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Collaborating Alone: The Role of Technology Infrastructure in Scientific Problem-Solving Practices

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Abstract

This paper examines collaborative work involving complex technological infrastructure, and contrasts this setting with other contexts of technologically-mediated collaboration. In doing so, we center the role of problem-solving practices as one of the key determinants of successful collaborative work. Data from interviews and observations with scientists indicated that while the complexity of technology infrastructure consistently demanded intensive and collaborative problem solving, the scientific research pursuits it enabled were often considered personal in the context of day-to-day work. We found that a) while being physically present in the lab with others was crucial to lab work, lab members largely perceived their work as independent and research goals as personal, b) though asking questions was considered a marker of learning, lab members tried to address technological failures individually before approaching others, and c) staggered work schedules made it difficult to share knowledge about technological failures. These findings suggest a tension between interdependent and independent work practices which are facilitated by situated problem-solving around technology infrastructure. This tension shapes members' expectations of each other and creates ethical dilemmas where they have to choose between pursuing collective collaborative goals versus niche innovative goals. We conclude with a discussion on how the sociomaterial outcomes of technology infrastructure are driven by its unpredictable complexity rather than specific functionality.

Introduction

Research on collaboration technologies often focuses on the design and use of technologies created specifically for purposes of interaction among group members involved in interdependent tasks (Olson & Olson, 2012; Flores et al., 1988; Winograd, 1987). For example, group decision support systems, knowledge management systems, email, video conferencing etc., facilitate different forms of connectivity between individuals and information in the hope of improving collaborative efforts. In investigating the organizational and social consequences of such tools and infrastructure, literature focuses on how their functionality affords or challenges collaboration amongst team members – i.e., how specific uses of technologies make collaboration easier or harder (Leonardi, 2011; Leonardi, 2009). This view of the relationship between technology and collaboration is based on two assumptions that may not hold in STEM research settings. First, though individuals' situated goals and backgrounds may differ, this literature assumes that collaboration technologies largely offer users similar features, producing the potential for a shared experience. Second, research on collaboration technologies situates the technology itself as a central space of interaction and collaboration, meaning that it becomes a shared site of team communication. These two assumptions do not clearly apply to the context of STEM team spaces, where collaboration involves use of an ecosystem of technologies such as scientific hardware machinery, data analysis and simulation software, and other electronic systems and their physical components that are collectively required to support scientific work. In this paper, we argue for the need to view collaborative work in STEM settings as the product of a sociomaterial assemblage that at times deters active, ongoing interaction among team members.

Our research study on three interdisciplinary STEM labs suggests that a complex, physically imposing ecosystem of technologies are assembled in idiosyncratic ways to support the various scientific inquiries that demand collaborative work. Our findings demonstrate that when any technological part of this ecosystem broke down or did not work as expected, lab members sought each other's help in brainstorming and interpreting the meaning of those failures. This collaboration was not predetermined or anticipated and was emergent in their day-to-day problem solving and learning practices. As a consequence, the sociomateriality of this technology infrastructure is centered around needs that are local, emergent, and situated in nature (Suchman, 1985) as each technological piece plays a role above and beyond its own functionality in shaping collaborative work practices. However, we argue that exploring the sociotechnical nature of these collaborations through the material functionality of technology infrastructures is incomplete unless the idiosyncrasy of such collaborations is fully understood.

For example, lab members acknowledged that the multitude of hardware and software technologies together were a means to pursuing scientific research questions. As a consequence, while the complexity of these technologies consistently demanded intensive and collaborative problem solving, their scientific research pursuits were often considered personal in the context of day-to-day collaboration; collaborative work was organized around personal goals. This finding challenges the importance of common goal setting that is often privileged in the design of collaboration technologies. In other words, the personal nature of scientific goals constantly conflicted with the collaborative demands these technologies placed on them. Our data suggests that a) while being physically present in the lab with others was crucial to lab work, lab members largely perceived their work as independent and research goals as personal, b) though asking questions was considered a marker of learning, lab members tried to address technological failures individually before approaching others, and c) staggered work schedules made it difficult to share knowledge about technological failures.

