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Pushing the Boundaries of Interdisciplinary Collaboration

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Abstract

This study examines the way participants of knowledge-intensive, interdisciplinary, project-based work in academic settings described the kinds of expertise that were valued by their groups. We found tensions in these descriptions, which suggest that an understanding of the kinds and value of expertise in these settings may benefit from broadening. We found that these labs served as spaces for members to socialize new students to the field, share norms and expectations, and distribute resources. Domain expertise was largely downplayed, while more intangible qualities such as curiosity and perseverance were amplified. Participants described their groups as sites of application and significantly, sites of learning the *culture of practice* that is expected. Implications of these findings are discussed, including theoretical and practical, and potential insights for engineering educators are surfaced.

Introduction

There is a great need to understand how novice engineers collaborate in interdisciplinary settings to accomplish STEM work. Teamwork, leadership, and other "social" elements of engineering are recognized as critical in engineering pedagogy (ABET, 2020), and have been a subject of study by engineering education researchers for years. How people collaborate depends in part upon how they assess one another's knowledge, skills, and potential contributions to their project. Communication scholars have developed a framework for understanding how individuals in highly knowledge-intensive settings, like engineering and design, signal, claim, and invoke expertise as they collaborate across disciplinary, demographic, organizational, and a myriad of other boundaries (Treem, 2012). This line of research recognizes expertise not as an inherent trait, or tied to credentials, formal roles, or other traditional "signals," but rather as a communicative accomplishment by which individuals signal and recognize expertise in others and surface these conceptualizations in the course of their work. For example, Barley and Treem (2020) studied the way domain expertise, or knowledge about a specific and narrow field, was less important in patient communication about emergency pediatric care than was process expertise, or knowledge about the ways in which different departments, specialists, and transport staff worked together—knowledge which was often held by nurses, not attending physicians. Recognizing how expertise is communicatively constructed, and then used to accomplish interdisciplinary work, offers insights to engineering educators working with novice STEM students to help them better recognize and utilize the various forms of expertise that may be present, but latent, in project-based work.

This study challenges the social-technical divide (Trevelyan, 2008) and argues that the type of knowledge that is valued in engineering and STEM settings may be limiting professionals' ability to fully engage with their work. Specifically, we examine the way participants of knowledge-intensive, interdisciplinary, project-based work in academic settings described the kinds of expertise that were valued by their groups. We found tensions in these descriptions, which suggest that an understanding of the kinds and value of expertise in these settings may benefit from broadening. We found that these labs served as spaces for members to socialize new students to the field, share norms and expectations, and distribute resources. Domain expertise was largely downplayed, while more intangible qualities such as curiosity and perseverance were amplified. Participants described their groups as sites of application and significantly, sites of learning the *culture of practice* that is expected. Implications of these findings are discussed, including theoretical and practical, and potential insights for engineering educators are surfaced. We conclude that there is room for engineering educators to more explicitly and mindfully develop skills such as perseverance alongside more traditional skills in order to more fully prepare future STEM professionals for their work.

Utilizing Expertise in Group Settings

Research across disciplines has noted that the identification and negotiation of expertise is critical for sustained successful team collaborations in organizational contexts where work is interdependent and problem solving is interdisciplinary. Most frameworks are largely economically rational frameworks that argue that the challenge for groups is to identify what expertise exists across members, and then develop ways to match tasks with that expertise or combine expertise in beneficial ways. Research on transactive memory systems (Wegner, 1987), cognitive interdependence (Hollingshead, 2001), and group decision making (Grundmann, 2017) all reinforce the idea that the main challenge for collaborative teams is surfacing expertise and determining the right forms of interdependence. These views of how expertise operates in team settings treat expertise as something that is both easily identifiable within individuals and roles, and something that can be applied discretely to a particular task or problem. Indeed, over time disciplines, professions and roles become affiliated with particular forms of expertise and assert jurisdiction over particular tasks and work roles (Abbott, 1988).

However, these frameworks regarding the utilization of expertise in group settings rely upon assumptions about the practice of expert work that may not match how individuals operate in STEM laboratory settings. These perspectives start from a common fundamental assumption that experts know and/or have the tacit knowledge (Collins and Evans, 2007) to act as they are expected to within the frames of specific context and time. Yet, though STEM laboratories are specialized groups with specific project goals and task responsibilities, they are also environments for learning, training, and discovery. As such, though lab members may have specialized skills and insights relative to lay individuals, it is also accepted and understood that they are operate in an environment where they likely lack the level of expertise to independently complete many tasks. Because individuals are not fully aware of what they are expected to know or do, aforementioned theories regarding expertise offer less insight into how "outstanding individuals" (Ericsson and Smith, 1991, p. 2) are distinguished in a collaboration or whether or not distinguishing such individuals is even a priority. This necessitates an examination of how laboratory members negotiate task responsibilities in an environment of uncertain and incomplete expertise among individuals.

