
with vendor repair technicians. At my request, this circulator went over her email and troubleshooting
logs and counted the volume of her interactions regarding these responsibilities. Her emailed response
indicates that she devoted a disproportionate amount of her time and effort to the degraded robot:
I’d say 15-20% of my time is spent coordinating repairs - 10% S [degraded model]; 5% Si [new
model]. The S issues do tend to be more of the major sort - camera head/cable or other
fiberoptic cables. – Circulator (e-mail correspondence, 4/9/2015)

Thus, Handler’s Traps deepened over time for those who entered them. Experienced staff became
all the more capable of handling the degraded robot as others’ capabilities waned in this regard.

**Temporal shifts**

30 minutes would be okay [to prepare for the next case] if we have a third person to drape, if
not [then] the patient’s in the room and we’re still draping and calibrating the camera and stuff
like that. You’ve seen that. - Scrub

Compensatory work began well before wheels in and continued until well after wheels out,
reducing coordination tension in a variety of critical ways. But compensatory work also created
coordination tension, not least because it was often rushed and forced. In particular, this tension was often produced during portions of each procedure that were relatively relaxed in OR 15. Preparation became a heated affair, straightforward portions of surgeons’ work became tense, and staff became agitated as they prepared to undock and undrape the robot, for example. In OR 15, these times were prized for chatting, gossiping, joking, listening to music and in general building positive relationships and energy for the work:

It [operating in OR 4] does suck the joy right out of doing the work. You need those times in operation where you’re totally relaxed, where you’re kind of enjoying yourself, where you’re kind of having fun. - Surgeon

Notably, surgeons also relied on this time in OR 15 to teach residents. All of this went out the window in OR 4 as compensatory work shifted coordination tension into these times and spaces.

Discussion

In this study, I asked how workers coordinated through degraded technology – and with what consequences. My findings show that coordination tension – the practical-affective stress experienced when valued methods, moods and goals become difficult to achieve, given local material arrangements – is a central threat to effective coordination in such circumstances. Effective coordination in the face of such tension is critically dependent on compensatory work, a supplementary set of activities involving recurrent reconfigurations of material arrangements, valued methods and compensatory work itself. I find that doing this compensatory work created four unintended consequences: Tension-Risk swaps in which workers paid an emotional toll as they mitigated risk, Qualitative Filtering in which workers and managers failed to exchange significant data on the trouble, Handler’s Traps wherein workers experienced with the degraded technology ended up having to work with it more and with less support, and Temporal Shifts in which coordination tension was relocated to times and spaces that would ordinarily be relatively tranquil. These findings are presented in Figure 5.

---INSERT FIGURE FIVE ABOUT HERE---
This study enriches our understanding of coordination involving technology in several ways. First, it shows the power of treating affect as integral to the methods and goals of coordinated work. Fairtown staff pursued surgical goals because they cared about them. They insisted on the methods they cared about. They cared about feeling satisfied by work done well and got frustrated when it was not. This caring drove the compensatory work they did to keep things on track. Careful consideration of my data showed that material arrangements challenged valued methods and goals, producing practical-affective tension in the same moment. Straining on tiptoe to stick a drape on a monitor that no one used was a pain—before, during and after it was done, and it was not analytically useful to parse affective and practical processes as workers struggled to keep things on track. Studying coordination in this setting without considering coordination tension would have excluded central and crucial dimensions of the compensatory work that kept the work flowing in acceptable ways—and that ultimately kept patients safe.

Second, research on coordination has not considered the implications of degraded technology. Keeping robotic surgery coordinated in OR 4 was hard because the “shitty” robot was degraded—specifically, under-maintained and under-resourced—making valued methods, moods and goals far more difficult to achieve than they were in OR 15. This study further shows the extensive compensatory work required to keep the work coordinated, given this technological degradation. Examining compensatory work revealed three new, interdependent mechanisms for coordination via degraded technology—reconfiguring material arrangements, reconfiguring the work and reconfiguring compensatory work itself. As in this case, studies of coordination could offer more useful explanations by considering the relative degradation of technologies that are deeply implicated in the work under study. More broadly, these contributions offer a strong endorsement to recent calls for considering materiality in the study of coordination (Okhuysen and Bechky, 2009; Beane and Orlikowski, 2015).