These findings suggest a tension between interdependent and independent work practices which are facilitated by situated problem-solving around technology infrastructure. This tension shapes members' expectations of each other and creates ethical dilemmas where they have to choose between pursuing collective collaborative goals versus niche innovative goals. We conclude with a discussion on how the sociomaterial outcomes of technology infrastructure are driven by its unpredictable complexity rather than specific functionality. In the following section, we discuss the meaning of collaboration and compare collaboration technologies (i.e., information and communication technologies designed explicitly to support interdependent, task-based work) with technology infrastructure that motivates collaboration (i.e., technologies necessary for teams to conduct interdependent work). In doing so, we center the role of problem-solving practices as one of key determinants of successful collaborative work.

Collaboration vs Collaboration Technologies: Sociomaterial Practices around Technology Infrastructure

Ervin and Keyton (2019) define collaboration as an interdependent set of actions that help a group achieve a shared goal. Similarly, Reeves et al., (2018, p. 2) highlight the importance of interdependence and "clarity of goals" between collaborating individuals. Roschelle and Teasley (1995, p.70) echo the importance of shared and clarity of goals and define collaboration as a process of continuously constructing and maintaining a "Joint Problem Space" and argue that communicative processes are crucial to creating that shared knowledge as they establish "shared language, situation, and activity" as the most important resource for knowledge negotiation (p.

69). Nicholson et al., (2000) focus on this communicative aspect of collaboration but also problematize it and argue that “differences in values, languages, problem-solving strategies, and other elements of professional behavior” (p. 41) often beset successful collaborative work. Katz and Martin (1997) take a broader perspective on collaboration and argue for both active and passive participation such as providing guidance, and sharing information and ideas as legitimate collaborative research activities. In these contexts, both formal and informal conversations, and spatial, and social proximity become important to the success of this passive collaborative work. However, regardless of the extent of involvement, shared goals and communication remain central to successful collaborative work. Collectively, these definitions position a shared experience of work —goals, space, language, actions—as fundamental to collaborations.

Technology mediated collaboration is also predicated on shared goals and communication but depending on the type of collaboration media, and the context of investigation, social dynamics considered critical to collaborative work keep changing and expanding. In other words, while collaboration technologies are designed to facilitate interdependent work, the mediated (i.e., virtual) nature of work practices these technologies afford provide workers with more agency regarding when and how they engage with the technology and with each other. For example, mediated collaboration highlights the importance of “structural effects” of teams and their interdependent tasks in increasing productivity of collaborative work, and therefore focuses on the ways technology supports the creation and maintenance of relations among individuals and information (Walsh & Maloney, 2007, p. 724). Communication is deemed helpful for collaborative work, but the presence or absence of interpersonal conflicts also influences the success of collaborations. Similarly, Distributed Computing builds and expands the meaning of shared goals by demonstrating the importance of cooperation through competition, also referred to as co-opetition, as central to collaborative work (Holohan & Garg, 2005). However, this literature on collaboration and technologies explains how mediated communication and coordination shapes and promotes collaborative work (Olson & Olson, 2012; Bravo et al., 2013; Hughes et al., 1994); it rarely centers the role of technologies as demanding collaboration and how such technologies shape collaborative work.

Literature on sociotechnical practices suggest that in collaborative work settings with high levels of technology use, socio-technical factors can motivate collaboration in unique and unanticipated ways (Dougherty, 1993; Suchman,1987; Leonardi, 2011). For example, physical tools and technology infrastructures such as simulation software, complex hardware equipment, etc., not only facilitate work but are indispensable to work and often motivate collaborative problem solving and learning in intense ways that use of auxiliary technologies such as email, video conferencing etc., rarely do. In order for such technologies to work, teams need to establish substantial software and hardware infrastructure that supports them (Star, 2010): internet cabling, special electrical wiring, soldering tools, safety equipment etc. are a few examples. This technology infrastructure is not considered as "collaboration technology" in the traditional sense but it nevertheless asserts sociotechnical influence on the collaboration dynamics of work teams (Orlikowski, 2007).

