Closing the Practice Gap:

Studying Boundary Spanning in Engineering Practice to Inform Educational Practice

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***Abstract*—How to adequately prepare engineering graduates for careers in industry has long been a concern for academics, policymakers, and employers. However, the realities of engineering practice remain somewhat mysterious to many students and instructors, often leaving engineering graduates underprepared for the workplace, and employers dissatisfied with new employees. In this work, we seek to better understand the job expectations and realities of working life as experienced by early career engineers. In this paper, we more specifically focus on three engineering practice scenarios drawn from three interviews to demonstrate the complex, sociotechnical nature of engineering work in large corporations. Our analysis of workplace boundaries, boundary spanning activities, and personal attributes revealed an inextricably linked set of concepts that we present in a new conceptual framework. We conclude with a discussion of implications for both how we understand engineering practice and approach the teaching of engineering. It is expected that this paper can help students, faculty, and industry affiliates reflect on the realities of engineering work.**

Keywords—engineering practice, boundary spanning, personal attributes, research to practice, sociotechnical

I. Introduction and Background

A recent National Academy of Engineering (NAE) report titled *Infusing Real World Experiences into Engineering Education* reflects growing interest in exploring the role of universities in "better preparing engineering students for the workplace" [1, p. 2]. This report and a bevy of other publications have repeatedly pointed to rapid and ongoing changes in organizational structures, work environments, and technologies [2] as some of the trends that continue to transform job roles and career pathways for engineers and other technical staff. In response, key stakeholders have argued that engineering graduates should have a wider range of capabilities. As aptly summarized by one industry representative quoted in the aforementioned NAE report: "Historically, engineers have received excellent technical education, but have generally lacked formal training in the additional skills required to succeed in today's globally connected, rapidly evolving workplace. Young engineers need to be taught how to think independently, communicate clearly and adapt to change to become leaders in the global marketplace" [1, p. 3].

Yet in pondering how such visions might be realized and scaled up, it is important to consider what specific gaps and challenges must be addressed. To begin, a variety of reports suggest wide disparities in student and employer perceptions of job readiness among college graduates. For example, one recent American Associate of Colleges and Universities (AAC&U) survey found that university students reported high levels of preparedness across a wide variety of learning outcomes, while employers consistently ranked graduates much lower [3]. Studies specifically focused on engineering reveal higher levels of satisfaction among employers regarding the technical capabilities of graduates, and general satisfaction with their lifelong learning and problem solving skills [4]. Yet in this same study, about a quarter of surveyed employers reported inadequate preparation in the areas of communication and teamwork, while nearly half were dissatisfied with the ability of recent graduates to understand the "contexts and constraints of engineering practice, design, and research" [4, pp. 48, 74].

These findings suggest a significant disconnect between what students are learning in the classroom versus the realities they face when they enter the workforce. This in turn raises questions about how educators might transform courses and curricula given what we know about engineering practice. Yet there remains a surprising lack of high quality research on engineering practice [5], and the literature that does exist is often not well known among many faculty, industry affiliates, and policymakers. In evaluating and reforming engineering curricula, policymakers at all levels do frequently solicit input, opinions, and advice from industry representatives. Yet the kinds of evidence typically drawn on by such individuals often appear rather anecdotal when juxtaposed with empirical studies that more broadly examine the experiences of practicing engineers in variety of fields, firms, and contexts.

As another difficulty and complication, outcome-based approaches are increasingly the dominant teaching and learning paradigm in engineering education. In engineering this is most potently reflected in the ABET EC2000 framework, which deserves considerable credit for moving engineering programs away from input-oriented curricular models and toward a more outcomes-oriented mindset that places more explicit emphasis on both technical *and* professional learning outcomes (i.e., Criterion 3). Yet even this reform can be critiqued for its emphasis on discrete learning objectives. One consequence is the continued maintenance of an artificial and arguably counterproductive dichotomy between the technical and non-technical dimensions of student learning, as well as a lack of appreciation for how professional work often involves simultaneously exercising a wider array of capabilities.

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Recognition of the latter is increasingly recognized in calls to investigate and promote "meta-attributes" or "meta-competencies" in engineering, with innovation serving as one among a number of notable examples [6].