Third, these findings highlight an additional coordination challenge that has been overlooked in the literature: lack of local experience with idiosyncratic technology. Against all odds, some workers came to know how to get procedures done safely and on time in OR 4 with the “shitty” robot. These individuals
regularly had to contend with other professionals who were only experienced with procedures on the “new” robot in OR 15, and all parties had to exert significant effort to bridge this barrier to the smooth performance of surgical work. Knowing what to do in the face of local idiosyncrasies with material arrangements (Sudnow, 1978; Harper, 1987) is a new kind of knowledge barrier for the coordination literature, which has focused on knowledge barriers rooted in occupational or functional differences (Bechky, 2003; Carlile, 2004; Kellogg, Orlikowski, and Yates, 2006). This barrier further highlights the importance of considering the implications of specific material arrangements for work with respect to coordination. Not all robotic surgical knowhow was created equal at Fairtown: it very much mattered where, when and with what specific system a robotic procedure was performed.

**Practical Implications**

Careful examination of the performance of robotic surgical work in OR 4 and OR 15 revealed that coordination tension and compensatory work were evident in both settings. While challenges, resultant coordination tension and compensatory work were prominent in work involving degraded – in this case unreliable and under resourced – technology, it was present in similar ways and to a lesser degree in work involving new, well-resourced and reliable versions of the same technology. This suggests that coordination tension may arise in much coordinated work and that workers likely have to engage in compensatory work to keep work flowing smoothly. As this study shows, these dynamics will likely become increasingly salient as organizations seek to extend ROI on technology by minimizing support and maintenance costs. How this plays out in different contexts, with differing technologies and through differing practices is an intriguing area for subsequent research.

Additionally, this study offers a likely brake to returns on top talent. As occurred at Fairtown, managers in many organizations may minimize support for significant investments in technology as they seek to maximize their return on such investments. Yet the compensatory work required to extract satisfactory value out of degraded technologies may both be invisible to these managers and hedge against undesirable outcomes. Managers may thus keep degraded technologies in service longer than is
wise, and miss the significant drain on slack organizational capacity as workers engage with degraded technologies in practice. Specifically, successful compensatory work disproportionately allocates the most capable workers to degrading technology, greatly increasing the likelihood that these individuals have a frustrating, draining work experience as they mitigate risk for the organization. Thus – at least to a point – compensatory work may serve as a brake on the advantageous deployment and retention of top talent.

Surgery with the “shitty” robot in OR 4 at Fairtown was failure intolerant work in which technological alternatives were particularly salient and the sunk cost of technology was high. When failure is cheap, alternatives are distant, and sunk costs are low, different responses may arise. Yet in an age of increasingly complex technologies, the central findings of this study – that coordination tension can arise as valued methods, moods and goals are jeopardized by material arrangements and that workers must compensate for this tension in order to get work done – is a useful contribution to subsequent studies of coordination. Likewise, the compensatory work identified – reconfiguring material arrangements, valued methods and compensatory work itself – are likely to address barriers to any collective work performed through technology. To the extent that organizations acquire complex technologies and seek to maximize their return by diverting scarce resources away from them, these findings offer insights into the often-invisible work done by those on the front lines to keep the lights on and the trains running on time.
Conclusion: Pushing Back from the Edge

Contributions

If this dissertation shows anything, it is that productive deviance was a crucial enabler amidst the pressures associated with robotic surgical practice at my field sites. Through a review of the literature, I found that Bernstein (2012) introduced, but did not explicitly define productive deviance, so I offered a definition to allow for careful analysis of my data: productive deviance consists of norm- and policy-challenging practices that are tolerated because they produce superior outcomes in the work processes governed by those norms and policies. After clarifying this important concept, I explored the ways that productive deviance played a crucial role in five discontinuous changes in surgical methods: the introduction of ether, antisepsis, surgical gloves, laparoscopic surgery and robotic surgery. Overall I showed that finding effective ways forward with new surgical technologies involved counternormative experimentation – for example deceiving and harming patients and causing inefficiencies. This set the stage for two in-depth investigations of productive deviance in robotic surgical work.