The materiality of such technology infrastructures is markedly different from those of collaboration technologies in similar work situations. For example, while collaborating via traditional collaboration technologies such as email, collaborating partners are equivalent in the sense that they share the same virtual space and can collaborate in similar capacities as facilitated by design features of those technologies. However, for complex technology infrastructures, this equivalence is less likely to be assumed as the technologies themselves are often physically spread out and interconnected (Star, 2010) such that they do not have predetermined and specific design features. Because of its modularity and interconnectedness, infrastructure design, broadly speaking, keeps evolving even when it is being used. For example, switching between different kinds of components and soldering mechanisms to make an electrical circuit work demonstrates the level of free-customizability of technology infrastructure in which this electric circuit is plugged. Given this modularity and interconnectedness, infrastructure cannot be accessed at the same time and in similar ways, and collaborating individuals often have different understandings of and experiences with different parts of such equipment (Nicolini et al., 2012). Such differences between collaborating individuals motivate collaboration for problem solving purposes and collaboration becomes an end in itself rather than being a means to an end as is the case for collaboration technologies.

Star (2010) refers to technology objects that encourage problem solving and meaning making across knowledge boundaries as boundary objects and Knorr-Cetina (1997) uses the term epistemic objects in referring to the capacity of objects to create shared knowledge. Such boundary and epistemic objects (Knorr-Cetina, 1997; Star, 2010) operate more as the object of collaboration in addition to being a mediator; a substantial portion of collective action is oriented towards them (Kaptelinin and Nardi, 2006; Nicolini et al., 2012; Swan et al., 2007). The materiality of this infrastructure is situated in its invisibility (Star & Ruhdler, 1996); as long as it continues to support work, it is an indication that its material components are working as intended. However, when there is a break down, infrastructure is no longer invisible and its materiality is embodied in the practice of mending the break down. It is during this time that its material complexity and flexibility is more intimately experienced, understood, and realized. This temporal unravelling of the materiality of infrastructure is connected to and emerges in problem-solving practices (Engestörm, 1990). Star and Ruhdler (1996) refer to this sociomaterial context as "infrastructure organized in practices" (p. 113) where practices are foregrounded in understanding infrastructural material (Bowker, 1994).

In this sense, material becomes independent of its material properties in determining the extent of its relationship with the social. For example, a tiny resistor, if short-circuited, can bring down the electricity supply of a whole building regardless of how materially miniscule it is in size. However, the extent of impact this short-circuit has depends on the socially consequential meaning of electricity supply to that building which could be a school, a residence, or a hospital. Consequently, the material aspects of infrastructure, independent of its traditional material properties, are distributed and embedded in not only corresponding electrical circuit and also the practices it supports. As complex technology infrastructures "trigger action," and shared goals of action shift towards problem-solving (Nicolini et al., 2012, p. 626), fluid daily practices become a site where the differences between the two kinds of collaborations unfold. Using problem-solving practices as a context for studying collaborative work in scientific settings that heavily rely on technology infrastructure, we ask the following research question:

RQ: ***How do technology infrastructures shape problem-solving practices in STEM labs?***

Methods

We collected data from three interdisciplinary STEM laboratories from three different universities in North America. Over a period of 16 months, we conducted 27 interviews (19 Zoom interviews and 8 on-site in-person interviews), attended 26 lab meetings, and shadowed three lab members in-person. Remote interviews and meeting observations began in the beginning of the Covid-19 pandemic in Spring 2020. However, we also conducted in-person interviews and observations in October 2023 when travel was considered relatively safe with regards to the pandemic. While lab members acknowledged the impact of Covid-19 on their day-to-day practices, the findings in this paper are based on themes that surfaced as repetitive and consistent across the data. Lab members noted that in-person collaborative work around hardware technologies was influenced as they had to either stay away from the labs altogether or take shifts to use the labs; collaborative brainstorming around simulation and coding technologies was less constrained and was conducted remotely. The interviews were spread across three labs—12 interviews from lab A, 8 interviews from lab B, and 7 interviews from lab C. The interviews lasted an average of 60 minutes ranging between 33–93 minutes. Observation of lab meetings was spread across lab A and lab B:16 observations for lab A and 10 observations for lab B. The interviews were conducted with graduate students, undergraduate students, lab engineers, professors/lab leaders, lab directors, and postdoctoral associates. Lab members serving in these roles often attended the weekly meetings we observed. In-person shadowing was conducted with a graduate student, a lab technician, and a postdoctoral associate from lab A. During the lab meetings, note taking was split between the two researchers attending the meetings; one of the researchers took notes on meeting conversations and the other researcher noted non-verbal communicative behavior. The interviews followed a semi-structured interview protocol built on questions about their day-to-day collaboration activities, different knowledge and technical skills of lab members, culture of these labs, and their expectations from each other, and any ethical dilemmas they faced in their work and field in general. These questions served as entry-points into discussions about specific lab experiences around collaboration and work priorities.

