CAREER: Ready for Change: Fostering Adaptability along the Engineering Pathway

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Introduction

Rapid technological advancement, demographic shifts, and globalization have been reshaping engineering work more quickly than ever [1]. The recent COVID-19 pandemic has also brought unprecedented socioeconomic, environmental, and political change over the past year [2]. Engineers must navigate these changes to innovate solutions to these pressing issues; yet research suggests that neither engineering students nor engineering professionals are sufficiently prepared in this area. This CAREER grant addresses the issue by developing the means to define, understand, measure, and teach adaptability as a key meta-competency for engineers. Adaptability is the ability to respond positively and productively to circumstances of volatility, uncertainty, complexity, and ambiguity [3]. It is often espoused as an essential skill by engineering employers [4] but generally not reified or taught within undergraduate engineering education.

Current approaches to fostering adaptability in engineering emphasize experiential learning opportunities such as team-based projects, co-op/internships, and undergraduate research. However, these activities seldom provide formal adaptability training, and whether they nurture or merely test adaptability is unclear. This project calls for adaptability to be explicitly taught and assessed, much like other professional skills such as communication and ethics that have been added to ABET criteria [5], to prepare students to solve today's ill-structured problems. The project uses a mixed-methods, research-to-practice design to systematically investigate and develop unified language and educational content related to adaptability within engineering.

In our first phase of research, semi-structured critical incident interviews [6] with twenty engineering managers are being conducted and thematically analyzed to develop a typology of the mindsets and behaviors necessary for adaptable engineering practice. This work is grounded in the U.S. semiconductor, medical device, and electronics industries, selected for their short product life cycles, evolving regulatory processes, and changing consumer demands that make adaptability paramount [8]-[9]. Our interview protocol probes managers about specific times when an engineering supervisee needed to adapt to the job. Managers are prompted to describe the circumstances leading up to the event, engineer's reaction, resources the engineer used, and outcome for each incident. They are also asked how they define adaptability and how their organization rewards and promotes adaptability. A project liaison at each company assisted the research team by identifying 3-5 engineering managers of different demographics and experience levels to interview. Interviews lasting approximately 60 minutes were conducted virtually, audio recorded, and transcribed.

We present initial findings from our interviews with engineering managers and outline the next steps for the project. This work will inform interviews of early-career engineers that explore the catalysts and barriers they perceive to being adaptable on the job, develop survey instruments to measure adaptive mindsets and behaviors, and create online educational modules to enhance the adaptability of engineers. The most immediate impact of the proposed work will be an increased understanding of what constitutes adaptability in engineering practice and the strategies that best cultivate its development.

Motivation and Background

Engineering adaptability has significant potential to benefit U.S. productivity, innovation, and workforce development in myriad ways. Employees typically take 6 to 12 months to get "up to speed" and become productive within their new companies [10] [11], during which time they also form crucial opinions about their jobs [10]. Helping engineers adapt to and cultivate mastery at work could enhance their job satisfaction and psychological well-being [11] [12], advantaging both the engineers and their organizations. This promise is especially attractive when considering early-career engineers starting first positions, many of whom call the school-to-work transition stressful and requiring adjustment [13]-[17]. Early-career engineers often describe differences between the skills needed for work and those learned in school [13], the difficulties finding information on the job [14], and the lack of regular feedback [15]. Engineers being skilled in adaptability before entering the workforce might therefore assist with engineering onboarding and retention.

A greater focus on adaptability may also boost engineering through upskilling and reskilling. Engineers change jobs or job roles every 5.1 years [18], requiring that they learn about the technical proficiencies, people, politics, language, goals, vision, and history associated with their new job (role) each time [19]. Enabling engineers to change their job (role) more often or easily may improve the likelihood that an engineer finds a position or organization that is a good fit, which carries positive implications for their performance and long-term contributions [20] [21]. In addition, studies show that women who take time off from working in engineering are more likely to change career fields or not re-enter the workforce at all, in part due to concerns about skill depreciation [22]-[23], even though 90% indicate a desire to return [24]. Considering engineering's poor retention rates (40% of all early-career engineers leave the field within three years of graduation [25], and 40% of women engineers leave the engineering field overall [26]), permitting engineers to enter, leave, and re-enter the profession could increase the size and diversity of the engineering workforce appreciably. This increase can, in turn, help companies innovate, create new initiatives, and pursue market opportunities [27].