This paper represents part of a larger effort to study and address some of the "practice gaps" described in the preceding paragraphs. A key starting point for our efforts centers on the notion of boundary spanning, which is another meta-attribute that has been identified by multiple stakeholders as a desirable capability for college graduates in general and engineers in particular [7, 8, 9]. In brief, we argue that boundary spanning occurs whenever a professional communicates, collaborates, and/or coordinates across boundaries. These activities and interactions can in turn involve many different boundary types, including organizational, job role or expertise, disciplinary, time, space, demographic characteristics, knowledge, etc.

The research presented in this paper is linked to three more specific objectives. First, we aim to investigate how early career engineers experience boundary spanning challenges in their day-to-day work. Second, we wish to examine the relation between the social and technical dimensions of engineering practice. And third, we intend to relate research to practice, namely by using our findings to critically evaluate and reimagine how engineers are educated. In the sections that follow we begin with a brief overview of our larger project, including a review of data collection and analysis methods most relevant to this paper. We then turn to preliminary results drawn from interviews conducted with three early career engineers. We close the paper by proposing a new conceptual framework and offering preliminary insights about some possible ways to close the gaps between engineering education and professional practice.

II. Methods

A. *Data Collection – Recruitment of Subjects*

We recruited research subjects for this study through multiple channels. Many of our participants were recruited through the co-op office at the authors' institution. This provided us with participants who had recently completed a co-op rotation and who were available on campus for an in-person interview. We also identified participants though this channel who had recently taken full-time positions. Additionally, we utilized our personal networks and implemented purposeful sampling strategies [10] to identify other candidates who met our participation criteria.

More specifically, our participation criteria required that participants had completed at least two internships or co-ops, with the most recent taking place at a large corporation with a manufacturing emphasis. Alternatively, a participant could have recently started in a full-time engineering position, also at a large corporation with a manufacturing emphasis. All participants were compensated with a $50 gift card after completing all of the study requirements, i.e., after completing their interview, or after completing a follow-up interview.

B. *Data Collection – Interviews and Subjects*

This research project started with three pilot interviews to support initial development and refinement of our semi-structured interview protocol, which utilizes both critical incident [11] and ethnographic [12] approaches to qualitative data collection. Each interview lasted between 30 and 90 minutes and was conducted in person or via Skype and audio recorded. More information about our interview methods and methodological decisions can be found in previous papers [13, 14]. All data collection was carried out under appropriate IRB approvals for human subjects research.

We interviewed 23 participants, of which 14 were completing or had completed intern or co-op assignments and 9 were full-time employees. Four participants also participated in a follow-up interview, of which one participant was an intern and three were full-time employees at the time of their second interview. The dataset therefore includes 27 total interviews. Of our participants, 10 are female and 13 are male. Nineteen identified as Caucasian, four as Asian, and 2 as Black (participants were able to select multiple). The interviewees held or were pursuing engineering degrees in a variety of fields, including aeronautical/astronautical, chemical, electrical/computer, industrial, and mechanical engineering. All data collection was carried out under appropriate IRB approvals for conducting research with human subjects.

C. *Data Analysis – Interviews*

Each interview was transcribed verbatim by a member of the research team or third-party service provider. The transcripts were reviewed for accuracy and then cleaned to remove any identifying information. Each transcript was coded using a hybrid deductive-inductive thematic analysis approach [15] and with the NVivo software used to carry out and coordinate the analysis process. All of the codes mentioned in this paper, including descriptions of each code, are presented in Table 1, below. Each interview was coded independently by at least two members of the research team, who then met up to discuss and resolve any disagreements. Part of this process involved developing parts of the codebook deductively based on themes that emerged from a systematic literature reported elsewhere [16]. While analyzing the data, we were also particularly attentive to let the data challenge and modify the codebook itself, including by allowing other themes to emerge inductively from the data.

In this paper, we focus on examples drawn from three participants. At the time of their respective interviews, Participant 1, male, was a full-time plant engineer working at a pharmaceutical manufacturing facility. Participant 2, female, was a full-time service engineer at an engine manufacturing company. Participant 3, male, was a student whose most recent position had been a summer internship in the Chinese branch of a multinational manufacturing firm. In this paper we elected to focus on three specific situations or work assignments experienced by these participants to highlight key insights from our emerging and evolving understanding of the interview data.

D. Data Analysis– Making Sense of the Data

As often occurs with qualitative research, our initial approach to data analysis did not go as planned [17]. We initially wanted to examine the codes of "learning" and "competencies and attributes" to understand what learning activities and experiences were perceived as most valuable in developing specific competencies and attributes viewed as important in the workplace. However, we found that it was difficult to ignore the many boundaries and boundary spanning activities co-occurring in the data or appearing in clusters as participants described specific incidents or situations.