The field notes taken during in-person interviews and field observations served a primary role in guiding the coding process and emergence of themes discussed in the findings section.

These themes were generated from lab members' responses to questions that directly and/or indirectly reflect on their collaborative work. The interviews transcripts, in-person field notes, and field notes taken over Zoom, were consulted to ensure that the patterns and themes identified during the in-person interviewing and observations repeated and recurred with force (Owen, 1984) across the three labs. The researchers discussed the emergent themes and compared the themes with their own experiences in the field along with the memos they took during interviews, and meeting and field observations. This data analysis was also accompanied by the manuscript writing process which informed the interpretive processing of interview and observation data. For example, writing the findings section helped researchers think through the connections between the research question posed and activities observed in the field. This process contributed to the iterative process of consulting data, writing the findings section, and discussing emergent themes with other researchers. These themes do not represent a comprehensive list of the collaboration dynamics in the lab but instead reflect on our interpretation of their work practices as it relates to the research question we asked.

Findings

Interdependent versus Independent Work

We observed tensions between lab members' perceptions regarding the expected interdependence in their work, and the individual demands of daily practices. The plethora of tools and hardware and software technologies along with their paraphernalia created many opportunities for lab members to run into technical issues that they were not familiar with or needed more guidance on. Many lab members across the three labs acknowledged the need to communicate and interact with others on a daily basis to ask questions about software and hardware tools, to collectively interpret the data generated by these tools, to share their scientific expertise with others, and to figure out logistical issues with regards to their work. However, they also indicated that their work was independent, their research goals were largely personal, that they most often worked alone, and they were not reliant on others especially when they had a good sense of their tasks. Commenting on the extent to which their work was interdependent, a graduate student working in lab A acknowledged collaborating on experiments with outside members but also considered their work as being primarily independent. Another graduate student from the same lab agreed with this perspective and explicitly disputed the suggestion that work was collaborative.

A postdoctoral associate who had been with the lab for upwards of 10 years acknowledged that lab members collectively valued independence in other lab members and that this was one of the goals of the lab: "...one of the things that people strive for is independence… part of the training is becoming an independent scientist and I think that people who are able to develop that independence do really well." However, when asked about their day-to-day work, they acknowledged communication and interacting with several members of the lab on a daily basis: "So… mostly... me personally... I interact with [a research engineer] … also talk with some of the graduate students… [they] ask me questions about code that I am very familiar with... I'll also speak with [lab engineer] usually when I am on my way into work... so if I have some target question… I'll stop by and talk." This reliance on others was not considered as constituting a collaboration or a form of interdependent work. When asked about how interdependent their work is, an undergraduate student from the same lab acknowledged that as new members in the lab they needed to ask questions and learn from others but also alluded to eventually being independent: "At the current moment I would say quite a bit... I am a beginner... I need to learn from the undergrad who is a lot more advanced... If he is not there, I am usually struggling trying to understand what I do. Once I know what I am doing its really independent work." In reference to the priority of their personal goals versus group goals, the undergraduate student also mentioned: "I won't say anyone is not concerned about the lab... but I will say most people in the lab are not there because they love the lab... In the long run, most people do research here because they want to get to something better that they care about." The interdependent work in the lab was carried out with an understanding that personal goals are a priority over group goals. In other words, unless lab members were working on similar research areas, investing time and effort in providing help to others rarely translated into an incentive directly related to their own research. Even when lab members were working on common research problems, they acknowledged making "sacrifices" when they potentially compromised on innovative research outcomes of their unique ideas by setting up the parameters of physical equipment in a way that allowed other lab members to collect data as well.

