The Career Pursuits of Engineering Students: Inquiries into Options, Informedness, and Intentions at the Education-Careers Interface

by

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ABSTRACT

This thesis examines how the career plans of U.S. engineering students shape the composition of the engineering workforce. The health of this workforce – including its demographic diversity and inflow of candidates with key skills – attracts substantial attention from employers, policymakers, and educators. Prior literature has identified patterns of systemic variation in career intentions among students in the engineering educational pipeline, where certain student subsets have exhibited a lower likelihood of pursuing traditionally categorized engineering occupations after engineering school compared to others. Examining these patterns of occupational intentions remains critical, as some of such patterns continue to hinder workforce development goals, including demographic diversification and retention of those with certain skills profiles.

We began our investigation by constructing a multivariate occupational sorting model for engineering students that incorporates factors shown in prior studies to be associated with students' occupational outcomes. We empirically validated this model using survey data from a sample of 1,061 senior year engineering students. We present results showing how different occupational outcomes are associated, on average, with different student-specific characteristics. Next, we describe findings from a randomized survey experiment conducted upon the same student sample. Here, we investigated how experimental manipulation of engineering job attributes influences students' preferences for jobs. The experiment allowed us to draw causal inferences about how jobs' attributes interact with students' characteristics to explain variance in job preferences. We discuss the experiment's implications for enhancing candidate-career matching and for mitigating undue attrition from the engineering pipeline.

We also present results from a systematic literature review examining the changing careers landscape faced by engineering students. Here, we identified core elements of traditional engineering jobs that endure in contemporary positions, and we characterize a set of increasingly prevalent engineering-related jobs that has arisen. We present a typology of engineering work built upon the review. The typology facilitates categorization of the engineering-relatedness of engineering graduates' diverse careers. We conclude by discussing how increased job market complexity strains engineering schools' ability to prepare students to make well-informed career decisions, and draw upon findings from the survey experiment to suggest ways that educators can remove impediments to ideal student-career matching.

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Preface

Each chapter of this thesis examines phenomena related to the career pursuits of university engineering students in the United States. Such phenomena include: the sorting of engineering students into different career pathways, the influences upon students' attraction to various work roles, the expansion and evolution of engineering jobs in industry, and students' development of preparedness to make career decisions amidst an increasing variety of options. Each chapter addresses a specific audience of stakeholders who are invested in engineering students' career pathways. Though the analytical scope of the chapters is adjusted for particular audiences, the sequence of chapters is intended to reflect the flow of a cohesive overall investigation. Since each chapter is designed to be capable of standing alone, some information is repeated across the chapters, and chapters include citations referencing information in other internal chapters.

Chapter 1 is intended for the engineering management audience, including those responsible for recruitment and workforce development. This chapter presents statistical models that characterize sorting patterns of engineering students into different types of expected career paths following graduation, and discusses implications for improving candidate-career matching. Chapter 2, meanwhile, is framed for the work and occupations research community. Here, findings from a conjoint randomized survey experiment are presented that examine the role of job attribute informedness in influencing key candidate subsets' attraction to jobs in their field of study. Chapter 3 addresses the engineering educator and education researcher audiences. This chapter discusses a systematic literature review that identifies enduring attributes of traditionally categorized engineering work, while surveying the contemporary jobs landscape to characterize newer positions closely related to engineering work. Based on the literature review, a typology of engineering work is presented that allows educators to assess the engineering-relatedness of the occupations that graduates attain.

Finally, Chapter 4 serves as an overall summary and discussion of this thesis' findings for the engineering educator audience. This concluding chapter comprises a critical review of factors that hinder and support students' preparedness to make well-informed career-related decisions as they approach graduation from engineering degree programs. The thesis ends by highlighting educators' opportunities to increase engineering students' preparedness to pursue well-fitting careers.

1. Occupational intentions of engineering students: An examination of candidate sorting at the college-careers interface

The health of the U.S. engineering workforce pipeline garners considerable attention from policymakers, academic researchers, and employers. Federally funded education and outreach programs aimed at drawing more students into science, technology, engineering, and mathematics (STEM) career paths in the U.S. constitute a multi-billion dollar effort annually (Mervis, 2013; American Institute of Physics, 2018) – and such programs, often lauded by industry leaders, have historically received bipartisan support in congress (Teitelbaum, 2014; Brown, 2017). In parallel, academic research on engineering workforce development has grown considerably since the turn of the 21st century: publication trends indicate a 10x increase in the annual number of journal articles related to the phrases "engineering workforce," "engineering talent," or "engineering careers" from 2000 to 2016 (Web of Science, 2018).

In this era of focus on the engineering workforce, rising numbers of candidates are indeed entering the engineering pipeline. Annual increases in numbers of students pursuing engineering degrees at U.S. universities have been recorded, both in absolute terms and as a proportion of all degree types, since the year 2000 (National Center for Educational Statistics [NCES], 2018; National Science Board [NSB], 2018). Recent reports, meanwhile, generally point to a sufficient and adaptive supply of engineering graduates nationwide relative to available positions (Anft, 2013; Salzman, 2013; Xue & Larson, 2015; Lynn et al., 2018). Yet, despite these apparent recruitment successes, key workforce development issues persist that are relevant to engineering managers and educators. The issues pertain less to the overall quantities of engineering degrees being awarded, however, and more to idiosyncrasies in the self-selection and career path sorting behaviors of candidates at various stages in the pipeline.

Such key sorting phenomena relate to engineering candidates' sense of fit and, in turn, to their retention in both degree programs and at initial occupations. As a result, the cross-section of candidates remaining in the pipeline – in terms of candidates' interests, abilities, and demographics – changes as cohorts progress from education stages of the pipeline into careers (Stevens et al., 2008; Lichtenstein et al., 2009; Atman et al., 2010; Cech et al., 2011; Frehill, 2012; President's Council of Advisors on Science and Technology [PCAST], 2012; Glass et al., 2013; Hunt, 2016). Relatedly, engineering students face a growing variety in employment opportunities available to them: engineering employers increasingly compete with other types of employers for individuals in the engineering pipeline, as engineering degrees have proven valuable to a variety of alternate career paths (Carnevale et al., 2011; Langdon et al., 2011). Yet, the resulting career path dispersion among engineering candidates does not consistently produce ideal candidate-career matches, either from candidates' or from engineering employers' perspectives (Correll, 2001; Stevens et al., 2008; Atman et al., 2010; Winters, 2012; Xu, 2013). This chapter begins by reviewing evidence of trends of imperfect matching and of systemic attrition in certain areas of the workforce and pipeline. It then examines factors associated with engineering graduates' sorting into various career trajectories at the college-career interface, proceeds to discuss how some of these factors can relate to imperfect matching, and concludes by discussing how employers and educators can take steps to improve sorting and enhance candidate-career fit.

The chapter centers on the development and empirical validation of a sorting model that unifies existing theory on engineering graduates' occupational outcomes. Employing a sample of 1,061 senior year engineering students surveyed at nine universities across the U.S., we first replicate existing findings on the factors associated with engineering and non-engineering occupational intentions (e.g., binary sorting) following graduation. We then extend this baseline model by developing and testing a multinomial outcomes model that examines the factors uniquely associated

with specific categories of occupational intentions. This latter model enhances engineering employers' and educators' understanding of candidates' departures from the engineering pipeline by highlighting that differing sets of factors are associated with different types of occupational intentions.

1.1 Background

As in past eras, policymakers today continue to call for strengthening the science and engineering pipelines in the U.S. through increased STEM degree production (Hira, 2010; Teitelbaum, 2014; as examples, see: Augustine et al., 2005; PCAST, 2012). Contemporary policy formulations have also included early-pipeline programs to promote STEM careers to underrepresented groups (Stine, 2009; Furman, 2013). Yet, with "degrees awarded" as a primary metric for success in much of the enacted STEM recruitment policy, other important downstream metrics are (perhaps inadvertently) deemphasized or missing – such as measures of career placement and of employer or employee satisfaction (Hira, 2010; Xu, 2013; Teitelbaum, 2014).

While the number of engineering bachelor's degrees awarded annually has increased by 68% between the years 2000 and 2015, outpacing a 53% overall growth in all annual U.S. bachelor's degree awards (NSB, 2018), evidence also suggests an accumulation of degreed engineers working outside of engineering (Langdon et al., 2011; U.S. Census Bureau, 2014). Concurrent growth in hybrid and engineering-related roles, such as in project management, may in part explain the latter claim, as participation in such roles is difficult to consistently classify and count (see: Chapter 3; see also: DiVincenzo, 2006; Lowell et al., 2009). Nonetheless, various reports suggest that engineering graduates increasingly take on jobs at or soon after graduation that deviate from traditionally categorized engineering roles (Carnevale et al., 2011; Langdon et al., 2011). In today's landscape of varied opportunities, as one study states, "an engineering major does not (necessarily) an engineer make" (Lichtenstein et al., 2009, p. 227).

1.1.1 Opportunities to improve candidate sorting

Career path dispersion and attrition are natural and expected phenomena in all workforce pipelines as candidates navigate the process of professional identify formation, build self-awareness, and become more informed about jobs (Lent, et al., 1994; Ibarra, 1999; Stevens et al., 2008; Eliot and Turns, 2011). Tolerating this dispersion is easier for employers when the potential labor supply is large enough to cover losses from the pipeline, as is the case in many sub-disciplines of engineering in our present time (Aft, 2013; Salzman, 2013; Xue & Larson, 2015); yet, the total headcount in the pipeline does not tell the full story in engineering. Recent literature suggests opportunities for mitigating systemic attrition from at least two key subsets of individuals among successful engineering bachelor's degree earners: graduates with comparatively strong interpersonal and leadership skills, and female graduates.

Engineering students with strong interpersonal and leadership skills, though highly sought for by engineering employers (Salzman & Lynn, 2010; American Society for Engineering Education [ASEE], 2013; Hartmann, et al., 2016), may perceive opportunity for greater return on these skills in other fields (Carnevale et al., 2011; Deming, 2017), and may be more likely to leave engineering, on average, compared to others (Atman et al., 2010). Though literature on engineering practice has long documented the embeddedness of social interaction and leadership in engineering work (Bucciarelli and Kuhn, 1997; Meier et al., 2000; Bucciarelli, 2002; Trevelyan, 2007; Trevelyan, 2010; Salzman and Lynn, 2010; ASEE, 2013; Hartmann, et al., 2016), recent reports point to a "soft skills" gap in the engineering workforce and to employers' perceived difficulty in recruiting technically capable candidates who also posses high levels of these interpersonal and leadership skills (Salzman and Lynn, 2010; Cappelli, 2015).

A second key opportunity involves addressing the various factors that hinder demographic diversity in the engineering workforce (see: Correll, 2001; Good et al., 2008; Amelink & Creamer,

2010; Cech et al., 2011; McGee & Martin, 2011; Ellis et al., 2016; Seron et al., 2016). Underrepresentation of women and certain minority groups in engineering is well documented (U.S. Census Bureau, 2014; National Science Foundation [NSF], 2017; National Science Board [NSB], 2018). This disparity is greatest for women, who make up 14.5% of the U.S. engineering workforce, despite composing 47.0% of the U.S. working population (NSB, 2018). Yet, attempts at boosting women's and minorities' representation in the engineering workforce by increasing their enrollment in engineering schools – which, itself, has been slow to occur (NSB, 2018) – are further thwarted by the disproportionate attrition of underrepresented candidates, particularly women, at or soon after the college-career interface (Frehill, 2012; Ayre, et al., 2013; Glass et al., 2013). Engineering employers, meanwhile, frequently cite increasing the diversity of their workforces as a priority (Johnson, 2017; Mohan, 2017; Olson, 2017).