The first was focused on learning. Norms surrounding learning robotic surgical technique mirrored those in open surgery, and were consistent with legitimate peripheral participation, the dominant theory on learning in communities of practice. When these accepted, legitimizing ways of learning critical robotic surgical skills were inconsistent with new methods and technologies, a few trainees found a way to competence through shadow learning – a collection of practices that ran counter to the norms and policies of the very community of practice they aspired to join. The second of these focused on coordination. When an organization degraded one surgical robot yet maintained norms and procedural requirements suited to a well-maintained unit, surgical staff kept related surgeries coordinated through compensatory work – interconnected activities that reconfigured material arrangements, valued methods and compensatory work itself. Like shadow learning, compensatory work ran counter to the methods and moods that the surgical community valued for robotic surgery. And like shadow learning, compensatory
work was effective: patients did just as well on the degraded robot as they did with the well-resourced one.

We have many examples of deviance in the organizations literature, and beyond Bernstein’s study of assembly manufacturing in China (2012) we have a variety of studies on what we can now call productive deviance (Gasser, 1986; Azad and King, 2008; Tucker, Heisler, and Janisse, 2014). In such studies, workers engage in practices that run counter to norms and policies that guide a particular work process, producing better results in that process than they would have if they had adhered to these governing norms and policies. But we did not have, and this dissertation supplies, studies of productive deviance that is tolerated by the very community that holds its constituent practices to be problematic. Shadow learning and compensatory work were enacted by people who simultaneously upheld norms and policies that discouraged and even forbade implicated practices. Yet shadow learning and compensatory work were tolerated because they allowed for better results.

**Implications**

We turn to new technologies for better results and often get increased rationalization in the bargain. In surgery, the journey from prehistoric trepanation to robotic prostatectomy has turned on making practices ever clearer, more repeatable, safer and more effective. This has involved a growing body of rules, norms, policy and law, a mushrooming set of support materials and tools, and greater observability of the surgical process. All this rationalization has arisen amidst our push for continuous improvement and has left less and less room for discretion, experimentation and error. This contrast is clear even between open and robotic surgery: cutting someone open to remove their kidney requires fewer checklists, fewer tools, less outside visibility and offers more flexible task allocation than using a robot does.

As I look beyond the confines of my data into a 21st century economy marked by this accelerating algorithmic and robotic expansion, two generalizations about productive deviance seem warranted beyond those that I offered in prior chapters. First, productive deviance may become more prominent as
rationalization expands. Rationalization seems to limit locally productive options for top performers and slackers alike, and workers can only be pushed so far. We prize autonomy and mastery, and productive deviance offers a crucial means of preserving them. Second and relatedly, such marked increases in productive deviance may not be stable. On the one hand communities of practice may normalize – perhaps even celebrate – productive deviance itself as they recognize that getting ahead requires subverting their own rules. It is hard to conceive of a meaningful normative order under such conditions. On the other hand, communities of practice may begin to forbid and punish productive deviance as they experience its community-degrading effects. It seems this would prevent the progress that such deviance allows or convert it into other forms of deviance (e.g., crime, protest). Communities would pay either way – the center may not hold without shared values, beliefs and related routines, and quashing innovation allows for jurisdictional capture from without.

Future Research

We do not have to look far or wait long to find opportunities to ground this speculation in empirical study. No matter how marginal the gains to the average worker, we continue to introduce technologies to radically expand productivity by complementing and substituting for skilled human activity. In contrast to surgery, robotics and AI are just now being introduced into domains of work involving many millions of people – ranging from long-haul trucking to pick and pack work in fulfillment centers to grocery checkout lanes. These technologies promise value through rationalization and the concomitant reduction of human labor inputs, and workers will have a point of view on these transitions. More to the point, as these transitions unfold, some of these workers, their managers and likely others will defy the norms of their own communities of practice in their quest for productivity and meaning. At least for a time, their communities will tolerate this defiance, allowing us an opportunity to understand the role of such productive deviance in our trajectory as a tool-dependent species.