TABLE I. DATA ANALYSIS CATEGORIES, CODES, AND DESCRIPTIONS

Boundary Types			
	Job Roles and Expertise		boundaries separating individuals based on profession, occupation, job function or role, discipline, etc.
	Knowledge		boundaries between different bodies of knowledge and/or knowledge communities
	Organizational		
		Inter-Organizational	boundaries between two or more organizations
		Inter-/Intra-Team	boundaries among members of a team or between multiple teams
		Hierarchical/ Vertical	boundaries that are hierarchical or vertical in nature (e.g., employees of different rank)
		Divisions or Units	boundaries within organizations at the division or unit level (e.g., HR, R&D, manufacturing)
	Personal Characteristics		boundaries involving different individual/group characteristics (e.g., gender, age, culture, , education, class, race/ethnicity), and personal traits (e.g., political views, personality)
	Time and Space		boundaries involving different geographic locations or regions, physical contexts or sites of work (e.g., HQ vs. plant), time zones, project phases or stages, shift work
Boundary Spanning Activities			
	Building and Maintaining Networks		activities that involve building and maintaining relationships, usually over multiple/repeat interactions
	Communication		general or cross-cutting communication-related activities that do not fit in other categories
	Coordination		activities such as cross-boundary organizing, negotiating, aligning goals, and managing conflict; also includes more general management tasks/activities, and simply "getting things done" (across boundaries)
	Information and Knowledge Management		activities such as scouting (e.g., searching for information), filtering or buffering (e.g., selecting relevant information), translating and transforming (e.g., manipulating information to make it accessible to others), integrating different information/knowledge, etc.
	Representing and Influencing		activities that involve promoting the legitimacy of one's efforts or work, representing one's work, seeking to influence stakeholders, etc.
Competencies and Attributes			evidence of explicit awareness of competencies, attributes, capabilities, and/or strategies discussed in the context of boundary spanning
Emotion			affective/emotional aspects of boundary spanning activities (e.g., frustration, anger, etc.)
Learning			explicit evidence of learning that occurs in the context of boundary spanning activities or work tasks; realizations about work/life balance
Technical Activities			work tasks/activities that involve technical expertise or tasks (e.g., calculations, analysis or modeling, design, CAD drawings, etc.)

We further realized that considering only one or two codes at a time was much too reductionist for the rich data we had collected, which included many thick descriptions of specific workplace experiences. In our efforts to make sense of our data from a more holistic point of view, we ran a number of queries within the qualitative data analysis software (Nvivo). Such queries allow us to search within our coded interviews for instances of co-occurring codes. For example, we were interested to see which boundary spanning activities co-occurred in the same incidents described by our participants. By running a query for all the boundary spanning activities co-occurring with technical activities, we identified three examples that demonstrate the overlapping nature of boundaries, boundary spanning activities, and other related themes in the experiences of our subjects.

III. FINDINGS

Here we present our findings through examples drawn from three of our interviewees. The first two examples describe specific projects or job roles, while the third reports more generally on some specific aspects of one student's internship. We italicize specific codes when they are mentioned in our write-up to help guide readers through the three accounts. All names that appear below are pseudonyms.

A. Installing a Distillation Column

At the time of his interview, Albert held a bachelor's degree in Chemical Engineering and was serving as a plant engineer at pharmaceutical manufacturing facility. He had been with this company for about a year and a half, and described his job role as involving a mix of routine maintenance and troubleshooting tasks coupled with managing capital projects. Here we focus on one part of his interview where he describes his experience overseeing the installation of a distillation column at the plant. It is worth noting that he inherited this project "mid-stream" from a retiring colleague, so most of the design and planning was already done when Albert took over.

In sharing some background details about the project, Albert showed awareness of both *Inter-* and *Intra-organizational* boundaries. More specifically, boundaries between *Divisions or Units* were evident in Albert's description of how an "internal R&D unit …helped design the basic requirements", while *Inter-organizational* boundaries were involved when a third-party firm was hired to "do basically the layout, in terms of paper documentation." Yet the interview suggests that Albert was not actively spanning these boundaries, likely because he joined the project at a later stage.

The boundary type *Time and Space* was much more prominent due to the scheduling pressures Albert faced in trying to get the column installed. These pressures were in turn linked to the crossing of two different *Inter-organizational* boundaries. On one hand, a customer of the facility had set a specific deadline for getting the new equipment up and running. On the other hand, a contractor was to install the column according to a mutually agreed schedule. Albert was thus serving as a kind of "linking pin," or an intermediary between his firm and multiple external organizations.