The evidence in both of these areas suggests that certain types of candidates who have the potential to thrive – and who are sought by engineering employers – are at greater risk of exiting the engineering pipeline at the college-career interface compared to others. This study constructs and validates statistical models of engineering students' expected occupational outcomes, through which we examine these and other career path sorting tendencies among senior year engineering students.

1.1.2 Why focus on the college-careers interface?

Initial jobs after college or graduate school, while often transient and part of a series of early-career iterations (Jepsen & Dickson, 2003; Arnett, 2007; Murphy et al., 2010), nonetheless set critical foundations for the longer-term careers that candidates achieve later in life. Studies show that career changes tend to become less frequent with age (Finegold et al., 2002; Jepsen & Dickson, 2003), and that, over time, it becomes increasingly unlikely that candidates who had "track switched" out of a technical discipline will switch back (Biddle & Roberts, 1994). Research also shows that the

thoroughness of candidates' informedness about available career options at the time of initial post-collegiate job searches (Werbel, 2000) and candidates' attainment of jobs that are aligned with their discipline of education (Xu, 2013) are associated with increased career satisfaction. Enhancing employers' and educators' understanding of the factors at play as engineering students encounter this critical college-career interface may afford opportunities to improve overall alignment between students and their career outcomes, help to diversify the engineering workforce, and enable higher retention of those with in-demand skills.

1.2 Theoretic basis

Extant studies offering explanations of engineering graduates' occupational outcomes tend to fall within social, economic, or educational theoretic areas. We review literature in each of these areas and distill the various factors that studies within each have associated with engineering and non-engineering occupational outcomes (or outcome intentions) of graduates.

1.2.1 Social explanations

Literature centered on social explanations of engineering graduates' career path behavior examines graduates' occupational outcomes (or intentions) in relation to the strength of their professional identities and to their socially- and culturally-informed senses of fit in workplaces, in roles, or in exercising key abilities. Such works posit that occupations carry with them sets of role expectations and workplace cultural norms, both of which inform the development of candidates' perceived compatibility with the occupation (Eliot & Turns, 2011; Cech et al., 2011; Ayre et al., 2013; Seron et al., 2016).

The development of professional identity is a phenomenon often discussed in the broad literature on careers (Ibarra, 1999; Cohen-Scali, 2003; Ibarra & Barbulescu, 2010; Slay & Smith, 2011). Numerous studies have examined strength of professional identity as a factor associated with

engineering students' persistence in or departure from engineering career pathways (Stevens et al., 2008; Matusovich, et al. 2010; Cech et al., 2011; Eliot & Turns, 2011; Ayre et al., 2013; Hatmaker, 2013; Cech, 2015). For example, Matusovich et al. (2010) find that candidates at highest risk of leaving engineering are those with "limited connection between engineering and the personal sense of self" (p. 300). Ayre et al. (2013) report an association between "sense of belonging" in a particular engineering field and persistence in that field (p. 230). Eliot and Turns (2011), meanwhile, find that those who had most strongly internalized a personal connection to engineering were those who had "[made] sense of themselves as engineers while [building] a personal vision of the engineering profession" (p. 649). This literature suggests that a strong professional identity is one marked by a clear sense of fit within and deep personal connection to a particular profession. Yet, research suggests that achievement of such a sense of fit or connection is far from inevitable among engineering students by the end of undergraduate studies; rather, many engineering students continue to grapple with professional identity as they prepare to graduate (Stevens et al., 2008; Lichtenstein et al., 2009). Based on this literature, we hypothesize that those engineering students who have established a strong professional identity by their senior year (e.g., as evidenced by identification with one specific profession) are more likely, on average, to expect to work in engineering after graduation compared to others.

A general and frequently applied framework on the development of occupational intentions draws on candidates' self-efficacy beliefs in the abilities requisite for achieving certain career development goals and, relatedly, on their personal interests in pursuing such goals. Social Cognitive Career Theory (SCCT), as presented by Lent et al. (1994), rests on a feedback-based model whereby candidates' beliefs in their abilities evolve as they set goals for themselves and attempt to achieve them. Contextual experiences, inclusive of social persuasions, encountered throughout this pursuit influence how candidates process performance feedback, and in turn, how they revise their interests

and self-efficacy beliefs. SCCT highlights that candidates' beliefs in their underlying abilities are not entirely objective. Theorists, for example, point to gendered norms and cultures as "socially constructed aspects of experience" that influence feedback processing related to occupationally relevant abilities (Lent et al., 1994, p. 105). Empirical studies of engineering students' career interests have frequently employed SCCT as an explanatory framework (see: Nauta et al., 1998; Trenor et al., 2008; Byars-Winston et al., 2010; Jones et al., 2010; Atadero et al., 2015; Lent et al., 2018). As expected, a commonality among these studies is their focus on candidates' ability beliefs as factors correlating with interests in occupations perceived to require such abilities.

Ability beliefs in two areas stand out among the pertinent literature as frequently examined for their association with engineering graduates' career outcomes: those beliefs related to mathematics abilities and those related to interpersonal and leadership abilities. Students' beliefs in these two areas may be salient factors in cases of poor occupational matching due to well-documented trends of misperception about the ability demands of real-world engineering practice in these areas. For example, scholars critique how mathematical problem solving in engineering school – in terms of type, frequency of use, problem framing, and available resources – differs from mathematical problem solving in engineering practice (Bucciarelli & Kuhn, 1997; Trevelyan, 2007; Trevelyan, 2010). Studies suggest that, while some aspects of engineering work certainly rest on mathematics, the way math is presented in the engineering curriculum (including its positioning as a "gatekeeper" subject (Winkelman, 2009) creates a discrepancy between university and real-world notions of a typical engineers' use of math on the job (Bucciarelli & Kuhn, 1997; Trevelyan, 2007; Winkelman, 2009; Trevelyan, 2010). Given that research has shown students' mathematics confidence to be associated with retention in engineering (O'Brien et al., 1999; Correll, 2001; Eris et al., 2010; Litzler & Young, 2012), and that self-assessment biases have been shown to exist in

students' perceptions of their mathematics abilities (Correll, 2001; Ellis et al., 2016), engineering work's reputation pertaining to mathematical demands may needlessly be pushing potentially well-fitting candidates away (see also Vest (2011) and Baranowski (2011) for a related discussion on engineering's "brand" among aspiring students). Similarly, but to an opposite effect, students with high self-assessment in interpersonal and leadership abilities may be drawn away from engineering careers and toward alternatives perceived to better leverage and reward such abilities (Atman et al., 2010; Litchfield and Javernick-Will, 2016; Deming, 2017). Again, occupational reputation may be a culprit: scholars note how analyses of engineering practice show marked demands for communication, coordination, and leadership abilities across various levels of engineering work (Bucciarelli & Kuhn, 1997; Salzman & Lynn, 2010; Trevelyan, 2010; ASEE, 2013; Hartmann, et al., 2016) – and how engineering positions are a well-known gateway into managerial roles (Biddle & Roberts, 1994; Perlow & Bailyn, 1997; Herkert, 2001; Anft, 2013) – yet, that the engineering curriculum has historically done a poor job of illustrating the social-technical work blend of engineering practice and of advancement opportunities to aspiring students (Bucciarelli & Kuhn, 1997; Trevelyan, 2007; Trevelyan, 2010; ASEE, 2013).

Mathematics ability beliefs have been studied extensively in association with candidates' retention in the engineering pipeline (Nauta et al., 1998; Correll, 2001; Eris et al., 2010; Litzler & Young, 2012), and research has shown that these ability beliefs are at least in part socially influenced, net of actual ability (O'Brien et al., 1999; Correll, 2001; Ellis et al, 2016). This literature does not suggest that raw ability is a trivial factor in ability belief formation; rather, it finds that raw ability is not alone in shaping ability beliefs (Nauta et al., 1998; Correll, 2001). We thus separately consider academic performance and quality of learning experiences as educational factors tied to occupational outcomes (see: *Educational explanations*). The influence of social and cultural factors

in shaping women's and men's math ability beliefs appears, at least in part, to be systemic, with women more likely to rate themselves lower in math ability than men who score the same on performance measures (Correll, 2001) and with women more likely then men to exit the pipeline based on the same performance feedback (Ellis et al, 2016). Meanwhile, existing studies find consistent empirical support for an association between strong mathematics ability beliefs and candidates' intention to pursue engineering careers. Correll (2001), for example, summarizes: "self-assessments of [mathematics] task competence were found to influence career-relevant decisions, even when controlling for commonly accepted measures of ability," noting an association between higher math self-assessments and increased likelihood of career path persistence in engineering (p. 1724). Similarly, Eris et al. (2010) find that "non-persisters [in engineering] are less confident in their math and science skills than persisters" (p. 379). Based on the existing research, we expect that those engineering students with higher ability beliefs in mathematics are more likely, on average, to persist into engineering careers following graduation. Further, prior research suggests a connection between ability beliefs and enjoyment. Goetz et al. (2006) and Sitzman et al. (2010) find an association between students' perception of their math performance or abilities and their anticipated enjoyment in using mathematics in tasks, jobs, or activities. Accordingly, we hypothesize that candidates in the engineering pipeline with higher expectations of mathematics enjoyment are more likely, on average, to expect to work in engineering after graduation compared to others.

Candidates' satisfaction with perceived career growth prospects in engineering, inclusive of opportunities to exercise leadership and to be promoted beyond individual contributor ranks, has long been a focus of the literature on engineering as an organizationally-embedded profession (Goldner & Ritti, 1967; Layton, 1971; Bailyn & Lynch, 1983; Shapira & Griffith, 1990; Watson & Meiksins, 1991; Biddle & Roberts, 1994; Allen & Katz, 1995; Perlow & Bailyn, 1997; Igbarria et al., 1999).

More recently, research in this area has explored associations between candidates' interpersonal or leadership ability beliefs and their likelihood of obtaining and persisting in early-stage engineering jobs (Byrd et al., 1996; Atman et al., 2010; Litchfield & Javernick-Will, 2016). Literature suggests enduring societal perceptions of a technical-managerial dialectic, whereby technical roles and management roles belong to distinct career tracks from which candidates must choose early in their careers (Allen & Katz, 1995; Perlow & Bailyn, 1997; Jemielniak, 2007; Joseph et al., 2012), and that moving between these tracks requires a jump or "track switch" (Biddle and Roberts, 1994). Yet, a substantial body of literature challenges this notion of a dialectic, highlighting the existence of hybrid roles (Watson & Meiksins, 1991; Allen & Katz, 1995; Williams, 2002; Hodgson et al., 2011; Joseph et al., 2012; Paton and Hodgson, 2016), the embeddedness of coordinative and leadership responsibilities in typical engineering roles (Bucciarelli & Kuhn, 1997; Trevelyan, 2007; Trevelyan, 2010), and the prevalence of engineering roles as gateways into management positions (Biddle & Roberts, 1994; Mael et al., 2001; Joseph et al., 2012). Despite evidence of blurred boundaries between "tracks," research suggests that candidates' intentions of leaving engineering at (or soon after) graduation are associated with higher self-assessed interpersonal or leadership abilities (Atman et al., 2010; Litchfield & Javernick-Will, 2016). Based on this literature, we hypothesize that engineering graduates possessing higher leadership ability beliefs are more likely, on average, to expect to work at non-engineering occupations after graduation compared to others.