Similar tensions were observed in work practices of lab B where asking for help or guidance did not necessarily translate into lab members perceiving their work as interdependent especially in ways that would elicit certain expectations from each other. A graduate student who was new in the lab commented on asking other people for help: "Because I am less experienced in the code... I could go to my advisor or someone that worked with a similar code earlier... If I mentioned my problem, they could say, 'I did do that earlier and I can help you with that.'" But while discussing their expectations from each other, they mentioned: "Right now, my work is not exactly tied to another person's work. So, it's not like anyone is expecting a deadline from me. It's again, based on my expectations from myself." When asked about relying on others for help, another graduate student from the same lab mentioned that they relied mostly on the lab leader because other students were working on very specific and niche topics: "If there are other grad students around, I'll ask them, but a lot of times people are working on really different things, and so I can’t always ask for help." But while discussing the importance of in-person communication and interaction, especially at conferences, they mentioned: "I think the pandemic has shown a lot of people that those in-person, casual interactions you have are so important. That’s how people come up with things. People come up with new collaborations and ideas from just having dinner together and then just spit-balling stuff." Even though this comment was made from the perspective of conference attendees, other members across the three labs unanimously acknowledged the importance of communication and shared similar experiences with their colleagues in the lab. A graduate student from lab C mentioned communication as one of the most important resources: "just communication... you can solve a problem together... You can brainstorm and build off of one another ideas and work on something to further each other's mindset, further each other's grasp of a concept." While the importance of communicating, learning, and building on existing understandings of scientific concepts was noted, day-to-day work practices were not organized to particularly encourage this kind of interaction.

Members from lab C provided a slightly different perspective to the question of whether their work was characterized more by interdependence versus independence. While they acknowledged highly interdependent work practices given the experiments they ran, their sense of independent work was built on being alone on a day-to-day basis. When asked about how interdependent their work is, a lab technician from lab C commented that while they needed each other's help in setting up physical equipment, they primarily worked alone: "He [another lab engineer] knows a lot... If there's just a process I haven't done before, he's great at walking me through that so that I can get comfortable with that... But on day-to-day stuff, usually, unless they're teaching the process to someone else, most everybody works alone." But at the same time, they mentioned that it was very important for them to be communicating quite often with each other: "Between the staff and I, we, of course, see each other most every day. Then, we'll either talk to each other down here on the [floor number]...we're communicating either in person or via Slack...just to be able to have that instant messaging so that everybody, including grad students who might be working with us, is aware of where they're at." The meaning of interdependence was defined in very specific ways in these labs—when their personal research work or experiment needed actual hands-on assistance or intellectual and scientific guidance they considered their work as interdependent but when they provided guidance to others, communicated about day-to-day logistical and technical issues, or spent a substantial amount of time they referred to as working alone, they largely considered their work as independent.