The role of knowledge in the pursuit of knowledge

In explaining how work is accomplished and expertise is negotiated in dynamic research environments focused on learning, Hutchins (1995, p.19) describes the process of collaborative "wayfinding" whereby actions emerge through the practice of generating context relevant knowledge continuously (Kuhn and Porter, 2010). This framework recognizes that the utilization of knowledge, and the relevance of expertise, is always situated and shaped by the particular problems faced by a group within a specific time and context. For example, knowledge and expertise tied to shifting research settings and resources such as novel research problems, research staff, and unwieldy physical technologies etc., demands consistent renewal, and therefore is not always transferable to different problems or settings (Van Maanen and Schein, 1978). Put differently, there is a tendency to view problems, and the expertise needed to address them, as far more static and recurrent than they are in practice. As a result, frameworks for recognizing and valuing expertise in laboratory settings may discount the emergent, situated, and even improvisational nature of knowledge practices in these settings.

It is critical to recognize that junior researchers training in interdisciplinary settings are in different stages of learning their craft, have widely varying research and career goals, and work within the confines of research labs with shared access to limited resources. Possibilities to seek individual experts and resources outside the lab are limited given their lack of wider network that is rather associated with higher academic ranks and more experience (van Rijnsoever et al., 2008). This is not to say, however, that junior researchers do not have access to these networks through their senior colleagues, but collaboration nevertheless with restricted immediate access to experiential knowledge and resources. Collaboration, therefore, becomes complex and challenging given limited resources, disciplinary differences, and coordination issues (Walsh and Maloney, 2007). Moreover, junior researchers are expected to produce expert-like outcomes despite the widely different work circumstances they have in comparison to their senior colleagues (Beane, 2019; Harvey and Bourgoin, 2018). They operate as experts-in-the-making, or novice-experts, in that their own standards of judgment for themselves are not stable and personal enough, i.e., their expectations from themselves are still evolving based on their mentors', and senior colleagues', expectations from them. They need to strike a balance between borrowing expert standards against building a set that is unique to them and their work practices.

As a consequence, they are learning to precisely evaluate the inevitability and consequentiality of the compromises they make in work which makes them more vulnerable to overreaching and/or struggling with imposter syndrome (Kets de Vries, 1990; Harvey and Bourgoin, 2018). Their domain vocabulary is still developing, making 'thinking-aloud' and communicative demonstration of problem-solving skills another challenge in collaborative situations. As individuals struggle with this "learning-credibility tension" (Harvey and Bourgoin, 2018, p.1612), they rely on performance metrics to communicate their progress, assert their learning abilities, and gain a sense of security in their work. But in such roles, metrics act as a double-edged sword—both under and over-performance are problematic to a reasonable assessment of the self. The inevitable comparisons with experts make overperformance less gratifying and a relatively higher tolerance for underperformance lowers the stakes behind demonstrating expertise because failure becomes a fallback option. On the contrary though, these challenges of self-assessment could also be mitigated by the fact that junior researchers are not weighed down by the baggage of expertise—presumptions, ego, and pressure. Moreover, junior scientists are less likely to be entrenched in an orthodox sense of belonging to a specific disciplinary tribe (Becher, 1989). Incentives to prioritize learning and collaborating are higher than competing and downplaying others.

In studying how differences in academic ranks manifest in collaborative work, power dynamics as dictated by one's role in a team has been known to influence access to resources (Ibarra & Andrews, 1995). But, in scientific research labs, critical resources are so limited within and outside the lab that scientists across geographically separated labs have to generate scientific goals collaboratively in order to ensure efficient use of resources—no matter the academic rank. In such contexts, it is possible that extraordinary resource shortage means that collaborative work processes become the default mode of working and could shift the locus of power in unanticipated ways. For example, in the collaborative data collection phase when scientists are using the same equipment to run different experiments, ability to accommodate requests regarding changes in equipment parameters is independent of academic rank and rather depends on access to and familiarity with facility operators and other individuals present at a data collection site. The old adage "It's not what you know, but who you know" is often played out in real time in these settings, with those able to identify the key personnel more able to achieve their desired outcomes. Investigating power dynamics with a focus on work practices around collaboration and problem solving can provide insights into shifting power and its leverage.

Additionally, problem solving processes tend to coalesce existing knowledge from disparate disciplines in unanticipated ways in order to generate innovative solutions (e.g., generating simulation models does not only require knowledge and expertise in physics but also in programming and statistics). When statistical models fail or machines stop working, problem solving collaborative sessions lead to creation of new knowledge that belongs to no specific disciplinary label. Less is known about negotiation of expertise in such contexts where new, discipline-agnostic, and context-specific knowledge that fundamentally determines expert behavior is continuously generated and renewed. In such scenarios it is challenging to distinguish 'good' solutions from 'outstanding' ones at the very moment a problem is solved which makes evaluation of expert behavior difficult—clarity about dos and don'ts in novel situations comes over time. Power dynamics that operate as a function of knowledge and expertise, therefore, remain fluid and their anchors are unveiled over time. Moreover, organizational settings where collaboration is guided more by common goal setting and lack of resources necessitates that exchange of interdisciplinary perspectives be situated and understood in context of other disciplinary perspectives—engineers cannot develop machines unless they have a fairly decent idea of the physics it is intended to achieve which has implications for how shared knowledge as power is theorized. In addition, funding of scientific research puts bureaucratic pressures on research labs' collaboration initiatives making negotiation of expertise inherently political.