1.2.2 Economic explanations

Literature indicates that the academic and career interests of students in the engineering pipeline are responsive to shifts in engineering job market conditions (Ryoo & Rosen, 2004; Salzman & Lynn, 2010; Bardhan et al., 2013; Lynn et al., 2018). In terms of year-to-year trends, cohorts in the engineering pipeline exhibit a willingness to alter their undergraduate degree pursuits (Salzman &

Lynn, 2010, Lynn et al., 2018) or graduate school intentions (Austin, 2014) as engineering job markets swing; meanwhile, candidates' career plans also reflect the availability and attractiveness of jobs outside of their degree fields (Carnevale et al., 2011; Anft, 2013). In recent instances where a sub-discipline's job market underwent a spike or drop in demand, students' career interests and enrollments have been shown to shift responsively, following a brief lag – such was the case during the recent spike-decline cycle in the petroleum engineering field in the U.S. (Lynn et al., 2018), and in computer-related fields that underwent similar demand swings near the turn of the 21st century (Salzman & Lynn, 2010). Observations of these types of cycles have prompted economists to posit that labor supply models based upon assumptions of unrestricted candidate mobility may better fit the engineering labor system than earlier models which assumed candidate lock-in and limited awareness of alternatives during the credentialing process (Felderer & Drost, 2000). Meanwhile, data indicate substantive differences across the various engineering degree fields in terms of labor demand and government-forecast job growth (U.S. Bureau of Labor Statistics, 2018a). The literature thus suggests that market factors should be controlled for in studies attempting to measure students' interests in engineering careers – such as by controlling for individuals' specific field of study, salary expectations, and the date(s) of survey data collection.

Beyond labor demand in specific fields, economics literature also calls attention to financial risk and job security characteristics of particular careers as important differentiating factors. Candidates' risk-seeking or risk-averse orientations have been shown to correlate with type of career attained (Saks & Shore, 2005; Caner & Okten, 2009; Sapienza, et al., 2009). Studies find that different careers carry different levels of inherent financial risk – and that engineering careers are relatively low-risk in comparison to alternatives, such as careers in business or finance (Saks & Shore, 2005; Caner & Okten, 2009). Correspondingly, these works find that candidates with risk-averse orientations are more likely,

on average, to pursue careers in engineering compared to other candidates (Saks & Shore, 2005; Caner & Okten, 2009). We thus hypothesize, based on this literature, that students with a financially risk-averse orientation will be more likely, on average, to expect to work at engineering jobs after graduation compared to their risk-seeking peers. Literature also suggests that individuals' student loan debt status should be controlled for in studies examining the occupational plans of college graduates, as studies have found that risk orientations are linked, on average, to family wealth and socioeconomic background, for which student loan status is a proxy (Houle, 2014; Hsu & Fisher, 2016).

1.2.3 Educational explanations

An array of recent studies has examined connections between engineering candidates' educational experiences and their commitment to engineering. These works have explored associations between engineering degree program retention or occupational intentions and factors such as: type of university attended (Chubin et al., 2005; Moore, 2006; Lichtenstein et al., 2009; Marra et al., 2009; Atman et al., 2010; Amelink & Creamer, 2010); academic performance (Mau, 2003; Moore, 2006; Stevens et al. 2008; Xu, 2013; Godwin et al., 2016); exposure to curricular or pedagogical innovations (Dym et al., 2005; Amelink & Creamer, 2010; Eris et al., 2010; Freeman et al., 2014; Atadero et al., 2015); and participation in internships and co-op experiences (Lichtenstein et al., 2009, Atman, 2010; Malcom & Feder, 2016). The findings in this literature suggest that studies examining engineering students' occupational plans should control for students' university, degree program, and academic standing to account for potential differences among students in the above areas.

Variance in students' persistence intentions in the engineering pipeline has been associated with characteristics of the institutions in which students undertake their degrees. Studies note that university type – in particular, whether an institution grants a proportionally large number of engineering degrees and is characterized as technically-focused – appears to be associated, on

average, with student occupational intentions (Lichtenstein et al., 2009; Atman et al., 2010). Lichtenstein et al. (2009), for example, report a substantive difference in the percentage of students stating they are *unlikely* to pursue engineering after graduation at a non-technically focused university (36%) compared to at a technically-focused university (14%). Various studies also report that factors related to faculty-student ratio and faculty culture, such as students' face time with faculty and the quality of faculty-student interactions, are associated with strengthened engineering intentions in students (Chubin et al., 2005; Moore, 2006; Lichtenstein et al., 2009; Amelink & Creamer, 2010). This literature underscores a need to control for students' host university and degree program in research examining occupational intentions.

The role of students' academic performance in influencing their persistence in the engineering pipeline has been examined extensively. Education research highlights an association between higher academic performance and increased likelihood of persistence in (or lower risk of attrition from) engineering (Mau, 2003; Moore, 2006; Xu, 2013; Stevens et al., 2008; Godwin et al., 2016). Mau (2003), for example, finds a significant connection between test scores and engineering career aspirations. Xu (2013) reports a significant association between STEM students' GPA within their undergraduate major and likelihood of persisting into a career in the field of the major. As discussed in the section on *Social explanations*, it is important to note that raw academic performance is embedded in a social system – the encouragement or discouragement students receive along with performance feedback can impact the way they process this feedback (Marra et al. 2009; Godwin et al., 2016). Additionally, academic performance's relation to persistence or attrition choices among those in the engineering pipeline is tied to the timing of the performance: studies discern particular milestones or "passage points" (Stevens et al., 2008) prior to graduation, such as deadlines to declare or change majors, where performance feedback's association with career path decisions is heightened

(Stevens et al., 2008; Ellis et al., 2016). Literature thus suggests that studies examining the occupational plans of engineering students should control for academic standing or graduation status in their major field, as variance in occupational plans may exist between students with stronger and weaker academic standing.

Beyond literature that examines general education-related factors, other studies examine the effects of specific curricular or pedagogical innovations on students' commitment to engineering. Here, educators have assessed educational approaches that increase opportunities for active learning (Felder et al., 1998; Freeman et al., 2014) or employ open-ended project-based assignments (Dym et al., 2005; Zhou et al., 2012; Atadero et al., 2015). Studies suggest that these types of teaching innovations can increase students' motivation toward or interest in engineering (Felder et al., 1998; Dym et al., 2005; Zhou et al, 2012), and increase students' persistence in degree programs (Felder et al., 1998; Dym, 2005). Scholars also posit that these teaching approaches introduce students to contexts that better emulate real-world engineering problem solving environments (Bucciarelli & Kuhn, 1997). Though research in this area does not directly connect these educational innovations to students' occupational plans, it nonetheless reinforces that studies on students' occupational plans should control for students' universities and degree programs, as educational innovations may be employed to differing extents within different universities and programs. Moreover, studies note that differences between innovative and traditional educational approaches can positively influence students' perceptions of the opportunities for creativity intrinsic to engineering work (Bucciarelli & Kuhn, 1997; Bernold et al., 2007; Zhou et al, 2012), which, in turn, relate to increases in students' commitment to engineering (Bernold et al., 2007; Atwood & Pretz, 2016). Based on this literature, we hypothesize that students' satisfaction with perceived opportunities to exercise creativity in engineering work is associated with an increased likelihood that students will expect to work in engineering after graduation.

Students' exposure to industry-realistic problem solving contexts can also be facilitated through engineering internships and co-ops undertaken during students' university years. Several studies associate students' internship experiences with an increased likelihood of career interest or outcomes in engineering (Atman et al., 2010; Zhao & Linden, 2011; Malcom & Feder, 2016). Similar to project-based education experiences in the core curriculum, internships can provide students with key opportunities to experience open-ended problem solving (Malcom & Feder, 2016) and to build a sense of engineering as a creative field (Zhao & Linden, 2011). Based on qualitative interview research, Litchenstein et al. (2009), find that internships can either be persuasive or dissuasive experiences for students, depending on the positivity of the experience (Lichtenstein et al., 2009). Among a broad set of factors tested for their association with engineering students' likelihood of pursuing an engineer job after graduation, Atman et al. (2010) found internship participation to be the factor most strongly associated with students' engineering career pursuits. While an association between internship participation and students' attainment of an engineering occupation after graduation could reflect an already-higher propensity for working in engineering among internship participants, the literature also suggests mechanisms within the internships themselves (e.g., exposure to open-ended problems, opportunities to work creatively) that could increase students' attraction to working engineering. Based on the literature, we hypothesize that students who experience a positive engineering internship are more likely to expect to work in engineering after graduation compared to those students who have not experienced a positive engineering internship.

1.2.4 A missing dimension: Diversity of alternatives

The conception of "engineer" as a distinct and homogenous occupational category pervades much of the literature on engineering students' career outcomes. Studies typically consider the engineering pipeline as clearly bounded, with candidates' status denoted as either within or outside

of it (Perlow & Bailyn, 1997; Stevens et al., 2008; Brunhaver et al., 2013). Such a binary conception of engineering implicitly assumes that graduates with non-engineering occupational outcomes belong to a single category as well. Yet, data shows that when graduates acquire jobs beyond those traditionally categorized as "engineer," such jobs could be in any number of alternate areas, including management, finance, and medicine, among many others (U.S. Census Bureau, 2014). Some of engineering graduates' alternate careers, such as those in project management or technical consulting, are likely to be more related to engineering compared to others (see: Chapter 3). In other words, an exit from the engineering pipeline could carry markedly different meanings, depending on the specifics of the alternate outcome. Scholars have criticized the existing conceptions of mutually exclusive and internally homogenous engineering and non-engineering outcomes (Perlow & Bailyn, 1997; Stevens et al., 2008), suggesting that important career path sorting information is lost when studies consider occupational outcomes in this way.

Yet, given that most of the existing theory on engineering students' careers conceptualizes outcomes sorting in a binary manner, the study outlined hereafter in this chapter begins by examining binary occupational expectations of students for purposes of replication and theoretical unification (e.g., the development of a baseline occupational sorting model). Next, however, the study explores the potentially important differences in factors associated with the variety of different career outcomes of engineering graduates. This latter analysis employs a multinomial outcomes model, allowing for an examination of whether factors associated with graduates' non-engineering outcomes differ depending on specific career outcomes. The chapter concludes with a discussion on how differences in factors associated with differing occupational outcomes carry implications for engineering employers and educators who aspire to improve the candidate-career matching of graduates.

1.3 Methods

1.3.1 Overview of survey approach

This study employed a survey approach designed to query senior year engineering students across the U.S. while maximizing response rate and minimizing sampling biases. In developing such an approach, we first negotiated conditions and constraints of data collection with several partner universities that would serve as survey sites (see: *Sampling and data collection* for details on partner university selection). The resulting research design reconciled the requirements of these partner institutions with the sampling goals. We obtained permission to administer the survey during required class times at the universities, and, accordingly, agreed to design the survey instrument to take 12 minutes or less to complete. We also agreed not to publish results in a manner that conveyed university-to-university comparisons. The negotiated survey approach centered on utilizing a compact, paper-based survey form, which allowed us to achieve a near-90% response rate and a sample of over 1,000 observations.

The concise survey format, however, restricted our ability to pose questions in a multitude of ways to assess respondents' comprehension of the questions. In light of this limitation, we employed strategies to attain confidence in the validity and consistency of responses. We first pilot-tested the survey in advance of the main study with a smaller sample of 99 participants to gauge the correctness of respondents' question interpretations and to make consequent refinements to question construction to enhance clarity. Additionally, we employed a criterion validation approach (Babbie, 2010) in the main study to assess measurement validity. This validation approach involved testing for the replication of expected relationships among independent variables, and necessitated including a small number of additional variables for this purpose, as described in Section 1.3.2 (*Conceptualization and measurement of variables*). Finally, measurement consistency was checked using a split-sample

approach to compare results from the chronological first half of the sample to those from the second half. These overall survey design and verification strategies align with the study's scope of replicating and generalizing theoretic relationships from prior literature, and of testing a unified model of engineering graduates' occupational outcomes using a maximally representative sample.