Asking Questions versus Figuring it Out

The perception of independent work in an interdependent work setting also reflected in how lab members decided to approach others to ask for help especially when they ran into failures. Because they considered it as their own personal work, they prioritized figuring out *their* technical failures by themselves. In lab A, a postdoc commented that investigating failures by yourself before asking others was valued by lab members: "if you can advance things yourself and then ask questions of others…'I want to advance this in this way and I would like to use this tool to do that.'" It was seen as being respectful of others' time. A graduate student from lab A acknowledged struggling with having to make the decision about asking for help: "I struggle with that so much. That is one of my biggest problems because I feel like I ask stupid questions, and I don't want to be the kind of person that is, all of this is easily researchable. Why did you waste my time?" Another reason lab members considered figuring things out themselves was because it was a way for them to learn. A member from lab B commented: "...if you look at your experiment and it fails, being able to figure out why is probably a pretty good indicator that you know what’s going on." They seemed to consider that the technical failures they ran into were their responsibility or as one graduate student from lab B described it—their "job"; they expressed feeling guilty for reaching out and asking questions of their lab leaders: "I don’t know. I feel like I probably rely on [the PI] a lot... I feel bad. Sometimes, I feel like he’s doing my work for me...If me and [another graduate student] are working on stuff together, usually we’ll kind of try to think of as much stuff as we can... to potentially narrow down the issue without asking [the PI] for help." Referring to the challenges of interpreting data generated by scientific equipment, a graduate student from lab C commented: "when I think about looking at the data and analyzing it and interpreting it, sure, I can do part of it by myself, but ultimately, I'm going to be talking to someone about it to understand it better". Another graduate student from lab C echoed: "I like to show up to a meeting with [the PI] having tried a few things and convinced myself that I've figured out what the solution is, or gotten to a point where I'm like... it's a good time to maybe check in with someone." Asking for help was a kind of favor for lab members and they had to initially struggle with a problem before approaching others. However, the reluctance to ask questions was not only to be respectful of others’ time but also to learn and to demonstrate that they were learning.

Senior members from lab C also acknowledged that when junior members in the lab had a problem with equipment, they were expected to ask questions because the equipment was expensive and also because it was an indicator that they were learning: "If you get stuck, you're going [to] ask before you break something. Because things are expensive." When asked how lab members made progress and advanced their learning, another senior member in the lab mentioned: "If you're willing to reach out and bug people, and ask stupid questions, and make mistakes and break things, you'll advance a lot quicker... it's going to lead to mistakes occasionally, it's going to lead to damage occasionally, but it's also the only way to move forward." The motivation of senior lab members to encourage junior members to ask questions was contradictory; they had to break stuff in order to learn but they also had to ask questions and be careful around expensive equipment. It created a tension between how lab members navigated problematic situations when they ran into technical failures; the decision to ask for help versus figuring it out themselves was not straightforward. An undergraduate student from lab B indicated that while some students tried to push through and solve issues by themselves, they considered asking others as a way to learn as well: "I did do my own problem-solving, but they were things that were squarely, like, I should be capable of, but if I gave it my best effort and couldn't figure out... they would help me. I feel like that's a productive learning relationship. I know that some people like to struggle through until they solve it." A senior graduate student from lab B acknowledged that figuring such problems was a way they demonstrated, not to just to others, but to themselves as well that they have learned: "at some point, you go from having to look something up to being able to just figure it out yourself... for me personally, that's gonna be a really big tipping point, when I feel confident enough in my knowledge and stuff." Both alternatives—asking questions versus figuring out problematic situations by themselves—contribute to scientific learning and demonstrated experience and expertise with lab infrastructure. The decision to go either way, therefore, was context dependent, and was made based on the expectations of the senior members, lab culture, and personal preferences of lab members.

Staggered versus Synchronized Work Schedules

The cadence with which lab members ran into failures, asked questions of each other, and communicated on a day-to-day basis fractured the time they spent together—it was interrupted and interleaved with substantial alone time. They saw different people at different days of the weeks, times of the day, and referred to different people for different kinds of failures and questions. When asked how they communicated with others in the lab, a graduate member from lab A mentioned "I usually use email… at least to start… if it's something like a bigger discussion that need to happen… be a time to talk on Zoom or something like that. or if they are already close and it is not a hassle for me to... schedule a meeting... can you meet this Tuesday... and then spend half an hour talking what I need to talk about…" Their interactions with others and their work schedules were staggered and guided by their own goals and needs along with others' knowledge and skills. While this member had to explicitly synchronize their lab hours in order to communicate with others, some other lab members relied on weekly meetings or they were just available in the lab most of the time. A senior lab member mentioned: "Usually, there are meetings... I would say those meetings are maybe for [the PI], who's doing bunch of stuff. For me, I'm here, so they find me all the time. I don't need any meeting with anybody." A postdoctoral associate from lab A who had expertise in multiple areas acknowledged that they were often in their office in person: "A lot of it is informal… just in our offices and in our cluster… you just walk across the hall and talk to them… other than that… email...G-chat sometimes…" Their approach to the time they spent physically present in the lab markedly varied by their roles and skills.