I am specifically focused on the role of productive deviance in two emerging forms of work: fleet supervision and human-robot collaboration. The former involves one worker supervising numerous semi-
autonomous robotic agents. Companies now produce and deploy fleets of mobile robotic systems that traverse physical environments for a variety of purposes. For example, Aethon Inc. specializes in materials delivery within healthcare contexts, Savioke Robotics focuses on delivering items in hospital contexts while improving the customer experience and Knight Systems, Inc. focuses on site security and customer asset management. In all of these cases, these systems navigate their environments and perform tasks with a high degree of autonomy, but groups of them are supervised by a single worker in a remote location. When a unit gets stuck, fails at a task or when people interfere with them, these technician-level workers get an alert, bring up onboard video and sensor data from the unit and manually pilot it back to routine territory, interacting with nearby people as needed. This new form of work likely presages similar work at a much broader scale in the transportation, construction, security and military sectors, and it is quite complex with respect to institutional expectations, observability and technical possibilities: remote humans work in their own organizational culture yet need to “drop in” via an algorithmically-guided, physical robotic avatar to numerous, diverse customer organizations to resolve problems.

The next generation of robotic surgical technologies provides an opportunity to investigate productive deviance in work involving human collaboration with robotic systems. While I was observing surgery, the da Vinci robot took collaborative surgical action in very minor ways: its onboard algorithms canceled out tremors in a surgeon’s hands, prevented the activation of cautery in both instruments simultaneously and prevented jagged, high-force movements. These effects are extremely subtle, and most surgeons did not mention them, let alone indicate that they represented any form of autonomous direction of surgical work. But the truly world-class surgeons I observed chafed against it and modified their technique to allow them to perform the ostensibly unsafe surgical maneuvers the system was trying to prevent. As in manufacturing, aviation, farming and the military, developments in this technology mean robotic systems will soon take a more active role in constituting skilled action. I expect to investigate how surgeons and surgical teams will respond to systems that play a much more obvious and
autonomous role in their work, and in particular when and how their responses constitute productive
deviance.

As I pursue these and other empirical studies, I also expect to revisit our theories of deviance in
organized life. Deviance requires challenging institutionalized expectations. But where, when how and by
what agents are these expectations institutionalized and challenged? I showed that even the world of
surgery – ostensibly collocated and collegial – is digitally dispersed in space and time, encoded in
algorithms, video and simulators, and involves numerous subgroups that enact markedly different
standards for the work in different times and places. Our theories of deviance need to expand to take this
diversity into account. Relatedly, algorithms and actuators may play a complex and theoretically salient
role in deviance in the 21st century: as we have recently seen (Orlikowski and Scott, 2014; Orlikowski,
2016), algorithms enact norms and policies of their own, and these are sometimes inscrutable, even to
those who have written them. Algorithms and the systems they actuate may therefore both label deviance
and become deviant themselves as they act in ways that stray from the norms and policies enacted around
them.
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Anteby, M.

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Ashforth, B. E., and R. H. Humphrey

Azad, B., and N. King

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Barley, S. R.

Barley, S. R., and G. Kunda
Barsade, S. G., and D. E. Gibson

Beane, M., and W. J. Orlikowski

Bechky, B. A.

Becker, H. S.

Beecher, H. K.

Benner, M. J., and M. Tushman

Berg, M.

Bernstein, E. S.

Bittner, E.

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Cummings, J. N., J. A. Espinosa, and C. K. Pickering

Dentler, R. A., and K. T. Erikson

DiBenigno, J., and K. C. Kellogg

Dill, M. J., and E. S. Salsberg

Douglas, J. D., and J. Johnson

Doyle, J.

Emerson, J.

Espinosa, J. A., S. A. Slaughter, R. E. Kraut, and J. D. Herbsleb

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Faraj, S., and Y. Xiao
Feldman, M. S., and W. J. Orlikowski

Ferneley, E., and P. Sobreperez

Fox, R. C.

Gasser, L.

Gawande, A. A.

Geertz, C.

Geller, E. J., and C. A. Matthews

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Harper, D. A.
Hinds, P. J., and D. E. Bailey

Hinds, P. J., and S. Kiesler

Hinds, P. J., and M. Mortensen

Hochschild, A. R.

Hutchins, E.