1.3.2 Conceptualization and measurement of variables

The study's dependent variable, expected occupational outcome, was measured categorically. Here, respondents were asked: "which one of the following represents how you will most likely begin your career journey after undergraduate graduation? Please check only one." Respondents were able to select from among occupations, graduate school, and write-in blank options. Beyond the option of "work as an engineer," other response options were informed by a recent study, documented in Chapter 3, that identified a set of engineering-related roles that graduates have increasingly pursued since the turn of the 21st century (e.g., roles in product or project management, technical consulting, or quantitative analysis). Further, a set of roles that are less engineering-related but for which engineering graduates are actively recruited was included (e.g., roles in management consulting, finance, or venture capital) (see: Shu, 2016). Finally, respondents had the option to indicate they planned to work in academia, "other," or to write in their response. The set of response options as presented in the study's survey form is shown in Table 1-A1 of the chapter's Appendix. Though survey length restrictions precluded us from presenting respondents with a more exhaustive list of options, the write-in response option allowed us to capture the range of alternative career expectations among the sample.

The study's key independent variables are summarized in Table 1-1. The variables' conceptualizations and their expected associations with the dependent variable, expressed as testable

hypotheses in the right column of Table 1-1, are derived from the literature review. The survey questions associated with these variables are presented in Table 1-A1 in the chapter's Appendix.

Table 1-1. Key independent variables and associated hypotheses

Independent Variable and Conceptualization	Assoiciated Hypotheses
	Compared to others among graduating engineering seniors,
Had positive engineering internship experience Subject has held at least one engineering internship or co-op position that they consider as a positive overall experience.	*Hypothesis 1* those who have had a positive engineering internship experience are more likely to list engineering as their expected initial occupation after university.
Averse to financial risk-taking Subject seeks income stability and job security in an occupation, and seeks to avoid occupations that have prospects for outsized financial windfalls that come at the expense of income stability or job security.	*Hypothesis 2* those who are averse to financial risk-taking are more likely to list engineering as their expected initial occupation after university.
Would enjoy working at a job involving advanced mathematics Subject would enjoy a job that regularly required the use of advanced mathematical concepts that they experienced as part of their undergraduate engineering curriculum.	*Hypothesis 3* those who would enjoy working at a job involving advanced mathematics from their field of study are more likely to list engineering as their expected initial occupation after university.
Identifies with a specific profession Subject envisions their ideal career as one that is based upon a specific profession.	*Hypothesis 4* those identifying with a specific profession are more likely to list engineering as their expected initial occupation after university.
Anticipates promotion into formal leadership role by age 25 Subject believes it to be likely that they will be appointed to a formal leadership position by age 25.	*Hypothesis 5* those anticipating promotion into a formal leadership role by age 25 are less likely to list engineering as their expected initial occupation after university.
Sastisfied with creative opportunities at engineering jobs Subject is satisfied with the availability of job opportunities in engineering that allow one to engage in creative design work.	*Hypothesis 6* those who are satisfied with ceative opportunities at engineering jobs are more likely to list engineering as their expected initial occupation after university.

Additional variables were measured for the purposes of empirical control and for criterion validation checks. These included demographic variables (e.g., gender and race), and subjects' student loan debt status, varsity athletics participation status, Greek Life participation status (including attainment of elected leadership positions at fraternities or sororities), undergraduate major, degree completion status (e.g., expected term of graduation: 1 = Spring 2017, 2 = Summer 2017, 3 = Fall 2017), and salary expectations at first full-time job after college or graduate school. The survey questions for each of these variables are also presented in Table 1-A1 in the Appendix.

Meanwhile, identification variables for university and survey period (e.g., 1 = November-December 2016, 2 = January-February 2017, 3 = March-April 2017), and a unique subject identification number, were assigned to each survey record by the researchers.

Criterion validation checks were performed for the key independent variables listed in Table 1-1. These checks involved testing for the replication of expected relationships among variables, and are reported on in the *Results* section. We established the following relationships from prior literature as validity criteria. First, we expect aversion to financial risk to be associated with socioeconomic status (Saks & Shore, 2005; Caner & Okten, 2009), a proxy for which is student loan debt status (Houle, 2014; Hsu & Fisher, 2016); thus, we test for an association between aversion to risk and student loan debt status. We expect enjoyment of working at a job involving advanced mathematics to be associated, on average, with mathematics test scores and academic performance in math (Tapia, 1996; Ma & Xu, 2004; Goetz et al., 2006). In turn, we expect values of the math enjoyment variable to be clustered by subjects' universities due to differences in admissions selectivity (U.S. News and World Report, 2018) and curricula across the schools; thus, we test for significance of differences, on average, of the math enjoyment variable across the schools. We expect identification with a specific profession to be associated, on average, with a greater likelihood of stating a categorized occupational expectation (e.g., as opposed to "other" or "unsure") – a phenomenon that literature on professional identity denotes as self-affiliation with an "external frame" (Eliot & Turns, 2011). We expect anticipation of promotion into a leadership role by age 25 to be associated, on average, with election to student leadership positions in Greek Life organizations (Posner, 2004; Dugan & Komives, 2007). Finally, we expect satisfaction with creative opportunities at engineering jobs to be associated, on average, with positive engineering internship experiences (Zhao & Linden, 2011). Given our concise

survey instrument, these validity checks served as a means to gain confidence that our generalized measures capture the characteristics intended.

1.3.4 Sampling and data collection

Beyond the criteria to sample engineering undergraduate seniors, several additional research design considerations drove this study's sampling approach. Since prior literature showed university type to be an important factor associated with career outcomes (Litchtenstein, et al., 2009; Atman et al., 2010), we deemed the sample's attainment of a broad institutional mix to be critical, inclusive of both public and private universities, large and small engineering schools, and geographical dispersion. The acquired sample consisted of engineering seniors from nine universities from locations across the U.S., including four public and five private universities (resulting in 59% of survey respondents from public universities). This institutional breakdown, with a substantial public engineering school component, provides sample coverage reflective of how at least 80% of U.S. engineering bachelor's graduates earned their degrees (Cech et al., 2011). Table 1-2 provides a list of the nine universities represented in the sample.

In addition to university types represented, we were concerned with controlling for transient job market factors that could influence subjects' career preferences or expectations. Both the timing of the study and survey subjects' degree fields, as noted in the literature review, could relate to exposure to market effects. For this reason, we opted to draw the entire sample from a single academic major currently exhibiting stable academic enrollments and job prospects: mechanical engineering. According to the U.S. Bureau of Labor Statistics (2018a), demand growth for mechanical engineers is classified as "average" relative to the broad range of U.S. occupations over the next decade; meanwhile, we note sharp differences in anticipated job market demand in other areas, most notably in certain computer software-related occupations where demand is comparatively surging (U.S.

Bureau of Labor Statistics, 2018b). Our literature review suggests no theoretic reasons why the factors examined in this study, once empirical controls are in place, should apply differently across the engineering majors, though our research design does not allow us to empirically evaluate the expected generalization. Meanwhile, we controlled for the timing of the study by establishing a limited survey window for data collection at the nine participating universities – November 2016 through April 2017 – and by employing survey period dummy variables as controls in the statistical models.

Table 1-2. Universities represented in the study's sample

University	Location (U.S. State)	Type	Percentage of university's mechanical engineering senior capstone class represented in sample
Boston University	MA	private	88.2
Carnegie Mellon University	PA	private	90.4
Massachusetts Inst. of Tech.	MA	private	92.0
Penn State University	PA	public	81.9
Santa Clara University	CA	private	85.7
Texas A&M University	TX	public	85.8
Tufts University	MA	private	83.0
University of Connecticut	CT	public	92.0
University of Michigan	MI	public	82.8

Finally, we took steps to maximize participation and to minimize self-selection biases in the sample. Key attitudes about working in a career in one's degree field could be disproportionately represented (or omitted) in the sample if candidates self-selected into this study. To mitigate this concern, we collected data on-site at each of the nine universities at instances where full attendance of the graduating class of mechanical engineers was obliged. A particular type of event provides this opportunity: class sessions for senior year capstone design courses. The campaign to recruit participating universities thus involved proposals to administer the survey within capstone courses. Email solicitations were sent to mechanical engineering capstone instructors and to department chairs

until we secured a sufficiently representative set of universities. The rightmost column of Table 1-2 lists the participation rates at each of the nine universities. In all cases, with the exception of Penn State University, participation rates represent percentages of the universities' entire senior class of mechanical engineers. At Penn State, engineering seniors have the option to complete interdisciplinary capstone projects hosted in neighboring engineering departments, and approximately half choose to do so; thus, the participation rate for Penn State reflects those mechanical engineering seniors completing their capstone project in the mechanical engineering department.

Notably, this study's sampling approach produced a set of survey participants who were all near the completion of their degree program and, based on self-reported graduation status information, were capable of satisfactorily completing coursework requirements for an accredited engineering degree. Participants' occupational expectations therefore reflect those of individuals able to complete academic work in engineering, and, thus, do not reflect those of students who began a course of study in engineering but voluntarily or involuntarily departed.

1.3.5 Analysis

Two individuals, an author of this study and a research assistant, independently carried out data entry from the paper survey forms and reconciled results to ensure an accurate final dataset. The data were then imported into Stata v.15 statistics software for analysis. Following tabulation of summary and descriptive statistics, we conducted bivariate hypothesis tests for each of the hypotheses listed in Table 1-1. The robustness of these results was assessed by carrying out the previously described criterion validation checks and split-sample consistency checks.

Next, we constructed a unifying model of engineering students' expected occupational outcomes that incorporated the combined set of theoretic independent variables. Here, we began with a logistic regression (logit) model that employed a binary dependent variable (expectation to work in

engineering: 0 = no; 1 = yes), and included the key theoretic independent variables from Table 1-1 along with demographic indicator independent variables. We estimated this model with and without a set of survey control variables, which consisted of indicators for the different universities in the sample, for subjects' graduation term, and for the period of survey deployment. We then estimated a variant of the logit model that also included an independent variable for subject's student loan debt status in order to assess the model's sensitivity to subjects' socioeconomic background. Finally, we estimated a logit model that included subjects' salary expectations at their first full-time job as an additional independent variable in order to assess the model's sensitivity to potential differences in salary expectations associated with different occupational pursuits. For all model variants, we estimated the models both with and without the set of survey control variables.

We next estimated a multinomial logistic regression (mlogit) model, employing the same independent variables as in the logit models, in order to examine possible differences in key independent variables' associations with different occupational outcome categories. The mlogit model thus required the designation of a categorical dependent variable. Here, we employed a variable consisting of five categories of expected occupational outcomes: 1) engineering; 2) project or product management, technical consulting, or quantitative analysis; 3) management consulting, finance, or venture capital; 4) non-engineering credentialed professions requiring a graduate degree (such as medicine, law, and faculty roles); and, 5) all others. Survey responses corresponding with Outcomes 4 and 5 were categorized based on subjects' write-in responses about their expected first full-time occupation: categorization in Outcome 4 was restricted to occupations with a formal entry criterion tied to a specific advanced degree, while Outcome 5 consisted of all remaining survey responses that did not fit the criteria of Outcomes 1 – 4 (e.g., "forest firefighter," "musician," "travel," "photographer," and "unsure," among many others).

Underlying methodological requirements govern the validity of mlogit models based on the specification of their dependent variables. Specifically, such models rest on an assumption of independence of irrelevant alternatives (IIA), which requires that the outcome categories constituting the categorical dependent variable be sufficiently independent from one another such that adding or removing outcome options does not affect the outcome odds among the options that remain (Long & Freese, 2006). Following construction and analysis of the mlogit models in this study, we conducted Hausman tests in Stata v.15 to demonstrate that IIA assumption was upheld.