Organizing for experts-in-the-making

Differences in the level of established knowledge, and associated task and role responsibilities, among individuals working in a heterogeneous group laboratory (where members' background varies by discipline, experience, and project) mean that priorities and motivations are likely to diverge at times. One consequence of these divergent goals and interests is that distinguishing experts among group members might not be a shared goal. Rather, the need to solve problems collaboratively in restrictive circumstances, and to produce near-professional outcomes (Beane, 2019) necessitates excellence, "resourcefulness, ingenuity, and creativity" (Tucker et al., 2021) to emerge in some form—no matter the descriptive label. Collaborative practices and communicative negotiation of expertise in such settings could, therefore, differ from existing understandings. There is a plethora of research on quality and quantity of scientific collaboration (Leogrande, and Nicasso, 2021) in academic and commercial institutions, international and cross-disciplinary contexts (Pelz and Andrews', 1966; Traweek, 2009), and in context of research questions urgent, niche, and/or political in nature. Literature on scientific collaboration often investigates 'scientists' as a heterogeneous group with diversity of discipline, geography, politics, team size, cohesion, research areas etc. with the exception of Kraut et al.,

(1990) who study physical proximity as correlated to collaboration amongst scientists of varied ranks. Less is known about how such differences in academic ranks manifest in day-to-day collaborative work practices that lead to innovative expert work to emerge. Moreover, it is challenging to derive such an understanding from existing literature that lacks a practice-based investigation of scientific environments. Apprenticeship work (Beane, 2019) and practice-based learning (Mann et al., 2021; Beane, 2019) largely encompassing “knowledge accomplishing” activities (Kuhn and Porter, 2010, p.23) can provide insights into how restrictive circumstances and necessities of junior researchers give way to invention and allow them to develop innovative problem-solving skills, develop expert work patterns (Treem, 2012), and develop a sense of security and confidence that later distinguishes them as experts. This study investigates experts-in-the-making in a scientific research lab with a specific focus on their communicative practices that yield to successful collaboration in diversified scientific work, and focuses on a single research question:

RQ 1: How do individuals in knowledge-intensive, interdisciplinary, and project-based university STEM labs communicatively negotiate the distribution of scientific work in ways that benefit personal and group goals?

Methods

Graduate and undergraduate students, professional engineers, and scientists employed by two interdisciplinary science laboratories in the U.S were interviewed, and observed remotely through Zoom interacting during respective team meetings over a period of 10 months. Both labs engaged in international collaborations, had federal and university funding, and encouraged within and outside lab collaborations motivated by access to resources and scientific facilities. Members ranged from physicists to computer scientists to engineers, representing an array of

STEM disciplines. During the time the labs were observed, they were in different evolutionary stages of leadership and their team meetings, interpersonal dynamics, and responses to interview questions reflected so—lab members less accustomed to an individual in a leadership position more often reflected on the differences between older and newer ways of organizing during interviews. Due to COVID restrictions, both interviews and observations were organized and conducted remotely over Zoom. The interviews were voluntary and organized by the researchers but the meetings were organized by individual lab leaders and researchers were invited to 26 weekly meetings for a period of 4 months—16 and 10 meetings each for the two labs. A total of 7 interviews, averaging an hour and ranging between 40-78 minutes, were conducted—3 and 4 interviews respectively with members of each lab. The interview questions were exploratory and open and the interview protocol was semi-structured to allow the interviewees to drive meanings that made most sense to the context they worked in. In spite of the semi-structured nature of interviews, the questions were kept as consistent as each interview allowed in order to make fair comparisons across interviews. The interview responses were anonymized and access to data was restricted to concerned researchers alone.

The interviews were transcribed using manual transcription service. Authors engaged in open coding of interview transcriptions, and discussed emerging themes during the coding process—themes relevant to the research question. During the coding phase, memos were generated. While doing the line-by-line open coding of the interviews, a running commentary on why a certain statement/finding/observation was important to the research question was made in the form of separate memos. For example, if an interviewee mentioned that they had never thought about a question that interviewer asked, authors made note of it and reflected on why that might be, how it reflects on interviewee's perception of the question, and how it implicated findings in context of the research question. This process ensured that important observations consequential for the research question did not get lost as the number and variety of open codes increased, and that the research questions continue to guide the open codes being generated. Similar process was followed during meeting observations and note taking exercise.

Findings

Our analysis found three major themes characterizing participants' experiences of their work practices, formal and informal work values, preferred ways of acquiring knowledge, and preferences to collaborate with other individuals inside and outside the labs. Most interview codes converged on a set of ideas that are not surprising on their own, but are provocative in how they challenge existing traditional understanding of what is important in preparing for STEM work environment. We discuss three major themes articulated as central tensions: curiosity versus disciplinary affiliations, perseverance and domain knowledge, and personal development through informal or formal collaboration.