Hutchins, E., and G. Lintern

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### Table 1: Robotic Surgeries Performed at Fairtown

<table>
<thead>
<tr>
<th></th>
<th>2013</th>
<th>2014</th>
<th>2015³</th>
</tr>
</thead>
<tbody>
<tr>
<td>OR 4 (daVinci S)</td>
<td>81</td>
<td>84</td>
<td>142</td>
</tr>
<tr>
<td>OR 15 (daVinci Si)</td>
<td>352</td>
<td>375</td>
<td>394</td>
</tr>
</tbody>
</table>
**Table 2: Material Arrangements Challenge Methods and Goals for Robotic Surgical Work in OR 4**

<table>
<thead>
<tr>
<th>Problematic Material Arrangements</th>
<th>Challenges to Methods and Goals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Resolvable During the Work</strong></td>
<td>Substandard workspace setup</td>
</tr>
<tr>
<td>Room must be reconfigured, Drapes and cords missing, Wrong/missing drapes and camera, Robot not in right position, Robot must be broken down (and often taken out of the room) if the next procedure isn’t robotic, Supplementary supplies are far away and/or in unknown/multiple potential locations, One of up to seven cords not plugged in properly</td>
<td>Substandard supplies</td>
</tr>
<tr>
<td></td>
<td>Substandard resupply options</td>
</tr>
<tr>
<td></td>
<td>Excessive setup and breakdown</td>
</tr>
<tr>
<td><strong>Not Resolvable During the Work</strong></td>
<td>Overly complex setup</td>
</tr>
<tr>
<td><em>Components:</em> Persistently fogged/scratched camera is indistinguishable from functional camera until used, Pitted viewing lenses in console, Degraded fiber optic cords and cord connectors, Weak springs, joints and locks that hold robotic instruments in place, Actuator, camera and lamp failures</td>
<td>Substandard perception capability</td>
</tr>
<tr>
<td><em>Integrated Hardware:</em> Draping the monitor on the robot requires seven-foot reach, White balancing and calibrating the camera is a manual process requiring one sterile and one nonsterile worker, Draping robotic arms requires extra space given monitor, Seven similar fiber optic cords must be distinguished for fourteen separate connections, Hands-and-knees setup for console pedals, Tower monitor must be draped, Lack of centralized OR information and control interfaces</td>
<td>Substandard control capability</td>
</tr>
<tr>
<td></td>
<td>Staff with limited knowledge of degraded technology</td>
</tr>
<tr>
<td><em>Controls:</em> Camera light too bright/too dark, Lag between surgeon console actions and video, 2D vision when one camera eye fails, Visual acuity lower than Si, Inability to cauterize with both instruments simultaneously, Stiff pedals, Manual adjustment of console ergonomics, Neck angle causes strain despite adjustment, Masters harder to move, Switching between lenses requires manual switch on console, Some pedals control more than one function, Ultrasound systems do not interface with 3D display</td>
<td></td>
</tr>
<tr>
<td><em>Staff (In)Experience:</em> Surgeons, circulators, scrubs, medical students with limited experience in OR 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2013</td>
</tr>
<tr>
<td>------------------------</td>
<td>------</td>
</tr>
<tr>
<td>OR 4, experienced$^{1/}$ surgeons</td>
<td>51</td>
</tr>
<tr>
<td>OR 4, inexperienced surgeons</td>
<td>30</td>
</tr>
<tr>
<td>OR 15, experienced surgeons</td>
<td>197</td>
</tr>
<tr>
<td>OR 15, inexperienced surgeons</td>
<td>155</td>
</tr>
</tbody>
</table>