1.4 Results

1.4.1 Overview of dataset

Surveys conducted at the nine participating universities resulted in a sample of 1,061 students. Summary statistics for the occupational outcome variable and subject demographics variables are presented in Table 1-3. A substantive majority of subjects expect to work as engineers (70.5%); this percentage includes those who plan to attend graduate school before working but expect their first full-time job to be in engineering. The next largest occupational outcome group, at 14.0%, consists of those expecting to work in project or product management, technical consulting, or as quantitative analysts – a result congruent with recent literature suggesting a prevalence of these occupations among engineering graduates in recent years (see: Chapter 3). The remaining occupation categories each encompass substantively smaller percentages (5.2% or less).

Table 1-3. Summary statistics

Variable	Percentage of Observations
Dependent variable: expected occupational outcome[1]	
Expects to work as an engineer	70.5
Expects to work in other field	
Work in project or product management, technical consulting, or quant. analysis	14.0
Work in management consulting, finance, or venture capital	3.9
Work in a (non-engineering) credentialed profession requiring a graduate degree	2.6
All other	5.2
Military service plans	
Full-time military service directly after college[2]	1.8
Graduate school plans	
Will attend graduate school directly after college[3]	21.7
Graduation term	
Spring 2017	90.9
Summer 2017	2.0
Fall 2017	7.1
Gender	
Female	23.1
Race	
White	70.9
Asian	19.3
Hispanic or Latino/Latina	8.2
Black or African American	3.8
Other non-white	2.3
Student loan status	
Will graduate with student loan debt[4]	38.9
Total observations (individuals in sample): 1,061	

Notes:
1. Graduating seniors reported their expected first job after college or grad school.
2. Individuals serving full-time in the military immediately following college are not counted among any of the other occupational outcomes above.
3. Individuals attending graduate school immediately following college are also counted among the occupational outcomes above; these respondents were asked to report their expected occupation immediately following graduate school.
4. Individuals counted here report having $10,000 or more in student loan debt.

1.4.2 Baseline theoretic relationships, validity, and consistency

Table 1-4 presents summary statistics for key independent variables, conditional upon subjects' expectations to work in engineering or non-engineering occupations. The table also

provides the results of bivariate hypothesis tests for each of the hypotheses listed in Table 1-1 and a comparison of subjects' mean salary expectations between expected occupations.

Based on a Pearson chi-square test, we find support for Hypothesis 1: positive engineering internship experiences are associated, on average, with expectation to work in engineering ($p < 0.001$). In support of Hypothesis 2, we find candidates' aversion to financial risk-taking to be significantly associated with expectation to work in engineering ($p < 0.001$). In support of Hypothesis 3, we find candidates' mathematics enjoyment to be significantly associated with expectation to work in engineering ($p < 0.001$). In support of Hypothesis 4, we find that candidates expecting to work in engineering are more likely to identify with one specific profession compared to those expecting to work in non-engineering occupations ($p < 0.001$). In support of Hypothesis 5, we find candidates' anticipation of promotion into leadership roles by age 25 to be associated with expectations to work at non-engineering occupations ($p < 0.001$). In support of Hypothesis 6, we find satisfaction with creative opportunities at engineering jobs to be associated with expectation to work in engineering ($p < 0.001$). Finally, we conducted a t-test to assess the significance of the difference in mean salary expectation between subjects in the two expected occupational outcome categories and find a null result (two-tailed test): subjects expecting to work in engineering report statistically similar salary expectations compared to those expecting to work in non-engineering occupations.

Table 1-4. Bivariate tests between key independent variables and expectation to work in engineering

Independent Variable	Percentage by Expected Occupation		Test Statistic[1]
	Engineering	Non-Engineering	
Had positive engineering internship experience	75.9	63.8	13.50***
Averse to financial risk-taking	83.8	64.9	40.05***
Would enjoy working at a job involving advanced mathematics	61.0	44.2	21.50***
Identifies with a specific profession	59.5	39.6	30.19***
Anticipates promotion into formal leadership role by age 25[2]	45.6	62.6	21.50***
Satisfied with creative opportunities at engineering jobs[2]	54.3	40.3	14.57***
	Mean and (SD) by Expected Occupation		Test Statistic[3]
	Engineering	Non-Engineering	
Salary expectation for first full-time job after college	$69,664 ($12,192)	$71,268 ($16,041)	1.60

Notes:
1. Reported bivariate test statistics are Pearson chi-square statistics.
2. Dichotomized results are presented here for ease of comparison. Original data are from 7-pt scales; affirmative responses are taken as those above the scale midpoint. The same statistical significance levels are achieved if raw scale results are tested using Mann-Whitney rank-sum tests for ordinal variables.
3. Test statistic is a t-statistic for significance of the difference in means (two-tailed test).
***p < 0.001; **p < 0.01; * p < 0.05

Results of criterion validation checks are summarized in Table 1-A2 in the chapter's Appendix. Statistical tests indicate support for each of the posited validation criteria: aversion to financial risk-taking is shown to be associated with student loan debt ($p < 0.05$); identification with a specific profession is shown to be associated with categorized occupational expectations ($p < 0.05$); anticipation of promotion into a formal leadership role by age 25 is shown to be associated with election to student fraternity/sorority leadership positions ($p < 0.01$); satisfaction with creative opportunities at engineering jobs is shown to be associated with positive engineering internship experiences ($p < 0.001$); and, enjoyment in working at a job involving advanced math is shown to be associated with university of enrollment ($p < 0.001$). These results provide confidence in the validity of the survey's measures of the independent variables. Moreover, results from the chronological split-sample consistency test, as reported in Table 1-A3 in the Appendix, suggest robustness of the survey measures across successive survey deployments. Here, each of the significant bivariate

relationships reported in Table 1-4 is replicated in both the chronological first half of the sample and in the second half; statistical significance is sustained at the $p < 0.05$ level or better for all associations in both sample halves.

1.4.3 Binary outcomes model

Results from our estimation of logit models of students' expectations to work in engineering are reported in Table 1-5. All models employ the same dichotomous dependent variable (expects to work in engineering: 0 = no, 1= yes). The first of these models, Model 1, was estimated based upon the six key independent variables listed Table 1-1, along with demographic indicator variables for gender and race. Coefficients are reported as odds ratios: values greater than one indicate that an increase in an independent variable's value corresponds with an increased likelihood of expected occupation being engineering, while values less than one indicate that an that an increase in an independent variable's value corresponds with a decrease in likelihood of expected occupation being engineering. We observe the anticipated directionalities of odds for all key independent variables based on the theoretic relationships replicated in Table 1-4. For instance, the odds ratio associated with enjoyment in working at a job involving advanced math, 1.583, indicates that an increase in math enjoyment from not enjoying to enjoying working at a job involving advanced math corresponds with a 58.3% increase in the odds that a student will expect to work in engineering. As shown, statistical significance at or better than $p < 0.01$ is found for all six of the key independent variables. Meanwhile, the odds ratio for the gender demographic variable, at 0.654, is also significant ($p < 0.05$), indicating that female gender corresponds with 34.6% lower odds of expecting to work in engineering compared to male gender. The odds ratios for all other demographic variables were not statistically significant.

Next, in Model 2, we added control variables to the logit model for students' university, their term of graduation, and the survey time period. In all cases, the odds ratios for these control variables were statistically insignificant. Further, the odds ratios for the six key independent variables remain similar and their significance levels are unchanged, suggesting adding these controls does not appreciably change the associations between the key independent variables and the dependent variable. However, adding the controls to the model resulted in loss of statistical significance for the gender demographic variable's odds ratio, though its directionality and magnitude remain similar. This loss of significance suggests that gender differences in occupational expectations, in our present sample size, are not robust across the survey settings we controlled for, though the directionality of odds remain consistent with prior studies. Meanwhile, increases in the likelihood ratio chi-square statistic and pseudo R-square values from Model 1 to Model 2 suggests that inclusion of the control variables improves overall model fit.

In Models 3 and 4, we added an indicator variable for student loan debt. First, in Model 3, we exclude the university, graduation term, and survey period control variables; then, in Model 4 we add these controls. In the cases of both Models 3 and 4, we observe that the odds ratio of the student loan debt indicator is insignificant, and that there are no appreciable changes in the odds ratios or significance levels of the key independent variables compared to Models 1 or 2. However, based on a comparison between Model 2's and Model 4's likelihood ratio chi-square statistic and pseudo R-square values, we conclude that adding the loan debt indicator modestly improves overall model fit. While the relationships between the key independent variables and the dependent variable do not appear to be sensitive to the inclusion of the student loan debt variable, we retain it due to its theoretical relevance as proxy for socioeconomic status, which has been shown, in past studies, to relate to career choice (see: Section 1.2.2).

Table 1-5. Logit models for engineering graduates' occupational outcomes

Dependent variable: expects to work in engineering (binary)	Odds Ratios					
Independent variables	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
Had positive engineering internship experience	2.180***	2.076***	2.210***	2.102***	2.252***	2.123***
	(0.410)	(0.400)	(0.419)	(0.408)	(0.448)	(0.432)
Averse to financial risk-taking	2.524***	2.511***	2.257***	2.515***	2.507***	2.511***
	(0.489)	(0.493)	(0.492)	(0.496)	(0.508)	(0.516)
Would enjoy working at a job involving advanced math	1.549***	1.539***	1.555***	1.543***	1.546***	1.531***
	(0.153)	(0.155)	(0.154)	(0.156)	(0.159)	(0.161)
Identifies with a specific profession	1.483***	1.473***	1.458***	1.447***	1.438***	1.432***
	(0.136)	(0.138)	(0.136)	(0.137)	(0.139)	(0.141)
Anticipates promotion into formal leadership role by age 25	0.745***	0.742***	0.743***	0.740***	0.745***	0.736***
	(0.050)	(0.051)	(0.050)	(0.051)	(0.053)	(0.053)
Satisfied with creative opportunities at engineering jobs	1.211**	1.202**	1.225**	1.215**	1.230**	1.218**
	(0.082)	(0.083)	(0.084)	(0.084)	(0.086)	(0.087)
Female	0.654*	0.732	0.692	0.774	0.681	0.765
	(0.130)	(0.153)	(0.139)	(0.163)	(0.142)	(0.169)
Asian	0.954	1.054	0.987	1.088	0.966	1.063
	(0.202)	(0.234)	(0.212)	(0.245)	(0.219)	(0.253)
Black	1.228	1.429	1.158	1.360	1.210	1.425
	(0.552)	(0.658)	(0.521)	(0.626)	(0.578)	(0.702)
Hispanic	1.410	1.553	1.380	1.524	1.616	1.789
	(0.455)	(0.518)	(0.447)	(0.510)	(0.554)	(0.632)
Other non-white	2.372	2.257	2.321	2.234	2.965	2.653
	(1.445)	(1.391)	(1.436)	(1.410)	(2.059)	(1.860)
Will graduate with student loan debt			1.125	1.125	1.129	1.129
			(0.102)	(0.106)	(0.105)	(0.111)
Log salary expectation at first full-time job					0.717	0.880
					(0.342)	(0.437)
University dummies	no	yes	no	yes	no	yes
Graduation term dummies	no	yes	no	yes	no	yes
Survey period dummies	no	yes	no	yes	no	yes
Constant	0.263*	0.242*	0.207**	0.185**	8.412	0.840
	(0.144)	(0.143)	(0.119)	(0.115)	(44.308)	(4.589)
LR chi-square statistic	130.12***	141.36***	132.84***	143.38***	126.02***	137.29***
pseudo R^2	0.129	0.134	0.132	0.143	0.134	0.146
Total observations	913	913	909	909	860	860

Notes:
All models are logit models; standard errors are in parenthesis.
Observation counts listed for each model are less than the study's full sample due to some subjects' voluntary omission of some survey questions.
Control variables (university, graduation term, and survey period dummies) are included when indicated; in all cases they are insignificant.
***$p < 0.001$; **$p < 0.01$; * $p < 0.05$ (two-tailed tests).