Curiosity vs Disciplinary Affiliations

Disciplinary affiliations were not deterministic; instead, curiosity and personal interest characterized the research trajectories for many of the participants. Indeed, disciplinary background may have provided the direction and impetus that initiated individuals in certain research settings, but respondents indicated that these categorizations did not often dictate specific work assignments and research collaborations. Aside from the logistics of funding and project availability, personal research interests and specific prior task or technical experience played the central role in directing work assignments. Though multiple respondents acknowledged that funding determined the overall possibilities of work assignments by directing the broad goals of projects, participants described a distinct effort to align their daily work practices with personal interests. As one lab member described the manner in which they took on particular projects, “I started working on that. But [the leaders] were initially setting up a different project for me to work on. And then after thinking about it and talking with some people, I said, ‘I’d really like to work on something a little bit different than that.’ And they said, ‘Okay. Great. We have this project if you’d like to work on it.’” In this way, the members of the lab sites in this study were not bounded to developing specific domain expertise as dictated by their disciplinary identities, and were instead encouraged to cultivate diverse interests and develop varied expertise. This lack of established expertise among lab members – whether they be doctoral, masters, or undergraduate students – created a context where they could likely pursue their desired skill development within the scope of whatever broad interests the lab was pursuing. The lack of knowledge was viewed as creating initial flexibility in terms of tasks assignments and responsibilities.

This may be a common way tasks and projects are delegated in student teams. Yet through the lens of expertise, we see that this practice is useful in developing varied expertise on teams, which has both pedagogical and professional development implications. A byproduct of this flexibility in assignments is that lab members were able to expand the scope of their work – or become increasingly specialized – based on situated curiosity, and less on directed needs. For example, one of the undergraduate students mentioned that most of their lab work involved working with resistors and soldering circuit boards despite having little initial knowledge about fundamental physics or electronics. They acknowledged that they not only learned while on the job but also developed interest and curiosity through that process, commenting,

> When I first arrived, I was doing mostly shadowing of one of the lab tech…and he taught me a lot about just basic stuff like soldering. And so, I hadn’t taken a physics class when I first arrived. So, he taught me some really basic physics. He was the first one to teach me that voltage is actually a potential, which seems fairly obvious. But it was something

> that I hadn't learned as a 16-year-old high school student…. It's [working with circuit boards] a lot of trial and error. It was the first board that I'd made. And it was a very simple board, but it took me a very long time to get it right, mostly because it was the first time I'd done it. And [leader's] mentality is sort of he gives you the tools you need and then you fail forward, which I really appreciate 'cause I've learned a lot about coding and about circuit board development and design by having the opportunity to fail forward over and over. So, it can be very frustrating sometimes, the science, but when you finish a project, it's always very rewarding.

This comment exhibits the type of "basic" learning that occurs as lab members figure out how best to contribute to the ongoing projects and role demands of the lab. Respondents consistently noted that areas of focus were dictated by situated demands and interests and less so by the application of existing knowledge or even a desire to develop a shared form of expertise. As an engineer in a lab reflected on the lack of need for specific knowledge prior to contribution, "I think anybody can do what I do if they try to do it. I had no training before I got here. Oh, yeah, what do I feel – oh, knowledge, knowledge – 'cause I was going to say care, you have to care. I don't know that you have to know anything, to be honest. I mean if you can put doll furniture together, or a model, I don't think you have to have any special knowledge." Given the fundamental motto of *learning-by-doing*, the questions around willingness to take on certain tasks were more prevalent than the questions around abilities to do them.

This is not to say, however, that classes and disciplinary training were viewed as irrelevant, but it did not dictate how work was accomplished in the labs. The labs in this study provided ample opportunities to work and learn given that an individual had the curiosity and relevant research aptitude to make use of those opportunities. Multiple graduate students compared learning through textbooks and classes with learning-by-doing and while they acknowledged that classes helped, their preferred way of learning was doing work, asking questions, clearing assumptions, and being around people from the lab. In sum, learning was viewed as a situated practice. One lab member described their experience of learning-by-doing:

> A lot of it comes from classes. I took two plasma physics classes last semester, and I feel like I learned a lot from that. There were a lot of things, terms that would regularly come up in the field that people would use, and I would just be like, I don't know what that is. I feel like I have a much better grasp on it now. It also just comes from spending a critical amount of time around people who talk about these things and then just looking it up or asking somebody, 'What is that?' For me, I really prefer to learn about things by talking to people about them so that I can ask questions to clear up the wrong assumptions that I will make rather than just reading a textbook. Because yeah, I can read a textbook, but I might read something incorrectly or assume something incorrectly. It's also just not as exciting to me to learn via reading a textbook. I'd much rather just have a conversation with somebody and ask about it. … When I was learning about one of the new diagnostics that I'm working on, I read as much as I could and then I had a meeting with my friend… She was still there at the time, and she did a lot of research on that type of diagnostic. I just talked to her for an hour and just asked a bunch of questions, and I feel like that really sticks with you a lot better, at least for me. Yeah, I think you learn a lot of that from classes, hopefully, but I think in reality you probably learn a lot about it from just talking to people and reading people's papers. A lot of that stuff, it gets covered in the intro section of people's papers.