$^{10}$ Projected figures

$^{1}$ Two surgeons fell in this category; 16 were relatively inexperienced with the degraded robot in OR 4
<table>
<thead>
<tr>
<th>Work Characteristic</th>
<th>Legitimate Peripheral Participation (Open Surgery)</th>
<th>Shadow Learning (Robotic Surgery)</th>
</tr>
</thead>
</table>
| Perceiving trainee mistakes | Harder/private:  
• Only expert perceives trainee mistakes, many are invisible  
• (AP sees resident nick a small vein, then can’t see them suture it in resulting pool of blood) | Easier/public:  
• Work is magnified and rebroadcast to all workers  
• (Resident nicks a capillary, causing a “bleeder” that appears ten times actual size on four TVs) |
| Managing risk of trainee participation | Easy/Concentrated:  
• Expert can rapidly and personally deploy deeply-practiced techniques to remediate trainee mistakes  
• Risk peaks in middle of procedure  
• (AP presses on a vein nicked by the resident, throws a stitch on it) | Very hard/Dispersed:  
• Expert must initiate, direct and wait for coordinated work to remediate trainee mistakes  
• Risk peaks at beginning and end of procedure  
• (AP waits for scrub to remove, clean and reinsert camera, suck blood to expose a vein nicked by the resident, cauterizes it) |
| Involving trainees | Extensive/necessary:  
• Expert requires trainee help  
• (AP retracts tissues and sucks fluids to allow resident to dissect tissues, sutures, cauterizes vessels) | Restricted/Optional:  
• Expert does not require trainee help  
• (AP operates alone, briefly grants resident control to dissect simple, less vascular/nervous tissues) |
| Barriers to delegating work to trainees | Low/Many/Continuous/Private:  
• Expert regularly, easily and quickly reallocates trainee’s work across many dimensions to varying degrees  
• Delegating tasks and related feedback are largely tacit and private  
• (Resident struggles to dissect tissue, AP gently pushes it apart, allowing resident to clamp the target artery) | High/Few/Discrete/Public:  
• Expert rarely, easily and quickly grants all-or-nothing control of the work to a trainee, announces control shifts  
• Delegating tasks and related feedback are largely explicit and public  
• (Resident struggles to dissect tissues, AP loudly instructs resident, verbally notes mistakes, digitally takes complete control of robot, dissects out and clamps the target artery) |
<table>
<thead>
<tr>
<th>Dimension of Difference</th>
<th>Legitimate Peripheral Participation (Open Surgery)</th>
<th>Shadow Learning (Robotic Surgery)</th>
</tr>
</thead>
</table>
| Relation to norms and policy for trainee learning | Consistent:  
- Proceeds according to norms and policy  
- (“See one, do one, teach one” seen as right and proper, enshrined in residents’ evolving role) | Inconsistent:  
- Runs counter to norms and policy  
- (Improper educational sequence, abstract practice modalities, working without approved supervision levels) |
| Learning sequence | Routinized:  
- Trainees engage with a known, regular sequence of learning opportunities  
- (Residents “see one” first, “do one” later, “teach one” last) | Opportunistic:  
- Trainees engage with learning opportunities as they present themselves in daily practice  
- (Residents use the simulator in quiet times on night shift) |
| Cohort relations | Collective:  
- Trainees develop skill together with extensive awareness of each other’s pathways  
- (Residents learn as a cohort, progress together) | Isolated:  
- Trainees develop skill on their own with very limited awareness of each other’s pathways  
- (Residents learn alone, progress at other residents’ expense) |
| Access to challenging work | Access for competence:  
- Legitimized, necessary role grants trainees access to work near the edge of their capacity  
- (Residents deeply involved in almost every surgical move) | Competence for access:  
- Skill from extensive norm- and policy-challenging practice grants trainees access to work near the edge of their capacity  
- (Residents gain access by showing robotic fluency) |
Figure 1: Intuitive Surgical’s da Vinci surgical system
Figure 2: Advertisement for Davis’s Pain-Killer, circa 1845

12 Scanned from New York Hospital Archives
Figure 3: da Vinci Procedures, Global\textsuperscript{13}

\textsuperscript{13} Compiled from multiple ISRG annual reports: http://quicktake.morningstar.com/stocknet/secdocuments.aspx?symbol=isrg
**Figure 4: Shadow Learning for Acquisition of Robotic Surgical Skill**