Engineering organizations, industry, and professional societies have all called for a greater focus on adaptability in engineering [28]-[34]. However, the definition of adaptability itself has become contested as the literature on adaptability continues to develop. Several terms for adaptability have been used interchangeably and without precision: adaptability [35], adaptive abilities [36], adaptive behavior [36], adaptivity [37], and flexibility [38]. Personal traits like self-efficacy, cognitive ability, cognitive agility, openness, and emotional stability have all been linked to individual adaptability [39]. Scholarly research on adaptability in engineering has been limited [40-41], yet adaptability has also been associated with engineering competencies such as collaboration, lifelong learning, and the ability to apply knowledge to unfamiliar problems [29]-[31], i.e., adaptive expertise [42] [43].

Adaptability is therefore theorized to be a meta-competency [44] [45] that consists of interrelated mindsets and behaviors for engineers, rather than any single skill or attribute. The lack of a framework for describing and understanding adaptability may partially account for why many engineering programs are still working to instill greater adaptability in their students [46]-[48]. Further complicating the issue, engineering activities said to foster adaptability are usually not intentional or explicit. These activities typically emphasize experiential learning opportunities, such as team-based projects, co-ops/internships, project-based learning, and undergraduate research [49]-[51], and lifelong learning practices [52] [53]. However, many engineering students struggle to connect these experiences to the work they will do after graduation [54]. Rather than nurture adaptability, they may just reinforce or evaluate students' existing adaptive tendencies. More research to clarify how we define, measure, and understand adaptability is needed before engineering educators can effectively teach it.

The past two decades have seen the integration of several other "human skills" [4] [55] into formal engineering curriculum (e.g., ethics, communication, and societal and global issues), partly in response to changes in accreditation standards [5]. Other studies show that, while human skills can be acquired in an experiential learning environment, they are best learned when explicitly taught and assessed [5, 56-57]. We take the position that adaptability would thus benefit from being explicitly taught and assessed to prepare students to solve today's complex challenges. This CAREER grant thus addresses this goal by developing the means to define, understand, measure, and teach adaptability as a key meta-competency for engineers. Specifically, this research addresses the following questions:

RQ1. What adaptive mindsets and behaviors are important for professional engineering practice?
RQ2. What factors influence engineers' ability to be adaptable?
RQ3. What strategies cultivate adaptability in engineering students and professionals?

Theoretical Framework

Career Construction Theory (CCT) [58] and Individual Adaptability Theory (IAT) [59] are the two most cited frameworks in the literature on adaptability [13]. CCT defines career adaptability as the culmination of four mindsets: concern, control, curiosity, and confidence [58]. IAT similarly describes adaptive work performance in terms of eight behaviors, five of which are suggested to be the most relevant to scientific and technical occupations [59]: problem-solving, dealing with uncertainty, learning, demonstrating interpersonal adaptability, and handling work stress. This project combines CCT and IAT into an initial typology of adaptive mindsets and behaviors (Table 1), to be built on and extended based on input from engineering managers, early-career engineers, and students. We also utilize the CCT framework to investigate the catalysts and barriers engineers perceive to developing and performing adaptability. CCT posits that individual adaptability is dynamic and influenced by previous experiences, cultural influences, socializers, and personal characteristics. This project will identify through qualitative interviews the personal and contextual factors that promote and limit engineers' adaptability.

Table 1. Initial typology of adaptive mindsets and behaviors, based on [58] and [59]

Mindsets	Behaviors
Concerned about (i.e., invested in) one's work and future career	Employs various methods and techniques to creatively solve problems
Feels in-control when faced with new or ambiguous situations	Acts and adjusts as needed when dealing with uncertain or unpredictable situations
Curious about new knowledge and opportunities, interested in many things	Learns new knowledge and skills quickly and enthusiastically, on a continual basis
Confident in one's ability to adjust to change	Is open-minded and flexible during interpersonal interactions; remains calm when handling work stress (e.g., unexpected challenges, high workload)

Research Design
This study is a five-year project with multiple phases that uses a mixed-methods, research-to-practice design to systematically investigate and develop unified language and educational content related to adaptability within engineering. We focus specifically on companies from the semiconductor, medical device, and electronics industries due to their short product life cycles, evolving regulatory processes, and changing consumer demands that make adaptability a very critical skill. The overall project trajectory is represented in Figure 1.