This comment exhibits how the process of knowing and learning-by-doing is context specific, i.e., it is grounded in problems at hand, and, therefore, yields better work practices in the lab. The rewards of accomplishing work and learning-by-doing feeds into the research aptitude and curiosity needed to sustain learning over time. A graduate student acknowledged that while deciding lab priorities, the lab leaders prioritized preserving the interest of lab members in the work they do: "So, I think, I don't know how it came to be, but I think it was a delicate balance of tasks. Do we need 10 diagnostics for the machines before the machines are built, probably not, but gotta keep people interested, I guess." The emergence of creativity, and expert work by extension, became a matter of willingness, availability of resources, and a culture that preserves and nurtures the latter. Disciplinary background was, therefore, only theoretically suggestive of who knew what in the team or in the field in general. In fact, it did not determine how collaboration partners were identified in practice.

Findings suggest that in identifying research collaborators who can persevere through complex problem solving, individuals turned to team members who were doing similar research;

had access to resources; and were easy, fun, and kind to work with. In describing what they needed to do their work well, a graduate student commented: “And so, I think enjoying what you’re doing is another important thing that I look for in other people working in the group.” The value of keeping people interested also came through how individuals described lab culture. Being kind, supporting, and helpful surfaced as major themes across multiple interviews and observations: “So, yeah, maybe this will circle back on the kindness and just being supportive….And I generally think that everyone in here is just trying to help everyone else do as good a job as possible.” Disciplinary affiliations might operate as a proxy rationale to satisfy the procedural hiring demands but do not determine the success or failures of collaborations—results are shaped more by research aptitude, curiosity, and interpersonal skills. Junior lab members who had not studied physics or engineering outside of the lab nevertheless made critical contributions to complex problem solving while the label of their professional roles might suggest a false impression regarding their disciplinary backgrounds.

Perseverance vs Domain Knowledge

Because lab members worked as experts-in-training, it was understood and accepted that there would be aspects of tasks and lab work they would lack the required knowledge and skills to conduct. As a result, respondents observed that it was perseverance, far more than knowledge, that determined what “sets apart” individuals in the lab. Lab members acknowledged that having domain knowledge or being smart can be helpful but over time “sticking it out” was central to achieving success in a given project. Of particular note, when asked what resources, helpful suggestions, and advice they received while working in the lab, interviewees did not mention much about domain specific knowledge; “making it through grad school” and “sticking it out” were instead the popular themes: “When I was an undergrad, the grad student I was working with, she told me. She was like, “Everyone will be smart. You are smart. I am smart, but I might be the smartest, but I am stubborn. As long as you just keep going through it, then you will do a good job.” They later added, “He [another student] also gave the same sort of advice of [that] everyone is smart, but what really sets you through is what you stick with… If you’re gonna feel discouraged, just stick through it. You might not feel like the smartest, but if you just stick through it then you’ll be a good student.” Domain knowledge or lack thereof to solve complex problems were not described as a deal maker or breaker, but persevering and continuing to learn through dynamic and frustrating situations was seen as essential. Respondents recognized the iterative nature of their roles, which they viewed as a long-term pursuit in which forms of knowledge and learning build over time. Given the long-term aspects of projects, perseverance was recognized as having tremendous importance in scientific research labs. This recognition of the value of perseverance was coupled with the awareness that work would often be frustrating and that they would inherently face problems that they were ill-equipped to address. This produced an environment in which lack of knowledge or abilities was not framed as a bottleneck, but rather an opportunity (and time) to learn and gain new knowledge and skills. A lack of persistence and steadfastness created problems in accomplishing work and collaborating with others. This holding perseverance over domain knowledge was a surprising divergence from the extant literature. While domain knowledge was still essential in these highly complex, advanced scientific projects, the participants significantly downplayed its role in the overall usefulness of other lab members and the overall success of their projects.

In referring to the knowledge and skills they gained over time, a final semester graduate student indicated that apart from learning more about the science in their field, they had developed work stamina: “So, I think I’ve made significant progress. I think I’ve learned a lot about science that I didn't know before, which is good. That means I've probably done something useful in the last five years. And I feel like I'm juggling more things now than I was able to at earlier points in my schooling. You know. I know things that I thought were unmanageable in undergrad, I'm like, yeah, that wasn't a big deal. Yeah. So, I don't know what I was complaining about." This comment is indicative of endurance and the ability to stretch oneself and not break which comes after having persevered through one's time in the research lab. It indicates that perseverance—the ability to endure and go on even when exhausted—is one of the most common challenges to overcome, one of the most important 'research muscle' to build, and a major accomplishment. By creating a supportive and kind environment, the group culture is also geared towards making perseverance possible so much so that these themes surface while discussing skills needed to succeed in the lab.