Finally, in models 5 and 6, we add an independent variable for the log of students' salary expectations at their first full time job. Again, we introduce this variable to model variants that both exclude (Model 5) and include (Model 6) the control variables for university, graduation term, and survey period. In the cases of both Models 5 and 6, the salary expectation variable's odds ratio is

statistically significant, suggesting that students who expect to work in engineering and students who expect to work outside of engineering anticipate earning similar salaries at their first full-time job. Further, in both Models 5 and 6, the odds ratios and significance levels of the key independent variables are not appreciably different than any of the earlier model variants, suggesting that the relationships between these key variables and the dependent variable are not notably sensitive to the inclusion of the salary expectation in the model. Meanwhile, Model 6's likelihood ratio chi-square statistic and pseudo R-square values remain similar to Model 4's, though the likelihood ratio chi-square statistics decreases slightly and the pseudo R-square value rises slightly upon the inclusion of the salary expectation variable. We retain the salary expectation variable due to its theoretic relevance in relation to engineering students' occupational pursuits (see: Section 1.2.2).

We establish Model 6 from Table 1-5 as our benchmark model of binary occupational expectations (e.g., engineering or non-engineering) for engineering students. Factors found to be significant in this multivariate logit model are the same as those that were significant in bivariate tests: positive engineering internship experiences, aversion to financial risk-taking, enjoyment of working at a job involving advanced math, identification with one specific profession, anticipating promotion into a formal leadership role by age 25, and satisfaction with creative opportunities at engineering jobs.

1.4.4 Multinomial outcomes model

We next constructed mlogit models based upon the independent variable sets employed in the logit models. We tested two model configurations, as presented in Table 1-6: one without the salary expectation variable included, and the other with it included (denoted as Models 1 and 2 in Table 1-6, respectively) – both of which otherwise include identical independent variables sets as those in logit Model 6 from Table 1-5. We estimated these models with and without the salary variable to assess

whether salary expectation's association with occupational expectations might differ across categorical sub-occupations in a manner that was not detectable in our binary (logit) models. The dependent variable in the mlogit models is a 5-category expected occupational outcome variable, with the base category set as "engineering," and the remaining categories as labeled in Table 1-6. Both mlogit Models 1 and 2 comply with the central mlogit modeling assumption – independence of irrelevant alternatives – as verified by Hausman tests in Stata v.15. In these tests, we found we could not reject the Hausman null hypothesis that outcomes are independent of other alternatives ($p < 0.9$), thus indicating support for the pertinent modeling assumption. Further, the odds ratios reported in Table 1-6 reflect odds relative to the base outcome. Ratios greater than one indicate that an increase in an independent variable's value corresponds with an increased likelihood of the associated outcome *relative to* engineering; the opposite is true for ratios less than one. For instance, in Model 1, the odds ratio for "averse to financial risk taking" is 0.229 for Outcome 3, suggesting that a change from risk-seeking to risk-averse corresponds with a 77.1% decrease in odds that a student will expect to work at Outcome 3 (e.g., management consulting, finance, or venture capital) relative to expecting to work in engineering.

The models summarized in Table 1-6 show differences in statistical significance and odds ratios of independent variables depending on the outcome category of the dependent variable. These results suggest that different factors are associated with different occupational outcomes among engineering graduates. We also note that, unlike in any cases of the binary outcome models, salary expectation is shown to be significant for three of the outcome categories in Model 2, and that the addition of the salary expectation variable produces changes in the significance levels of other variables. Moreover, Model 2 exhibits improved model fit compared to Model 1, based on increases in likelihood ratio chi-square statistics and pseudo R-square values between Models 1 and 2, suggesting appropriateness of including the salary expectation variable in the model. We thus deem Model 2 the better fitting of the mlogit models.

Table 1-6. Multinomial logit (mlogit) models for engineering graduates' occupational outcomes

Dependent variable: multinomial expected occupational outcomes set — Odds Ratios

Outcome 1 (Base Outcome): Engineering	Model 1				Model 2			
Independent variables	**Outcome 2** Project or product mgmt.; technical consultant; analyst	**Outcome 3** Mgmt. consultant; finance; venture capital	**Outcome 4** Other credentialed professions requiring a graduate degree	**Outcome 5** All other	**Outcome 2** Project or product mgmt.; technical consultant; analyst	**Outcome 3** Mgmt. consultant; finance; venture capital	**Outcome 4** Other credentialed professions requiring a graduate degree	**Outcome 5** All other
Had positive engineering internship experience	0.663	0.221***	0.528	0.318**	0.704	0.173***	0.486	0.274**
	(0.160)	(0.089)	(0.255)	(0.111)	(0.177)	(0.077)	(0.275)	(0.105)
Averse to financial risk-taking	0.598*	0.229***	0.471	0.215***	0.601*	0.180***	0.723	0.212***
	(0.147)	(0.096)	(0.268)	(0.073)	(0.151)	(0.084)	(0.479)	(0.080)
Would enjoy working at a job involving advanced mathematics	0.660**	0.642	0.922	0.692	0.667**	0.599*	0.839	0.700
	(0.079)	(0.147)	(0.271)	(0.132)	(0.082)	(0.151)	(0.285)	(0.145)
Identifies with a specific profession	0.687**	0.495**	1.981*	0.646*	0.715**	0.504**	1.844	0.570**
	(0.078)	(0.108)	(0.680)	(0.114)	(0.084)	(0.118)	(0.687)	(0.109)
Anticipates promotion into formal leadership role by age 25	1.429***	1.677**	0.499***	1.288*	1.429***	1.424*	0.433***	1.423*
	(0.120)	(0.277)	(0.084)	(0.162)	(0.125)	(0.250)	(0.089)	(0.202)
Satisfaction with creative opportunities at engineering jobs	0.789**	0.876	1.007	0.852	0.785**	0.856	0.806	0.888
	(0.065)	(0.134)	(0.186)	(0.108)	(0.066)	(0.137)	(0.166)	(0.122)
Log of salary expectation for first full time job					0.831	27.990**	880.783***	0.128*
					(0.520)	(34.708)	(1381.623)	(0.108)
Controls included	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
LR chi-square statistic		270.96***				298.46***		
pseudo R^2		0.170				0.201		
Total observations		925				874		

Notes:

Models are multinomial logit models; standard errors are in parentheses.

Observation counts listed for each model are less than the study's full sample due to some subjects' voluntary omission of some survey questions.

Controls included consist of the survey control variables (university dummies, graduation term dummies, and survey period dummies), student loan debt indicator variable, and demographic variables employed in logit Model 6 from Table 1-5

***p < 0.001; **p < 0.01; * p < 0.05 (two-tailed tests).

Table 1-7 presents a summary of the factors found to be significantly associated with each occupational outcome category from mlogit Model 2. Results suggest that candidates expecting to work in the most popular alternative outcome category (Outcome 2: those expecting to work as project or product managers, technical consultants, or analysts) differ from candidates expecting to work as engineers in several ways: the former are less likely to be averse to financial risks, less likely to enjoy working at a job involving advanced mathematics, less likely to identify with a specific profession, more likely to anticipate promotion into formal leadership roles by age 25, and less likely to be satisfied with creative opportunities at engineering jobs. Results also imply that subjects in the Outcome 2 category, on average, had similar internship experiences and expect to earn similar salaries as those expecting to work as engineers.

Results from other outcome categories suggest other unique differences (relative to the engineering) across various factors. For example, those expecting to work in Outcome 3 (management consulting, finance, and venture capital) and Outcome 4 (other credentialed professions), on average, expect to earn higher salaries than engineers at their first full-time job (mean salary expectations for Outcomes 3 and 4 were $75,581 and $84,375, respectively), while those expecting to work in Outcome 5 ("all other") expect to earn lower salaries than engineers (mean salary expectation for Outcome 5 was $65,870). Those expecting to work in Outcome 4 exhibit, on average, a similar strength of professional identity as engineers – yet, in this case, such is presumably toward their alternate professional pursuit (e.g., medicine, law, etc.). Further, those expecting to work in Outcomes 4 and 5 anticipate enjoying working with advanced mathematics to a similar extent, on average, as engineers.

The mlogit model results highlight important areas of heterogeneity among those who leave engineering, and call into question broad generalizations about engineering attrition – be they that attrition is primarily driven by math aversion, or salary pursuits, or professional identities. Our

results suggest that such generalizations may be true for certain sub-groups, but may be untrue, or even opposite in effect, for others. The results suggest that a candidate-career matching perspective – one that takes into account factors on both the candidate side and on the career side – is most appropriate for understanding the occupational sorting of individuals in the engineering pipeline.

Table 1-7. Summary of multinomial analysis: factors associated with distinct occupational outcomes

Compared to engineering graduates expecting to work as engineers (Outcome 1): Those expecting to work in...	...are	Percentage among non-engineering outcomes
Outcome 2 Project or product management, technical consulting or analysis	- Less likely to be averse to financial risk-taking - Less likely to enjoy working at a job involving advanced mathematics - Less likely to identify with a specific profession - More likely to anticipate promotion into formal leadership roles by age 25 - Less likely to be satisfied with creative opportunities at engineering jobs	54.5%
Outcome 3 Management consulting, finance, venture capital	- Less likely to have had a positive engineering internship experience - Less likely to be averse to financial risk-taking - Less likely to enjoy working at a job involving advanced mathematics - Less likely to identify with a specific profession - More likely to anticipate promotion into a formal leadership role by age 25 - On average, expecting a higher salary	15.2%
Outcome 4 Other credentialed professions requiring a graduate degree (e.g., medicine, law)	- Less likely to anticipate promotion into a formal leadership role by age 25 - On average, expecting a higher salary	10.1%
Outcome 5 All other	- Less likely to have had a positive engineering internship experience - Less likely to be averse to financial risk-taking - Less likely to identify with a specific profession - More likely to anticipate promotion into a formal leadership role by age 25 - On average, expecting a lower salary	20.2%

It is important to note the associational nature of these results: our data allows us to observe characteristics of expected occupational sorting behavior, but it does not allow us to make causal claims about the underlying sorting mechanisms. For example, we cannot claim whether candidates specifically plan to work in Outcome 4 because it pays better, or whether they pursued these roles for other reasons and then simply expressed their perception of market compensation rate on the survey. The results do, however, shed light on candidate attributes and expectations, which could inform employers on how to highlight job features in ways that counter existing perceptions among key candidate groups.

1.4.5 Limitations of results

In addition to limitations associated with the non-causal nature of the study's results, readers should take other precautions when interpreting this study. First, we sampled from one specific engineering degree field (mechanical engineering) in order to control for job market effects. We caution that we cannot empirically verify that our results generalize to other fields in the engineering pipeline, though we're aware of no theoretical reasons why results should not generalize across fields. Future efforts to replicate these results in other degree fields would increase our confidence in this generalizability.

We also made the tradeoff of using a highly constrained survey format in order to reach a large sample and achieve a high participation rate. We took steps to establish validity and consistency of our concise measures, both by piloting the study and by incorporating criterion validity checks and split-sample consistency checks. We believe this tradeoff appropriate, despite our inability to employ more formal robustness checks requiring additional survey questions and a longer survey form, given this study's scope of replicating known variable relationships and its focus on theoretical unification, rather than testing new theory formulations.

Finally we note that the multinomial occupational outcomes analysis in this study would have benefited from an even larger sample. Some readers, no doubt, are curious about candidate sorting patterns into a more granular set of occupational outcomes compared to the five broad outcome categories we reported on – such as an outcomes set that includes specific categories established for individual job types (e.g., "medical doctor," "project manager," etc.). Such an analysis would have required a larger sample, as our present study was limited by sub-sample sizes in each outcome category. Moreover, compliance with the IIA assumption suggests that, though the

outcome categories we employed were somewhat broad, the categories are sufficiently independent to allow for category-specific sorting trends to be discerned.