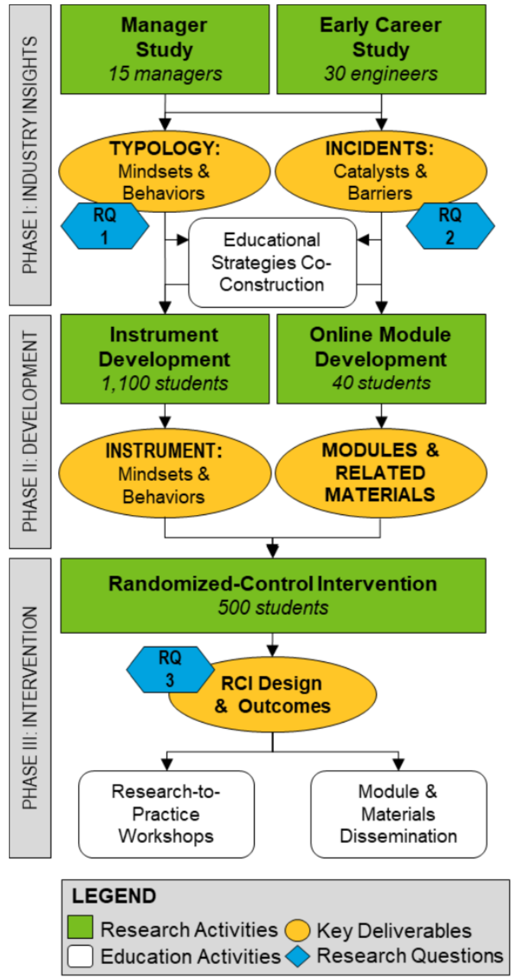

FIGURE 1: Integrated research and education

We will use semi-structured interviews with managers and early-career engineers to generate critical incidents of what adaptability for engineers in all three industries looks like. Consistent with the research goals of defining, measuring, and understanding adaptability, we will use these incidents to: (1) identify a unified typology of the mindsets and behaviors necessary for engineers to adapt in engineering practice, (2) understand the catalysts and barriers that early-career engineers experience to being adaptable, and (3) develop instruments to measure adaptive mindsets and behaviors in engineering. The findings of this research will inform the following educational objectives: (1) design, implement, and evaluate a set of online modules to increase the adaptability of undergraduate engineering students, and (2) develop resources and workshops that engage educators, employers, and student-support professionals in the co-construction of strategies that enhance engineering adaptability.

Data Collection: Manager Interviews
In our first phase of research, semi-structured critical incident interviews [6] with engineering managers are being conducted and thematically analyzed to develop a typology of the mindsets and behaviors necessary for adaptable engineering practice. The critical incident technique grounds participants' responses in the details of specific past events, rather than rely on over-generalizations, and has been previously used in other studies of engineering practice, e.g., [14], [60], [61]. The interview protocol is designed to collect managers' thoughts about how they define adaptability in the context of engineering, traits associated with adaptability, and emerging industry trends requiring adaptability. It asks managers about specific times when an engineering supervisee needed to adapt to the job and either exhibited or did not exhibit adaptability. Managers are prompted to describe the circumstances, engineer's reaction, resources

the engineer used, and outcome for each incident. They are also asked to reflect on how their organization hires for and rewards adaptability.

Interviews are being conducted with 15-20 engineering managers at four companies in the southwestern U.S. based on guidelines related to reaching code saturation in qualitative research [62] [63]. Engineering managers of different experience levels and demographic characteristics have been recruited at each company with the help of an internal project liaison, most typically, a senior engineering manager themselves. Each company has different approaches to external research, with some requiring the signing of non-disclosure agreements (NDAs). Interviews have been approximately 60 minutes long and conducted virtually via Zoom. Participants have been offered a $40 Amazon gift card and certificate of completion (i.e., for corporate volunteering reporting) as a thank you for their time. Several managers have declined the gift card and been happy to contribute to the study without the incentive.