A graduate student from lab A acknowledged that their time together was not just a matter of routine: "So, we have separate meetings for each experiment and so there's more than just that group meeting per week that we would talk to each other." They also mentioned that sometimes, their communication was rather informal where they would follow up on email or chat. "And so, when I had meetings with [the lab members], I'm like, "Oh, if you have any more questions, feel free to shoot me an email or call me or something and we can talk about things. So, there were sometimes more informal things like that. And then sometimes if I need to talk to [the PI] and I'm in a meeting with [the PI], I'll just say, 'Hey, can I talk to you for five minutes,' because that's sometimes easier than trying to set up a time to talk." Another student from the same lab acknowledged the causal communication: "Well, with [the PI] usually I either text, Gmail, or G-message. It's very casual. We have a very casual relationship I'd say. And then, with the other students I'm really mostly friendly with a couple of other people, and usually it's just G-chat or text". Their temporal work rhythms were not formally synchronized given their dynamic work practices, personal goals, and unanticipated and spontaneous failures.

Discussion and Conclusion

Distinct work practices around technology infrastructures i.e., a lack of synchronized work schedules, divergent approaches to seeking help, and interdependence in work motivated by independent research agendas, challenge the meaning of collaboration and the idea that successful collaboration demands and encourages shared goals. These practices operate within a problem-solving culture that is not reliant on convergent goals in the sense of traditional forms of collaboration. In reference to material infrastructure and how it motivates situated problem-solving practices, Nicolini et al. (2012) and Corellete (1989) discuss a similar phenomenon they refer to as "community without unity" (p.621) i.e., individuals engaged in such problem solving around technology infrastructure have different understandings of the technological object with "contradictions and conflicts abound" (p. 621). We argue that in addition to different understandings of technological objects, the lack of shared goals and practices around these objects creates ethical dilemmas when members have to choose between a) common and collaborative versus unique and innovative research inquiries given limited access to technologies, b) investing personal time and effort versus seeking others' help on problems with shared infrastructural resources, and c) providing support to fellow lab members versus minimizing this help in favor of personal research outcomes.

The labs we studied owned and maintained technology infrastructure as a shared resource—it was everyone's responsibility in the lab and nobody's responsibility specifically. While providing problem solving support on this infrastructure was expected, it was not a priority for most lab members; especially because it is challenging to pin-point problems in complex technologies without investing significant time in troubleshooting and navigating the layers of complex structures of such equipment. This "embeddedness" (Star & Ruhdler, 1996, p.113) of infrastructure where components (and failures) are "sunk into" (p.113) each other much like "Russian dolls" (Nicolini et al., 2012, p. 622) leads to murkier boundaries around what lab members could expect from each other and from themselves; there is scope for ethical dilemmas to emerge. However, having to consistently deal with tenuous day-to-day failures deprioritizes the need to explicitly acknowledge these dilemmas. Consequently, while such dilemmas continue to arise, day-to-day practices make them invisible and unnoticeable (Margolis, 1993; Engeström, 1999), and the ways in which they are navigated become a personal decision and a part of implicit lab culture.

Technology infrastructures are deeply embedded in the day-to-day scientific practices but their relationship with ethical decision making in day-to-day work is not deeply deliberated. While the focus of this research study and corresponding instruments was on collaboration and learning, an explicit investigation is needed of the different kinds of hardware and software technologies these labs deploy. For example, studying coding practices specific to the creation of research software can illuminate the extent of work-related decision making that goes into writing and using source code; decisions that largely remain hidden and invisible (Moor, 1985). Similarly, investigating big and unwieldy hardware technologies such as telescopes, lasers, or particle accelerators, that assert their influence on day-to-day work by taking up substantial physical space, can demonstrate that technologies' influence on work is not limited to their functionality. Such technologies shape collaborative ways of working in unanticipated ways by physically constraining and/or encouraging certain types of movements around them. Additionally, collaboration can be problematized beyond the scope of problem–solving practices in order to richly appraise technology infrastructure as a site of ethical dilemmas and to understand the intricacies of ethical decision making in scientific research labs.

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