<table>
<thead>
<tr>
<th>Premature Specialization</th>
<th>Abstract Rehearsal</th>
<th>Undersupervised Struggle</th>
<th>Consequences</th>
</tr>
</thead>
</table>
| Observing and participating in work with the new technology years before formal training begins, at the expense of generalist training, by:  
  - Supporting related research  
  - Receiving specialist mentorship  
  - Participating in the work | Practicing via simple simulation, analyzing recorded work when empirically-faithful rehearsal is prized:  
  - Practicing basic skills in simulation  
  - Analyzing recordings - entire procedures for familiarity  
  - Analyzing recordings - challenging segments just before work | Struggling near the edge of capabilities in real work with limited expert supervision, via:  
  - Working for superstars who rely on trainees to drive volume  
  - Working with lower-skill experts  
  - Working at institutions with less cost strain | Learning  
  - Those who engage in shadow learning build significant skill  

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th>Unintended Consequences</th>
</tr>
</thead>
</table>
|  |  |  | Limited Organizational Learning  
  - Slow adaptation to tolerated, undisussed practices |
|  |  |  | Matthew Effect for Skill  
  - Shadow learners get rapid, unequal and exclusive access to the work |
|  |  |  | Hyperspecialization  
  - Shadow learners prepared for hyperspecialized work yet most take generalist positions |
|  |  |  | Limits to Professional Capacity  
  - Longer training cycle and hyperspecialization constrain the flow of expertise into the profession |
Figure 5: Managing Coordination Tension via Compensatory Work, Given Degraded Technology

(Solid arrows denote increases in coordination tension, dashed arrows denote decreases)

<table>
<thead>
<tr>
<th>Material Arrangements Challenge Valued Methods, Moods and Goals</th>
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<td><strong>Resolvable During the Work</strong></td>
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<td>- Substandard workspace setup</td>
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</tr>
<tr>
<td>- Substandard resupply options</td>
</tr>
<tr>
<td>- Excessive setup and breakdown</td>
</tr>
<tr>
<td><strong>Coordinate Tension</strong></td>
</tr>
<tr>
<td>- Practical-affective stress</td>
</tr>
<tr>
<td>- Further challenges valued methods, moods and goals</td>
</tr>
<tr>
<td>- Motivates compensatory work</td>
</tr>
<tr>
<td><strong>Not Resolvable During the Work</strong></td>
</tr>
<tr>
<td>- Overly complex setup</td>
</tr>
<tr>
<td>- Substandard perception capability</td>
</tr>
<tr>
<td>- Substandard control capability</td>
</tr>
<tr>
<td>- Staff with limited knowledge of degraded technology</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Compensatory Work Reduces but also Increases Coordination Tension</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reconfiguring Material Arrangements</strong></td>
</tr>
<tr>
<td>- <strong>Stashing</strong>: making needed supplies ready at hand</td>
</tr>
<tr>
<td>- <strong>Fishing</strong>: securing rarely used supplies from uncertain remote locations</td>
</tr>
<tr>
<td>- <strong>Propping</strong>: recreating familiar, temporary tools from generic supplies</td>
</tr>
<tr>
<td>- <strong>Tweaking</strong>: making small, interdependent adjustments that shape inputs and/or outputs</td>
</tr>
<tr>
<td><strong>Reconfiguring Compensatory Work</strong></td>
</tr>
<tr>
<td>- <strong>Rushing</strong>: accelerating work</td>
</tr>
<tr>
<td>- <strong>Forcing</strong>: applying extra effort</td>
</tr>
<tr>
<td>- <strong>Venting</strong>: expressing and being responsive to stress</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Consequences</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Effective Coordination</strong></td>
</tr>
<tr>
<td>- Flow of interdependent work maintained</td>
</tr>
<tr>
<td>- Valued goals achieved</td>
</tr>
<tr>
<td><strong>Tension-Risk Swaps</strong></td>
</tr>
<tr>
<td>- Goals achieved at expense of staff stress</td>
</tr>
<tr>
<td><strong>Qualitative Filtering</strong></td>
</tr>
<tr>
<td>- All filter qualitative data</td>
</tr>
<tr>
<td>- Managers assess technology as adequate</td>
</tr>
<tr>
<td><strong>Handler’s Traps</strong></td>
</tr>
<tr>
<td>- Experience with neglected technology leads to more such work</td>
</tr>
<tr>
<td><strong>Temporal Shifts</strong></td>
</tr>
<tr>
<td>- Tension shifted to normally relaxed portions of the work</td>
</tr>
</tbody>
</table>