As a project manager, it is perhaps not surprising that Albert's boundary spanning activities involved many different kinds of *Coordination*. In general, he summarized that his "main job was to make sure it [the distillation column] was installed correctly, do all the commission activities, and basically coordinate the contractors to put everything in place." Elsewhere Albert describes another key aspect of *Coordination*, namely working to align goals among multiple groups or stakeholders. As he explained, "I was in a leading position to make sure everyone was on the same page and make sure there was enough communication between all the parties involved." This passage was also coded as *Communication* given Albert's explicit mention of this theme.

As a more specific *Coordination* example, Albert described how he was responsible for ordering and managing an inventory of more than one hundred instruments required for the distillation column, and then making sure that these parts were turned over to the contractor and installed in the right sequence to avoid a "ripple effect" of delays. Here Albert was likely working with vendors as well as the contractor. Hinting at the complexities and challenges involved with this aspect of the project, Albert stated: "Coordinating that was interesting."

As time pressures increased, Albert also drew on a wider repertoire of boundary spanning strategies. For instance, *Representing and Influencing* activities were important in his efforts to bring the contractor's goals and perspective back into alignment with the expectations of other stakeholders. Albert more specifically describes a "pretty intense" and "very honest" meeting with the contractor to reopen communication channels and determine why the schedule had slipped. He also went on to describe how the contractor had a divergent view of the project timeline, and then addsed "Necessarily having a certain amount of influence on people without… Verbally, it can be hard, but I mean, that's just part of life."

While the preceding examples primarily focus on *Inter-organizational* dynamics, Albert was also frequently challenged to span a variety of boundary types within the firm. For example, *Intra-team* boundaries were evident in his description of weekly meetings and other interactions with a core group of coworkers, which included another project manager, two process engineers, the head of project engineering, and an operations specialist from the plant. As this overview suggests, working with this team additionally required the crossing of *Job Role and Expertise* boundaries, as well as *Hierarchical or Vertical* boundaries given variations in the status/rank of the associated coworkers.

Yet perhaps just as importantly, Albert's work with this group involved *Information and Knowledge Management* activities to help span *Knowledge* boundaries. Albert offers one particularly compelling example drawn from his weekly meetings with the members of this same project team:

> "One of the really important things was to make sure that, because everyone was coming from a different perspective, make sure that we're all talking about the same things and speaking the same language, so to say. I think one of the main tools for that was to have the PNID [piping and instrumentation diagram] out and showing specific names of instruments or parts of that system, so that everyone could call without, everyone sitting at the table could call it out and it had a picture in front of us to make sure that we're all talking about the same thing."

As this passage indicates, the PNID came to serve as a kind of "boundary object" in these meetings, providing the members of the team with a physical document that helped them span knowledge boundaries due to their different backgrounds, expertise, and terminology preferences. Albert's depiction of these exchanges additionally reveals his sensitivity to how information is translated and transformed to establish shared meaning and understanding within a diverse work team .

Albert also encounters and spans other boundaries between *Divisions or Units* within the organization. In this regard, he shows awareness for how his own goals and priorities as a project manager charged with installing equipment may diverge from what is desired by the process engineering and/or operations staff. He specifically describes the kinds of requests typically made by these units during or after such an installation, like adding more instrumentation or addressing ergonomic issues that have surfaced. Albert describes the use of deferral tactics to respond to such requests, as when he states: "No. Sorry we can't do this at this point, because we need to really finish this project. How about in the future we take note of it, then in the future we can always put something in … once we are running." This approach reflects aspects of *Coordination* (and specifically negotiation) and *Representing and Influencing* activities to help Albert span boundaries.

In terms of *Competencies and Attributes*, Albert generally projects a sense of confidence in knowing how to handle particular assignments and situations, and shows awareness for specific strategies that can be used to span boundaries. As a consequence, his account has no explicit reference to how his work on this project involved *Learning*. Nonetheless, some passages coded as *Emotion* provide indirect evident that Albert at times struggled – and likely learned – through his project work. For instance, *Emotion* is evident when Albert describes his efforts to verbally influence the contractors, which was clearly a challenging and memorable experience for him.