The demographics for our 16 interview participants to date are shown in Table 2. Notably, one goal of recruiting was to oversample for women engineers and engineers from underrepresented backgrounds to capture a more balanced perspective on adaptability based on differing demographic characteristics and experiences. Meeting this goal has been more challenging at some companies than at others. For example, participants at one company in the semiconductor industry – a field with relatively low representation of women [64] – have been all men, while mostly women engineering managers have been interviewed at a medical device company – a field in which the representation of women has been relatively higher [65]. Recruitment also started during the COVID-19 pandemic, resulting in additional unexpected changes to initial plans. One company that initially committed to participating in the study ultimately decided not to participate and was replaced by another company. Even still, our current range of companies enables us to characterize differences in adaptability needs by such organizational characteristics as size and industry.

Table 2. Interviewee characteristics by company and gender

Company	Interviewees	Female	Male
Mid-Size Medical Device Company	4	3	1
Very Large Semiconductor Company	4	1	3
Large Semiconductor Company	4	0	4
Mid-Size Semiconductor Company	4	0	4

Data Analysis: Initial Coding

Interviews were transcribed and cleaned before being entered into the Dedoose software. A hybrid deductive-inductive thematic analysis approach [66] is being used to analyze the interview transcripts. The first step for analyzing each research question has been a deductive analysis where each transcript is carefully read and coded for statements related to the CCT and IAT frameworks. The second step has been an inductive analysis of the data using open coding and theoretical memoing to allow codes not grounded in either framework to emerge. Themes for each analysis will be generated once all coding is complete by combining and sorting the codes from each step into categories. As an initial analysis, we explored how managers defined engineering adaptability at the beginning of their interview to start to uncover the adaptive mindsets and behaviors necessary for engineering practice (RQ1).

Preliminary Findings

Several themes aligning with the CCT and IAT frameworks emerged from this initial analysis. When asked to define adaptability, managers explicitly described it in terms of behaviors from the IAT framework, including learning new knowledge, being open-minded, adjusting to ambiguous and unpredictable situations, and handling unexpected challenges. They also named curiosity about new knowledge as a key mindset to adaptability but did not mention other mindsets present in the CCT framework, such as confidence, feeling in control, or feeling concerned (i.e., invested) about their work.

Beyond the IAT and CCT frameworks, managers also mentioned other mindsets and behaviors associated with engineering adaptability, alluding to three categories: technical, interpersonal, and intrapersonal (our characterization). Engineering managers suggested that engineers adapt to new technologies, software tools, and technical tasks as engineering work continues to change. Engineers must also be open to new approaches and ideas, able to recognize other ideas outside of their own and work well on teams. Ideally, engineers will also possess self-awareness so that they can take initiative in the areas they need to develop and learn and self-regulation to recognize and manage their emotions in stressful situations. One manager termed these skills as "emotional" skills distinct from "technical skills" and discussed the importance of an engineer having both to be adaptable.

Engineering managers also mentioned the gap between what students learn in school and their work on the job. They noted a need for students to apply their knowledge and skills to the work being conducted, which often differs from what is learned in school, and adjust to new organizational contexts. From managers' observations, we also noted that adaptability appears different in different job roles and organizational contexts. For example, adaptability needs in a semiconductor manufacturing role differ from adaptability needs in a medical device manufacturing role, and manufacturing roles, from research and development roles.

Future Work and Implications

Data collection and analysis of the interviews with engineering managers will be completed this summer. Findings from this work (particularly those related to the critical incidents managers share) will be used to update our initial proposed typology of adaptive mindsets and behaviors for engineering practice. The next phase of the project involves interviewing early-career engineers to understand how they comprehend adaptability and the catalysts and barriers they experience to being adaptable (RQ2). We will then create online educational modules to enhance the adaptability of engineers and develop survey instruments to measure adaptive mindsets and behaviors with which to evaluate them. The most immediate impact of the proposed work will be an increased understanding of what constitutes adaptability in engineering practice and what strategies best cultivate its development.

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