One way that perseverance manifested in these laboratory settings was as a willingness to communicate and interact with others in an attempt to gather situated knowledge or address emergent needs. While referring to scientific equipment that is hard to access, and operate, one of the graduate students mentioned:

> I think you need good communication. It always comes down to that because the number of problems that I've seen happen because of a lack of communication is a lot, and it can be really expensive too. If you can't communicate your targets on time or your [experimental] parameters on time, that destroys the entire experiment and you can't even do that.

Conducting experiments across facilities was a collaborative endeavor and when an experiment failed, all collaborators suffered. An implication of this was that 'good' communication was less about providing the right answer or sharing specialized knowledge, and more about communicating situated resource needs, project logics, and parameters of tasks so that individuals had the space, materials, and time needed to conduct work. Productive communication was intricately tied in with an understanding of equipment and project design. In responding to the benefits of sharing information, one of the respondents mentioned,

> So, you can avoid some pitfalls that are inherent to a particular facility rather than a particular experiment or something like that. So, there are some facilities where you're all hands on and you have to – they may say, 'We have a [specific piece of equipment]. You have to set up everything else.' And so, if you want to be really ambitious there, that can hurt you if you don't have enough people to actually set all of that stuff up…And if you're at a really big facility where they have people who set up everything and you basically bring in the thing they're gonna [use for the experiment], then there are different issues to worry about, but still things to avoid. And so, I guess, that's the way I see it, is...I think messing up the way you think the science is gonna go is part of learning the answer to these questions. But it's helpful to not have to fight the facility to do that.

The valued knowledge in this sense had little to do with the fundamental disciplinary knowledge, and much more to do with effective ways of working and how to productively interact with others to accomplish needed tasks at a particular time and in a specific context.

Note that this understanding or knowledge is not contained within a single individual. This situated knowledge is created as equipment designers, assemblers, experiment designers, facility engineers, and other collaborators communicate about how best to conduct work. As one lab member noted,

> And so, you have to be able to talk to the technicians that are setting up different measurements or setting up the… current machines that we use. And you have to be able to talk to the directors of the facilities and the people who manage the facility because they're the ones who are trying to schedule you or figure out what you're trying to do to keep things organized. And then there's collaborators and things like that. So, I mean, you need to be able to at least communicate with people well.

Respondents recognized the value of interpersonal communication in the process of learning and accomplishing work. Thus, perseverance operated as a central characteristic in how participants described their fellow lab members, with some explicit emphasis on the value of communication. Given the highly complex and deeply scientific work of these labs, this reframing away from domain knowledge was notable.

Personal Development through Informal vs. Formal Collaboration

The emphasis on situated learning, and the centrality of interpersonal communication to accomplish tasks, indicate the necessary interdependence among lab members and the ways knowledge development operated as a social process. However, despite a very active culture of helping and supporting one another in the lab with respect to experiment design, simulation, programming code etc., when asked about the nature of collaborative work within the lab, individuals commented that their work was quite independent of one another in terms of goals, daily work, and desired outputs. In other words, although lab members interacted with each other to learn how to best conduct their individual work, the work itself was not collaborative in the sense that one individual's work fed into other people's work. When asked if they collaborated with others in their lab one respondent replied, "Within my group? Not at all; it's completely independent, I'd say my research has been completely independent of other students in [the group]. My [lab 1] work is mostly an independent project, and then my [lab 2] work is very dependent. The group members do depend on these results. I work with them." Another student working in the lab echoed these sentiments, noting:

> So, not really. So, most of the graduate students' work is independent of other graduate students. We all have different experiments that we run with other collaborators and things. But the work for a single experiment is typically on a single graduate student. I guess the only time that's different is when someone's handing something off to someone else and then there's – you're just trying to retain all of that knowledge from one person to the next.

There was an understanding that though individuals' work often relied on the same equipment, used the same resources, and applied similar procedures, there was often little or no overlap in the specific focus of the research or problems or questions addressed. Thus, the relative importance of the socialization and informal mentoring is amplified in these labs.

However, despite not having interdependent or shared collaborative goals, the same individuals acknowledged that they often looked to other members in the lab for making contextual sense of complicated theories or experiment design. In discussing if they ever seek knowledge from other lab members when conducting their work one respondent noted,

> Yeah. All the time. So, like I said, we use these big [specialized] machines. And I couldn't even begin to tell you how to operate that whole facility. You know. I know bits and pieces of how things work, but the details of getting that whole facility to run is not only at least ten-person job on a day of, but a few dozen people job to keep things running consistently. We couldn't do any of our work without relying on that knowledge. And then on the other side of things – or I guess more in-house – we do a lot of experimental work. But we also do computational work to simulate these experiments that we're gonna do to either try and pick out [scientific] results or figure out the timing of our measurement and come up with a guess of how things are gonna operate. And understanding how all that computational – the infrastructure – works, is another thing that I rely on other people knowing a bit more about. So, I can really understand what a simulation means when I see something in a simulation.

These comments indicate that relying on each other for knowledge, and for what lab members referred to as technical assistance, help, and support was not considered a collaboration. Rather, they described a *culture of practice* as lab members strived separately to develop expertise, together.