Reflecting on these experiences, Albert more generally adds that "interacting with people was probably, actually, the key aspect of this project." Yet one should not take this to mean that the technical dimension of the work was superfluous or unimportant. In fact *Technical* activities repeatedly co-occurred with boundary spanning activities in Albert's discussion of this project, such as when he discussed how the PNID was used in project meetings. Albert's technical knowledge, as well as his awareness for the limits of that knowledge, were critically important aspects of his job role. They provided him with knowledge, skills, and credibility that helped him carry out his work. Yet as this overview suggests, it is often not possible to draw a clear line separating Albert's technical work and qualifications from his manifold social interactions that crossed many different kinds of boundaries.

B. Global Service Engineering

Savannah holds a bachelor's degree in Aerospace Engineering and works as a service engineer at an engine manufacturing facility. At the time of the interview she had been in her current position for about four months. Prior to her full-time position as a service engineer, she worked at the same company as a co-op student, and then after graduation participated in a rotation program for new hires. In her role as a service engineer for engines, Savannah must be available to answer questions and troubleshoot issues for operators (i.e., customers) around the world, including Asia and Africa. She is also the reliability disruption lead for engines, and these roles require her to span many different kinds of boundaries and engage in a variety of boundary spanning activities.

Perhaps the most obvious boundaries Savannah faces in her role as a service engineer involve *Time and Space*. Since she has operators who use her company's engines all over the world, she must deal with geographic and cultural boundaries on a daily basis. For instance, she describes a "7:45 AM call with Germany because our fleet is global so they do front-end stuff. If there's any issue, the first thing anyone does is they call Germany … We always have a meeting [in the] morning with them to coordinate all of our issues that are going on currently in the fleet, keeping the line of communication open."

As the preceding example suggests, Savannah must also communicate across *Personal Characteristic* boundaries. Elsewhere she elaborates on this theme by describing her experiences working with operators from Asia: "I get a lot of questions which seems to be a cultural thing." Savannah goes on to explain that not all her data can be shared, so while she cannot tell some operators certain things, she must "try to come to a ground where you're telling what is appropriate, but also not offending anyone." This in turn serves as an example of *Information and Knowledge Management* since she is selectively filtering information across *Inter-organizational, Personal Characteristic* (i.e., cultural), and *Time and Space* boundaries.

The boundary spanning activity of *Communication* is obviously very important in Savannah's work, not only in terms of communicating with operators around the world (*Inter-organizational)*, but in interactions with her team and other teams (*Inter/Intra-Team)*. In addition to communicating needs to members of her team, she notes that "there's also [the] maintenance, repair, and overhaul team that we can work pretty closely with if there's something wrong with the shops." And Savannah must again work across *Inter-Organizational* boundaries when she undertakes *Coordination* activities with authorized maintenance centers to get work done on engines that need maintenance or repair.

In order to *Communicate* and *Coordinate* effectively, Savannah relies on her technical skills, including by utilizing her extensive reliability data to provide answers to the many questions she receives. She must be able to quickly and reliably respond to questions, such as "I have this failure, can you track and tell me if we had this failure before? Is this a new thing or is this old?" In order to answer such questions, Savannah must again conduct *Information and Knowledge Management* activities, such as verifying her data so as to be able to answer the questions efficiently and accurately.

In the midst of all the *Communicating* and *Coordinating* that Savannah does in her job role, she needs to make sure she is doing these things effectively. For example, in her interactions with customers, where she must work across an *Inter-organizational* boundary, Savannah has come to realize the importance of keeping the right people in the loop:

> "Trying to figure out, for example, the customer has an issue and you're solving the issue but maybe they've gone through the regional customer manager or something like that, and then they feed the issue to you. It's trying to figure out how to get the message back to the customer in the easiest way possible.
>
> However, not ignoring anyone, not keeping anyone out of the loop, and not hurting anyone's feelings because there's certain people who want the correspondence to go through them like regional customer service managers and they want everything you say to the customer. They want them to be this little focus point of contact which is understandable, that's what they want. You send everything to them and then, they send everything to the customer which seems to be redundant but that's what they do, and it's okay.
>
> You have other people who don't care, but you just have to figure out where that relationship is with your particular person. It's not difficult per se, but just figuring in out."

As this passage suggests, Savannah's *Communication* and *Coordination* activities are very prominent. But these in turn also shade into other relevant activities. For example, *Representing and Influencing* is evident when she tries to influence customers, while *Building and Maintaining Networks* is salient in her discussion of evaluating the status of her relationships with other stakeholders.