1.5 Discussion

This study highlights patterns of systemic occupational sorting among engineering graduates. We find that senior year engineering students who plan to work at engineering jobs after college or graduate school differ, on average, from their degree classmates who plan to work at other occupations – yet, that this latter group comprises candidates with characteristics sought by engineering employers. In a labor economy where various types of employers compete for talent from the engineering pipeline (Carnevale et al., 2011; Langdon et al., 2011), and where engineering firms seek to diversify their workforces (Johnson, 2017; Mohan, 2017; Olson, 2017), engineering recruiters have reason to improve the present sorting system. Moreover, our results suggest that engineering educators inquire more deeply about the education-careers transition: as students approach graduation, are they sufficiently informed and best prepared to select initial occupations that will lead to satisfying, well-fitting careers?

Though our results do not reveal the causal mechanisms underlying the observed sorting behavior, existing theory links occupational preferences both to candidates' perceptions about themselves and to their perceptions about occupational roles (Lent et al., 1994). Literature further suggests that the extent to which candidates are accurately informed about roles relates to their likelihood of achieving optimal occupational fit (Autor, 2001). As logically follows, those aiming to improve candidate-career alignment in the engineering pipeline should work to enhance candidates' informedness about roles and to rectify roles' incongruence with sought-for candidates' needs and goals. Our results suggest several areas that employers and educators can strategically target in efforts to improve this alignment.

For example, in developing engineering position descriptions and recruitment approaches, employers should expect that candidates' perceptions of a given job's mathematics demands, its opportunities for early-career leadership, and its opportunities to exercise creativity will be salient in shaping candidates' attraction to the job. We are not suggesting that a position description should downplay mathematical demands if such demands truly exist; rather, we point to the danger of exaggerating or laundry-listing mathematical obligations in ways that do not aptly reflect the role, given known issues of candidate under-confidence in math (net of actual ability) (Correll, 2001). Our findings, meanwhile, suggest employers should consider honing recruitment messaging to emphasize leadership opportunities and growth trajectories accessible from entry-level engineering positions – especially in cases where engineering employers desire candidates with leadership confidence and abilities (Hartmann, et al., 2016). Under present conditions, results indicate that the engineering graduates expecting to exercise leadership early in their careers are less likely to plan to work in engineering. Further, our results suggest little downside to a strategy of enhancing and promoting creative aspects of engineering roles to increase the roles' attractiveness. We find that those pursuing certain non-engineering paths (e.g., project or product management, technical consulting, or analysis) report, on average, significantly lower satisfaction with perceived opportunities for creativity in engineering jobs compared to those with engineering occupational expectations, yet none of the groups expecting to work outside of engineering reported significantly higher satisfaction with creativity in engineering jobs compared to those with engineering occupational expectations. In other words, results suggest that boosting students' perceptions of creative opportunities in engineering should only increase the appeal of the field among students.

Our findings convey nuanced implications about compensation strategies for recruiting engineering graduates. The multinomial outcomes analysis (e.g., Table 1-6) finds higher

compensation expectations, on average, among those pursuing certain non-engineering roles (e.g., those pursuing management consulting, finance, venture capital, and other credentialed professions, who constitute, in aggregate, 6.5% of the study's overall sample). Yet, our findings suggest that other job characteristics, such as mathematics demands, leadership opportunities, and creative opportunities, are more salient factors than salary among candidates in the largest of the non-engineering outcome groups (e.g., those pursuing project or product management, technical consulting or quantitative analysis, who constitute, in aggregate, 14.0% of the overall sample). Such candidates do not expect to earn significantly different salaries, on average, than engineers. Results also indicate that candidates' financial risk orientation is associated with expected occupational outcome. Commensurate with prior literature, we find that candidates with a financial risk-seeking orientation are more likely to expect to work at a non-engineering occupation (Saks & Shore, 2005; Caner & Okten, 2009) – and, among candidates expecting to work in product management, technical consulting, analysis, management consulting, finance, or venture capital (who constitute, in aggregate, 17.9% of the overall sample), individuals also possess higher early-career leadership role expectations, on average. Results thus suggest that employers aiming to recruit candidates possessing leadership confidence should consider including financial incentives beyond base salary, such as bonuses tied to success measures, to boost jobs' attractiveness to candidates with financial risk-seeking orientations.

Educators are also well positioned to influence engineering graduates' career paths. Given the strong association we and others (Atman et al, 2010; Zhao & Linden, 2011; Malcom & Feder, 2016) find between internship experiences and engineering occupational outcomes, universities' efforts to promote internship or co-op experiences to students – including programs that integrate industry co-ops into degree tracks – could influence students' intentions to work in engineering. Our results also reinforce past findings relating engineering students' strength of professional identity

with intentions to work in engineering (Stevens et al., 2008; Matusovich, et al. 2010; Cech et al., 2011; Eliot & Turns, 2011) – here, too, educators can make an impact, as literature highlights that faculty interactions play a key role in helping students develop their professional identities (Lichtenstein et al., 2009, Amelink & Creamer, 2010).

Our findings suggest that educational approaches aimed at boosting students' confidence in mathematics could help avert the loss of high-potential but under-confident candidates from the pipeline. Similar to past studies that report an association between female gender and math confidence-related factors (Correll, 2001, Ellis et al., 2016), we also find that females in our sample were less likely to expect to enjoy a job involving advanced math compared to males ($p < 0.05$, based on a bivariate Pearson chi-square test). While we did not directly measure mathematics ability in this study, we note past results demonstrating that differences, on average, in women's math self-assessments compared to men's do not correspond significantly with actual mathematics performance differences; rather, women appear to under-assess themselves, net of actual performance (Correll, 2001). Both past results and ours suggest that educators' continued efforts to close this math confidence gap are well founded and can contribute to improving gender diversity in the engineering workforce.

Finally, we call attention to the gradient of engineering-relatedness among the alternate career pursuits of engineering graduates. Our findings expose a question of results interpretation that academia and industry must reckon with: what constitutes a graduate's "departure" from engineering in an era when substantive numbers of ostensible departures lead to roles closely related to (or complimentary with) engineering roles? Here we refer to results indicating that 14% of subjects in our sample expect their first full-time job to be in areas such as product or project management, technical consulting, or quantitative analysis (e.g., Outcome 2) – roles that often involve frequent

collaboration with engineers (see: Chapter 3). Those concerned with interpreting the health of the engineering pipeline should acknowledge the increasing prevalence of these roles. For instance, the leading professional society of Project Managers experienced a quadrupling of its membership between 1999 and 2005 (DiVincenzo, 2006)); tech giant Google, meanwhile, recruits candidates for its "associate product manager" positions directly out of college (Levy, 2011). It is beyond the scope of this paper to determine whether trends of graduates' occupational outcomes in Option 2 should disappoint or reassure engineering employers – we surmise that the answer likely depends upon the employer, as some employers may recruit college seniors for both Outcome 1 and Outcome 2 roles in parallel, while others may consider individual-contributor engineering roles (e.g., Outcome 1) as the preferred entry point into their firms' technical career ladders. Regardless of particular firms' tactics, this study's results shed light on the average characteristics and expectations of graduates in the two outcome groups, assisting firms in their formulation of recruitment and marketing approaches to shape candidates' expectations about roles. We also note that even such firms wishing to recruit for both Outcome 1 and Outcome 2 positions, yet who seek to enhance diversity across all of their positions, may still find it prudent to consider strategies for boosting the attractiveness of traditionally categorized engineering positions in order to diversify cohorts at those positions.

1.6 Future Work and Conclusions

Beyond future research to further assess validity and generalizability of these findings (as discussed in *Limitations of results*), this study's results can also be extended through research designed to identify causal mechanisms underlying the occupational sorting of engineering graduates. In the present study, supply-side and demand-side candidate-occupation matching effects are likely comingled: subjects reported their expected occupational outcomes, which presumably reflect the combined and interrelated effects of their own preferences, their sense of employers'

likelihood of hiring them for certain roles, and their unverified perceptions of the characteristics of particular types of jobs. Follow-on experimental work could be designed to isolate candidates' preferences for specific job attributes, or employers' preferences for specific candidate characteristics. These latter types of measurements could be achieved by research designs in which experimental subjects rate randomized profiles (e.g., candidates rate profiles of jobs and employers rate profiles of candidates) in order to isolate factors causally tied to preference effects. Further, follow-on research employing controlled trials could be used to examine the efficacy of new recruitment approaches tailored toward attracting candidates with sought-after characteristics. Employers and researchers could partner together in order to test whether the typical candidate sorting trends revealed in this study could be altered by specific changes in recruitment approaches for actual open positions (e.g., a target candidate pool could be randomly split, and differing recruitment materials or methods could be used upon "treatment" and "control" groups). Stated broadly, this present study's utility could be bolstered by follow-on research that identifies pragmatic, actionable means for improving candidate-career matching.

We conclude by recognizing that a more holistic examination of the college-careers interface – one that not only accounts for differences among engineering graduates, but also considers the variation in occupational opportunities they pursue – enhances our understanding of the factors underlying engineering graduates' occupational intentions. Though all subjects in this study were near completion of accredited engineering degree programs in the same field, different types of candidates within our sample tended toward different types of occupations. At least five candidate archetypes emerged from our empirical analysis. The majority-type encompassed those intending to work in engineering (70.5% of the sample), and consisted of individuals who, all else equal, were more likely to have had a positive engineering internship experience, more likely to be risk averse,

more likely to enjoy working with math, more likely to have a strong professional identity, less likely to expect to take on an early-career leadership role, and more likely to be satisfied with creative opportunities in engineering work. The other four types (encompassing the remainder of the sample) differed in marked ways from those intending to work as engineers – and some such differences are likely desirable to certain engineering employers. The default candidate-career sorting pattern revealed in this study can serve as a comparative baseline to which the outcomes of revised recruitment, counseling, and job design initiatives – those aimed at better matching candidates with careers – can be compared.

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Chapter Appendix

Table 1-A1. Survey questions

Question for Dependent Variable

Expected occupational outcome

Which one of the following represents how you will most likely begin your career journey after undergraduate graduation? (please check only one)

[Work as an engineer]
[Work in product management, project management, technical consulting, or quantitative analysis]
[Work in management consulting, finance, or venture capital]
[Work other: _____]
[Grad school, then work as an engineer]
[Grad school, then work in product management, project management, technical consulting, or quantitative analysis]
[Grad school, then work in management consulting, finance,or venture capital]
[Grad school, then pursue a career in academia]
[Grad school, then other: _____]
[Other: _____]

Questions for Independent Variables

Had positive or negative engineering internship experience(s)

Have you ever worked at an engineering internship or co-op? (either at a company or at a government/non-profit organization; this question does not refer to university labs)

[Yes] [No]

If yes, please check one or both of the following:

[At least one internship/co-op was a positive experience]
[At least one internship/co-op was a negative experience]

Averse to financial risk-taking

If you had to choose between either of the following compensation schemes, which appeals more to you? (please check only one)

[Guarantee of a consistent upper-middle class salary, but with no chance of additional large monetary payouts]
[A chance for large non-salary monetary payouts, but with high uncertainty in your annual salary and/or job security]

Would enjoy working at a job involving advanced mathematics

Which of the following better describes your relationship with mathematics? (please check only one; assume "advanced mathematics" is within the bounds of your major's curriculum)

[A job that regularly requires use of advanced mathematics concepts would be enjoyable for me]
[A job that regularly requires use of advanced math would not be enjoyable for me]
[I'm unsure]

Identifies with a specific profession

When you envison your ideal career, is it based upon a specific profession? (e.g., doctor, engineer, lawyer, consultant, artist, etc.)