When individuals discussed how they decided who to collaborate with or how they met collaborators, they indicated formal research collaborations amongst individuals they were not necessarily familiar with. It was at these settings beyond the immediate lab that individuals sought connections with those who shared similar project or problem-related interests and specialized knowledge in an area. One respondent described this process:

> Through conferences; you sit through a bunch of different talks, and you catch one slide that's like, oh, this is my only tangential to what it is I do. I do this one topic, and we collaborate a lot with other groups. It's a small field. It's not terribly big, so we all kind of know each other and we all kind of gossip about each other. We kind of know who knows what or you know somebody who knows what, and you can usually find a trail for somebody.

When discussing collaboration, respondents tended to view the nature of collaborative work materially in the sense that it meant individuals were present at the same time, using equipment simultaneously, and working with the same data and analytical tools on a project. This interpretation of collaboration and interdependence/reliance could be an influence of the usage of this word 'collaboration' in the field in general as being synonymous to formal research collaborations. As such collaborative work was something that was viewed as both occurring outside of the immediate laboratory setting, and being resource-intensive. It was not necessary, possible, or even desirable, for all individuals to pursue this type of work. As one respondent noted,

> I think it depends on the nature of the collaboration. But there can be a lot of – red tape isn't the right word. But there can be a lot of annoying things that pop up when you have to work with some of the national [facilities] or you have to work with… at some facilities. And there are some people in better positions to get through some of those things or to help with various parts of the project.

Individuals were confident that work within their respective labs provided opportunities for personal development, but were more skeptical about the benefits of collaboration which would require actions and access that might be beyond what they could control.

The cognitive and social dispositions regarding collaboration with others, therefore, bears disciplinary impressions of those of the field. As evident from aforementioned comments, these formal collaborations are burdened with expectations of overlapping interests, insecurities of collaborating with 'free-riders,' and hesitancy in approaching unfamiliar individuals. Within-lab interdependencies that are less formal did not bear such burdens of the commitment associated with what individuals consider as formal collaborations—expectations and demands from each other and collaborative outcomes in general were lowered, seeking support was less challenging, and providing support was more likely to be perceived as goodwill gestures given the lack of clearly defined 'gains' associated with formal collaborations; there is space for new ideas and creativity to breathe allowing for personal development.

Discussion

This study found that three central tensions existed in participants' descriptions of their experiences in highly knowledge-intensive, interdisciplinary project-based labs. The researchers considered the tensions between curiosity and disciplinary affiliations, perseverance and domain expertise, and personal development through informal or formal collaborations. The findings offer several implications to theory and practice. They illuminate some of the struggles of professional development in interdisciplinary project-based academic settings, and offer insights that may be of use to engineering educators as they seek to cultivate novice engineers who will one day engage in professional practice in such knowledge-intensive interdisciplinary settings. While some of the findings are not shocking on their surface, the implications for practice may be significant.

For example, delegating tasks by curiosity instead of discipline may be a common way tasks and projects are delegated in student teams. Yet through the lens of expertise, we see that this practice is useful in developing varied expertise on teams, which has both pedagogical and professional development implications. Indeed, while many project-based engineering endeavors emphasize learning or applying specific knowledge, our findings suggest that they rather more significantly served as spaces for members to socialize new students to the field, share norms and expectations, and distribute resources. Domain expertise was largely expected to be developed by parallel classwork, while the labs themselves served as sites of application and significantly, sites of learning the *culture of practice* that is expected. Despite being labeled as members of a "group," many participants reported feeling relatively independent in their work tasks from group members. Rather, they described their sense of community as a space for trial and error, sharing collective wisdom, and troubleshooting with the group. With the work itself reframed as secondary to these experiences, the relative importance of the socialization and informal mentoring is amplified in these labs. The importance of the *social* development of the students became central to these experiences. Thus, perseverance became a defining feature of their descriptions of successful group members, rather than development of deep or impressive domain expertise.

This privileging of perseverance over domain expertise was a surprising divergence from the extant literature. While domain knowledge was still essential in these highly complex, advanced scientific projects, the participants significantly downplayed its role in the overall usefulness of other lab members and the overall success of their projects. In deemphasizing domain knowledge in favor of perseverance, these participants may be inadvertently making space for different people with diverse backgrounds to succeed in this setting. On the reverse, this emphasis on adherence to work and communication norms may serve as a gatekeeping function, which would disallow an individual with significant domain expertise but lacking in the communication or the "appropriate" performance of perseverance from succeeding and proceeding to professional practice. This finding merits future study, as it holds significant implications for the role of diversity and inclusion in project-based academic settings.

Learning and Interdisciplinary Work Practices: A Dynamic Function of Context

Curiosity, perseverance, and personal development as skills most suggestive—even more so than disciplinary affiliation, domain knowledge, and formal collaborations—of successful and continual accomplishment of work in STEM laboratories is a provocative finding but not surprising. It is provocative because disciplinary affiliations have been known to exert a stronger influence on work practices—even more so that work practices influence academic learning. Electrical engineers often “assign” themselves to different tasks on a project than mechanical or biomedical; physicists would approach the same project differently from computer scientists. A wide variety of ‘job descriptions’ and work practices for similarly named professional roles attests to the incongruence between academic and professional settings and mitigate the potentially surprising nature of these findings—work contexts are inherently dynamic and independent of corresponding academic inspirations given the differences in their organizing strategies and professional motivations. This is not to say, however, that these differences are unjustified. The idea is rather to acknowledge and embrace these differences and provide scope and space for alternate approaches to learning and knowing to be proactively acknowledged, established, and encouraged.