To be successful in her job role, Savannah clearly has clearly needed to develop a variety of supporting *Competencies and Attributes*. For example, being able to understand what her customers need and then respond in appropriate ways are very important capabilities for someone in her position. Responding appropriately can also get even more complicated when *Communication* and *Representing and Influencing* activities happen across *Hierarchical/Vertical* boundaries, as when Savannah states: "I have correspondence with some people who are more important than I am. Sometimes, I need their response pretty quickly and to pick up the phone and call someone who's much farther above you and say, 'I need you to drop what you're doing and I need you to respond to me, and do this thing for me,' can be hard for me."

From this example, we can see that boundary spanning is often multifaceted in that it involves a variety of specific strategies and activities that are used to cross different types of boundaries, often simultaneously. While Savannah utilizes and employs her technical expertise every day, she does so while carefully and deftly navigating many social and organizational boundaries.

C. Internship in China

At the time of his interview, Hector was nearing completion of his Mechanical Engineering degree. While Hector describes other work experiences in the interview, the example presented here involves his gap-year internship experience in a Chinese manufacturing company. During this period, he was engaged in designing part of an air purification system. Here we focus on one segment of the interview in which Hector describes at length the nuances of working in a culture other than his own.

Given the global nature of his job role, Hector not surprisingly emphasizes on mutliple occasions the importance of crossing boundaries associated with culture, as well as other individual differences (*Personal Characteristics*). As a part of his job role in China, for instance, Hector talks about interactions with his Chinese manager, and he describes how he and his manager had divergent goals. This ability to identify and work through other individual differences among co-workers/team-mates was coded as *Personal Characteristics*. Hector shows awareness of such differences as he talks about his manager: "I'm not sure if it was a cultural thing, but anyway. His goals were definitely very different than mine, and probably than the company's were." Hector also demonstrates awareness of boundaries related to *Personal Characteristics* in his comments about different ways of working between the US and China, including in terms of social interactions and even the way people structured their workday and approached their assigned work tasks.

Hector also encountered other boundaries during his internship. For instance, the *Hierarchical/Vertical* boundary was spanned on a day-to-day basis when he interacted with his manager. He also talks about situations where his team had to interact with a group of U.S.-based counterparts who helped evaluate their design work, thereby crossing *Divisions and Units* and *Time and Space* boundaries.

Whereas the previous passages cast light on the various boundary types that Hector encountered, he also undertook a number of specific boundary spanning activities/tasks during his internship. Not surprisingly, *Communication* was one of the most prevalent boundary activities evident in Hector's remarks. For instance, he talks about communicating as a way to uncover and navigate cultural and other personal differences (*Personal Characteristics*). This is evident, for instance, when he talked about trying to better understand his manager's objectives for the project: "It's just something I've learned to kind of pick up when I talk with Chinese people now. After talking with a lot of them you can kind of glean by what they're saying or not saying, um, what their goals are."

Representing and Influencing and *Coordination* activities also surfaced in Hector's remarks, most often in spanning *Divisions or Units* and *Hierarchical/Vertical* boundaries. These themes are particularly evident when he talks about his role in helping to manage the divergent Chinese and U.S. perspectives that came to light in the aforementioned design evaluation process. For example, he explains that:

> "Whenever there was a conversation between the Chinese teams and the American teams, you could definitely see a lot of gaps, I guess, in understanding. And when I was there I tried to reconcile it but it doesn't always work, right?"

Here we find clear evidence of *Coordination* tasks such, as negotiating across boundaries and managing conflict.

This same example also involves *Representing and Influencing* activities, which are especially evident when Hector explains the specific strategies he used to bridge the U.S. and Chinese sides of the design review process:

> "Ultimately my stance is still more American than Chinese, right? So it was really just how to present it, how to take what the American side was telling us and try to present it in a way that my manager would be willing to accept."

As another example of how Hector tried to strategically influence a superior, he explained how he recognized the importance of giving a somewhat exaggerated toast to his manager during a dinner event. He added that doing so was important as a way to both "fit in" with the host culture and gain favor with (or "suck up to", in his words) his manager.

In order to engage in such complex boundary spanning engineering work, Hector had to develop and leverage a variety of *Competencies and Attributes*. One of the key attributes that he reflected on during his interview was his willingness to adapt to the Chinese cultural context. Apart from emphasizing the differences in the two cultures, Hector also talks about his attributes/beliefs in engaging in a culturally rich design experience. Regarding how he approached adapting to the culture, he explains:

> "I guess I partially felt that way because, you know, I was coming into their environment, it's my job to adapt to what they're doing, not the other way around. At least in the work place "

On a similar note, Hector also emphasized the need for establishing shared understanding of how things work as another way to engage with people across boundaries. For instance, he expressed the importance of shared understanding when he remarked: "I did try and go out of my way to, you know, be delicate there because, you know, what I'm expecting is different than what their expecting, they don't understand what I'm expecting." Knowing about and adapting to the culture were central dimensions of Hector's experience.

When probed about the *Learning* that occurred prior to and during his internship, Hector additionally described the value of experiences such as "interactions with other Chinese people", "exchange programs through college," and engaging with Chinese pop-culture and media. Hector's account helps underscore how his *Learning* provides *Competencies and Attributes* that further enable his capacity to span boundaries, both on the job and beyond. For instance, Hector explains that "by doing that [interacting with other Chinese students] you manage to learn a lot of things." As noted above, for example, his extensive prior experiences interacting with Chinese people improved his ability to build a relationship and interact more effectively with his manager and colleagues while in China.

More generally, Hector's experience as an intern in China reveals the intricacies involved in working across boundaries, as well as how boundary spanning activities are linked to a variety of *Competencies and Attributes,* as well as associated *Learning* experiences.

IV. Discussion

In this discussion we first aim to develop a more holistic view of our findings, as well as relate our results to other research. We then consider what the findings might mean for rethinking how we prepare our students for professional work.

The examples given above suggest that early career engineers are frequently challenged to span many different types of boundaries in the workplace, which in turn involve a variety of boundary spanning activities. This finding resonates with other studies. For example, Brunhaver et al. found that "working with people" was the most common professional skill reported by 57 young engineers [2]. Many in this group also mentioned the importance of communication and information finding skills. Further, large majorities of subjects reported that the workplace was where they mainly developed such capabilities. Additionally, Trevelyan's empirical research on engineering practice leads him to conclude that "coordination," or "working with and influencing other people so they conscientiously perform necessary work to a mutually agreed schedule" is a major dimension of what engineers do [18, 19]. His detailed discussions of typical coordination-related activities also have considerable overlap with many of the specific boundary spanning activities and boundary types identified in our research [18]. It is additionally worth observing how these researchers describe engineering in more holistic terms. For example, Brunhaver et al. argue that "successful practice requires integrating of several kinds of skills and knowledge, from the technical to professional and organizational" [2]. Along similar lines, Trevelyan argues for a reframing of engineering as a "human social performance" [19], and his references to "coordination" and "technical coordination" can be inferred as a kind of meta-attribute that "relies on a hierarchy of many other more fundamental technical and interpersonal skills" [19, p. 198].

Yet this in turn points to questions about how all of these things (e.g., practice, performance, knowledge, skills, etc.) are conceptually related. We encountered similar issue in coding our own data, especially in finding that our initial efforts to carefully delineate specific codes and themes gave us the impression that we were moving too far away from the lived experiences of engineers working on complex, multi-faceted problems and projects. Conversely, we found that viewing our codebook and data analysis efforts and in a more holistic and integrated manner suggested a more compelling approach to portraying and reimagining the realities of practice.

Writing up and reflecting on the three examples above thus led us to develop a conceptual framework, as presented in Figure 1, that relates boundaries, activities, learning, emotion, personal attributes, knowledge, and skills. When we explore the kinds of boundary spanning experiences described by our subjects, we often find ready evidence of the specific types of boundaries being crossed, along with the various activities (including boundary spanning, technical, and/or other activities) employed to span those boundaries. Yet here we also note the utility of a competency pyramid [20] model to underscore how observed activities are frequently linked to underlying knowledge, skills, and personal characteristics. Indeed, the relative effectiveness of an individual undertaking a particular activity often crucially depends on a variety of foundational competencies and attributes. As a further point of clarification, our data provides tentative evidence for the claim that boundary spanning is a meta-attribute in the sense that boundary spanning activities frequently require individuals to simultaneously draw on and leverage various sets of competencies and attributes.