Academic and professional research institutions have both acknowledged that an aptitude for these skills is important to succeed in STEM environments, but such discourse often frames them as *motivators* that are only instrumental in initiating individuals into learning disciplinary knowledge. More often than not, it is the domain specific knowledge that assumes a central and decisive role, and is a determinant of how successful work is accomplished in real practical scenarios that are dynamic and chaotic. The problem is that when framed as motivators, these skills are assumed to be either present or absent and less as skills that can be attained, protected, and nurtured. Curiosity or perseverance are not in and of themselves taught in a degree program,, but rather, they find their place in the inferential elements of learning, in mottos, and in job descriptions of professional roles. As a consequence, there is less explicit focus on how to develop these skills. These findings, therefore, have implications for existing understandings in how education, and professional and interdisciplinary work in these settings is envisioned—it widens the possibilities and opportunities but also demands a substantial shift in elements of knowing and learning that are assumed as focal to successful work practices.

Note that organizing processes that yield to a learning and work environment that focuses on how to learn, be curious, and persevere are emergent and context-specific as well. These findings suggest that we might need to temporarily 'park' the ideas of 'focal' and 'primary and secondary' skills—the idea is not to fixate on elements such as disciplinary knowledge, and corresponding practices but to rather acknowledge that these focal elements may change and shift in meaning in varying contexts or might as well cease to be focal altogether as key to successful STEM work becomes a function of context and any singular set of focal skills will either not serve or yield to intended work outcomes across different settings. And even if they do, they might not manifest across different settings in the same way. Questions of successful interdisciplinary collaborations might, therefore, translate into questions about motivations and practices they yield to.

Power Relations: A Dynamic Function of Time

Power as a function of knowledge suggests that knowing more has more leverage in accomplishing successful work. Therefore, those who know more have more influence, and better access to resources as work structures in their corresponding institutions yield better to them than others. But, when curiosity, perseverance, and personal development through informal collaboration become the levers of successful work practices, it becomes relatively challenging to identify locus of power—asking who is more curious is not as helpful, especially given the lack of measures of curiosity and perseverance. In fact, even if such measures were to be developed and utilized, they may not serve the intended purpose because unlike knowledge, curiosity and perseverance are elements that ebb and flow with time. Moreover, there are clearly defined ways to develop knowledge and maintain it and, therefore, there is relatively more control over the ability to attain and keep it. But curiosity and perseverance, just like creativity, are dependent on work environments and personal circumstances that are difficult to pin-point but nevertheless are instrumental in hosting successful work practices—it is challenging to develop, maintain, and ensure a 'steady supply' of curiosity and perseverance at will. Identifying precisely when specific contexts yield better to curiosity and perseverance provide a better understanding of developing and keeping these skills, i.e., answers to questions about 'who' or 'how' are less revealing and relevant than questions about 'when.' In such scenarios, power relations are bound to remain in flux—shifting with time as work and personal circumstances shift.

Interestingly though, curiosity, perseverance, and personal development through collaboration also bear an innocuousness that evades or challenges existing perceptions of power and control structures. For example, concertive control, and self-surveillance as reproducing or manifesting in curiosity and perseverance is harder to identify and dismantle especially when such reproduction is not consistent and its manifestation changes for individuals over time. In fact, curiosity challenges theories of concertive control by hinting at an unstated willingness to act—a willingness that is preceded and driven by freedom of thought rather than oppressive self-made informal values as motivations to act. The difference between the two being that this willingness is an object of admiration by the self and the others—while self-surveillance may be an object of self-admiration as one takes pride in disciplining oneself but it is less likely to be admired by others as they are better positioned to observe the concertive control. Note, however, that control always operates through elements that have leverage over organizational resources—

situating curiosity and perseverance within that space can provide insights into how it manifests in practice. This shifting and evasive power locus also interacts with other levers of power—discourse, network, resources—in unanticipated ways which is consequential for theorization and praxis of power.

Conclusion

This study provided an initial examination of the role of expertise in knowledge-intensive, interdisciplinary, project-based academic settings. Specifically, we surfaced questions of what type and whose knowledge are described as valuable to these groups, and the potential implications of these conceptualizations. Perhaps because of the interdisciplinary setting, these groups deemphasized domain expertise in favor of more intangible qualities such as curiosity and perseverance, which opens space for different kinds of scientists to potentially break into these spaces with the proper socialization and training. More data will enrich existing knowledge about power dynamics, interdisciplinary work, and specificities of STEM work and its relation to context and time. Further data collection is expected to corroborate, speak to, or challenge the findings discussed thus far, and also mitigate the limitations of having conducted small number of interviews.

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