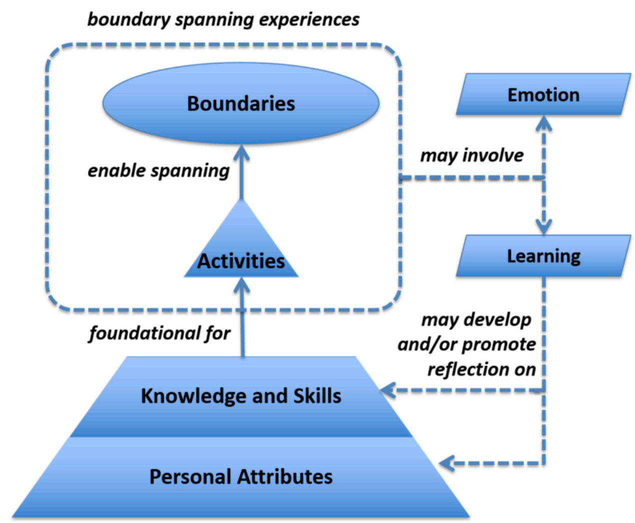

Fig. 1. Boundary Spanning Conceptual Framework

From this framework and our associated data, we also propose that boundary spanning experiences may involve emotional as well as learning components. Indeed, these dimensions of boundary spanning can be helpful and productive, especially by allowing an individual to reflect on and continue development of their knowledge and skills to become a still more effective boundary spanner. Emotion and learning can also encourage a person to consider how various personal characteristics (e.g., personality traits) may support or hinder their boundary spanning capabilities. And again, raising one's metacognitive awareness of such strengths and weaknesses can spur further performance improvements.

This model is also useful in thinking about the relation of what are frequently referred to as the "social" and "technical" dimensions of engineering practice. In both our research and other relevant scholarship, engineering practice is often portrayed as a relative mix or proportion of social and technical work. For example, other interviewees participating in this project have described that a third of their work time is spent on solitary technical work, and about two thirds of their time is spent interacting with other people [14]. These numbers are in turn closely aligned with research findings from other scholars, including results from larger-scale studies of time use among practicing engineers [21].

Yet in the preceding examples and conceptual model, we intentionally avoid making *a priori* distinctions between the technical and social aspects of engineering practice. We instead observe that the experiences of our respondents are often thoroughly *sociotechnical*. Their interactions with other people frequently jumble together technical details with considerations of costs, schedules, political alliances, and culture, regularly jumping unexpectedly from one such consideration to others. And even when technical details seem to recede into the background, the technical expertise of the engineer is an important factor in how others perceive their role, legitimacy, and influence. And if the engineer finally finds a moment to perform some solitary technical work, sooner or later they will again find themselves crossing social boundaries, such as when they seek out information or advice from colleagues, share a design for review, seek resources to carry out a project or initiative, or even delegate technical tasks to be done by others.

If we take seriously these findings and observations about engineering practice, what are the implications for the practice of educating engineers? On the one hand, it can be argued that the best way to expose students to the boundary spanning realities of engineering practice is to encourage or require completion of internships or co-op rotations. On the other hand, it is arguably not feasible to provide such opportunities to every student. Further, there is a real risk that as more students participate in on-the-job learning, ever more will experience confusion and alienation as they struggle to understand how their workplace experiences are related to formal learning at school. Indeed, most engineering programs continue to protect the "purity" of core technical coursework in the engineering sciences – which tends to be highly theoretical, mathematical, and scientific. Anything perceived as non-technical is often relegated to the edges and margins of the curriculum, whether it be in professional seminars, elective coursework, or extracurricular activities. Further, the organization of the curriculum around discrete learning objectives means many missed opportunities to help students cultivate the kinds of meta-attributes they will likely need to succeed and excel in the world of professional practice.

The aforementioned NAE effort to bring more "real-world experiences" into engineering represents a positive step toward addressing some of these issues and gaps. So too are ongoing efforts to expand the use of problem- and project-based learning (PBL) in engineering [22, 23]. Casting a still wider net, additional inspiration can be found in even earlier calls to reform engineering curricula, such as Bordogna et al.'s advocacy for a more "integrated" and "holistic" approach to engineering education [24]. More recently, Sheppard et al. have proposed a "spiral" or "networked" model for engineering courses and curricula, along with a recommendation to expand the use of "project-centered learning" in engineering [25]. Related ideas are reflected in Trevelyan's work, including in descriptions of his own efforts to develop and deploy team projects to promote coordination skills among mechanical engineering students [18] and a book aiming to provide an in-depth yet accessible introduction to the realities of engineering practice [26]. Such approaches are intriguing and attractive precisely because they can encourage students to better appreciate the inherently sociotechnical realities of engineering practice, while also cultivating their capabilities and identities as boundary spanners.

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