[Yes] [No] [Unsure/can't envision ideal career]

Anticipates promotion into formal leadership role by age 25

How likely is it that you will be appointed to a formal leadership position early in your career? (e.g., by age 25) Please circle the appropriate number on the scale:

[7-pt scale: very unlikely, unsure, very likely]

Satisfied with creative opportunities at engineering jobs

How satisfied are you with the availability of job opportunities that allow graduates to engage in creative design work in engineering jobs after college? Please circle the appropriate number on the scale:

[7-pt scale: entirely unsatisfied, unsure, entirely satisfied]

Table 1-A1. Survey questions [Continued]

Questions for Independent Variables [continued]

Gender

What is your gender?

[Female] [Male] [_____]

Race

How do you identify yourself by race and/or ethnic origin?

[American Indian or Alaska Native] [Asian (Incl. Indian subcontinent)] [Black or African American]
[Hispanic or Latino/Latina] [Native Hawaiian or Pacific Islander] [White] [_____]

Student loan debt status

Please indicate true or false for the following statement:
Following undergraduate graduation, I will personally owe $10,000 or more in student loan debt that I'll need to repay.

[True] [False] [Unsure]

Varsity athletics participation status

Have you participated in a collegiate varsity athletics program?

[Yes] [No]

If "Yes," how many seasons wil you have participated in before graduating?

[_____]

Greek life participation status

As an undergraduate, were you a member of a fraternity or sorority?

[Yes] [No]

If "Yes," did you hold an elected leadership position within the fraternity or sorority?

[Yes] [No]

Undergraduate major

Are you a Mechanical Engineering student? (either by degree major or by home department)

[Yes] [No]

If "No," then what is your home department?

[_____]

Degree completion date/status

When do you expect to complete your bachelor's degree?

Please indicate the month and year you will earn your degree:

[Month: _____] [Year: _____]

Salary expectation at first full-time job after college or graduate school

At whatever point in life you take your first full-time job after college or graduate school,
what starting salary do you expect to earn? (in $/year in today's dollars)

[_____]

Table 1-A2. Results of criterion validation checks for key independent variables

Independent Variable	Percentage by Subgroup		Test Statistic[1]
	Has student loan debt	Otherwise	
Averse to financial risk-taking	82.6	77.0	4.60*
	Provides categorized occupational expectations[2]	Otherwise	
Identifies with a specific profession	55.7	38.2	6.45*
	Has held elected leadership position[3]	Otherwise	
Anticipates promotion into formal leadership role by age 25[4]	61.6	48.7	7.93**
	Had positive engineering internship experience	Otherwise	
Satisfied with creative opportunities at engineering jobs[4]	56.0	38.5	25.27***
	Across the sample's 9 universities: Mean and (SD) of university clusters[5]		
Would enjoy working at a job involving advanced mathematics	54.8 (9.8)		29.21***

Notes:
1. Reported test statistics are Pearson chi-square statistics from tests of independence of variables across subgroups.
2. Uncategorized occupational plans are those associated with "unsure" and "all other" occupation responses.
3. Elected leadership positions are in fraternity/sorority student living groups.
4. Dichotomized results are presented here for ease of comparison. Original data are from 7-pt scales; affirmative responses are taken as those above the scale midpoint. The same statistical significance levels are achieved if raw scale results are tested using Mann-Whitney rank-sum tests for ordinal variables.
5. Comparative results across universities are redacted per research partnering agreement.

***p < 0.001; **p < 0.01; * p < 0.05

Table 1-A3. Results of chronological split-sample consistency checks

Independent Variable	Chronological First Half of Sample[1]			Chronological Second Half of Sample[1]		
	% by Occupational Outcome		Test Statistic[2]	% by Occupational Outcome		Test Statistic[2]
	Engineering	Non-Eng.		Engineering	Non-Eng.	
Had a least one internship or co-op that was a positive experience	79.0	64.8	10.03***	72.9	62.7	4.47*
Averse to financial risk-taking	83.8	69.0	13.00***	83.8	60.5	28.87***
Would enjoy working at a job involving advanced mathematics	60.7	43.4	11.58**	61.3	45.1	9.88**
Identifies with a specific profession	59.5	40.2	14.55***	59.5	39.0	15.67***
Anticipates promotion into formal leadership role by age 25[3]	46.3	61.5	8.90**	36.4	55.0	12.77***
Satisfied with creative opportunities at engineering jobs[3]	57.0	42.2	8.37**	61.7	48.3	6.53*

Notes:
1. Chronological sample halves consisting of n=531 and n=530 observations were formed based on the order of sample collection.
2. Reported test statistics are Pearson chi-square statistics.
3. Dichotomized results are presented here for ease of comparison. Original data are from 7-pt scales; affirmative responses are taken as those above the scale midpoint. The same statistical significance levels are achieved if raw scale results are tested using Mann-Whitney rank-sum tests for ordinal variables.

***p < 0.001; **p < 0.01; * p < 0.05

2. Celebrating differences: A conjoint analysis of job preferences among engineering students

Numerous studies have examined how variance in career plans among diverse students shapes the composition of the U.S. engineering workforce. Research activity in this area persists as the engineering profession continues to confront factors hindering its demographic diversity (Correll, 2004; Amelink & Creamer, 2010; Cech et al., 2011; McGee & Martin, 2011; Hatmaker, 2013; Seron et al., 2016) and as employers continue to call for improvement in the development and retention of engineering candidates with strong interpersonal and leadership skills (Salzman & Lynn, 2010; Cappelli, 2015; Hartmann et al., 2016). A subset of the relevant literature has analyzed students' occupational plans in relation to generalized demand-side phenomena, such as systemic biases in employers' candidate preferences (see, e.g., Reskin, 1993; Anker, 1997; Gray et al., 2007) and differences in labor demand between engineering and alternative fields for certain skill profiles among candidates (see, e.g., Shu, 2016; Célérier & Vallée, 2017; Deming, 2017). Meanwhile, other contemporary studies have focused on supply-side processes – students' development of career-related preferences, beliefs, and goals – in explaining differences in students' intentions to work in engineering (see, e.g., Correll, 2004; Stevens et al., 2008; Lichtenstein et al., 2009; Cech et al., 2011; Seron et al., 2016). The existing literature builds compelling cases that both generalized demand-side phenomena and individual-level supply-side processes can explain variance in career plans of students in the engineering pipeline.

Yet, engineering work, itself, varies considerably (Perlow & Bailyn, 1997; Ranson, 2003; Goold, 2012; Brunhaver et al., 2013), and it is unlikely that most candidates are accurately and comprehensively informed about differences in work attributes across possible roles (see: Manning, 2011, p. 976 - 978). Such differences may include proportions of time allocated to individualistic

technical work versus collaborative or coordinative work, the mix of skills employed, and the types of career advancement trajectories available, among many others (Perlow & Bailyn, 1997; Ranson, 2003; Brunhaver et al., 2013). Nonetheless, extant studies that have examined occupational intentions of candidates in the engineering pipeline often make implicit assumptions about uniformity of engineering work and about consistency of candidates' conceptions of engineering jobs (Brunhaver et al., 2013). Herein, we introduce a research design that avoids such assumptions in order to examine whether differences in students' awareness of specific engineering job attributes can explain a portion of the variance in students' job preferences.

In this study, we analyze data from a conjoint survey experiment to assess the effects of job attribute differences on undergraduate engineering seniors' attraction to jobs, and to test for interaction effects between subject characteristics and job attributes upon job attraction. We sampled senior year engineering students from a diverse set of U.S. engineering schools for the survey experiment, first collecting "pre-treatment" data on key subject-specific variables shown in prior studies to be associated with engineering students' career intentions; such data served for purposes of experimental control and interaction analyses. We then engaged subjects in the conjoint survey experiment itself, which involved subjects' assignment of preference ratings to a series of randomly manipulated job profiles. The random control of this experimental design allows us to draw causal inferences about the role that job attributes play in shaping candidates' preferences for jobs – here, the estimands of interest are average marginal component effects (AMCEs) (Hainmueller et al., 2014): specific job attribute manipulations' effects upon subjects' attraction to jobs. We test several such manipulations corresponding with realistic differences in engineering work documented in literature and reviewed in this chapter's Section 2.2 (*Bringing the work in: Key dimensions of engineering jobs*). Meanwhile, the pre-treatment data measured for each experimental subject corresponds with

explanatory variables from a recently developed and empirically validated supply-side model of engineering students' career intentions, as documented in Chapter 1. This unified model aggregates sets of factors from previous works resting on supply-side explanations of variance in students' occupational intentions. Thus, the pre-treatment data about experimental subjects, combined with our experimental manipulation of job attributes, allows us to bring both subject-specific characteristics and job attributes into an integrated analysis of job preference.

Recent advances in conjoint survey experimental methodology provided the framework for this study's research design. Conjoint surveys have long been used in product development and marketing research to assess subjects' preferences toward combinations of product attributes (for reviews, see: Green et al., 2001; Rao, 2014). However, recent work by Hainmueller et al. (2014) produced a set of proofs, assumptions, and verification procedures that allow conjoint methods to be used for causal inference of factor effects shaping such preferences. This new approach has expanded conjoint methods' applicability in social sciences research, beginning with multi-attribute preference analyses in political science contexts (see, e.g., Hainmueller & Hopkins, 2015; Carnes & Lupu, 2016). Herein, we describe our adoption of these methods to assess engineering students' job preferences based on underlying job attributes.

As its central question, this study asks whether additional variance in engineering students' job preferences is explained by the effects of interactions between subject-specific characteristics and engineering job attributes – variance beyond that which is explained by the sum of such factors' independent marginal effects. In short, we inquire whether certain subsets of engineering students tend to react differently than others (in their expressions of job preference) when informed about particular realistic attributes composing given engineering positions. We investigate this question using the job preference data collected in the study's conjoint survey experiment fitted to statistical models with

interaction terms. The subsets of engineering students whose job preferences we examine through interaction analyses are those with distinct characteristics pertinent to existing supply-side explanations of students' occupational interests – for instance, subsets with differences in strength of professional identity, enjoyment in working with mathematics, leadership aspirations, and gender, among others (see Section 2.1: *Supply-side processes and occupational intentions of engineering students*). Beyond this study's primary inquiry into systemic differences in job preferences among key student subsets, our research design also allows us to ascertain general trends in job attribute preferences across the full sample. Knowledge of such trends can assist at a broad level in strengthening engineering employers' recruitment and retention strategies.

This investigation advances the literature on processes shaping the composition of the engineering workforce by examining how students' informedness of engineering job attributes influences their career interests. Sufficiency of students' informedness about engineering work – and homogeneity of students' conceptions of such work – have been taken as givens in much of the existing literature on engineering students' career intentions (Brunhaver et al., 2013); this study, meanwhile, examines the implications of such assumptions. If significant job preference interaction effects exist between subject differences and realistic engineering job differences, then these assumptions may mask important sources of variance in students' career intentions – especially in our present era of expanding varieties of engineering work in industry (Chapter 3; see also: Williams, 2002). Meanwhile, despite substantive prior work, the quest to understand variance in engineering students' occupational interests remains critical, as progress toward diversifying the engineering workforce has been notably slow – for instance, the percentage of women among practicing engineers in the U.S, across all disciplines of engineering, has yet to rise above 15%, (National Science Board [NSB], 2018). Examinations of additional mechanisms underlying engineering students' occupational

interests, such as that presented in this study, contribute to the knowledge base available to policymakers, educators, and employers who work to design initiatives aimed at developing and shaping the engineering workforce.

We begin the sections that follow with a review of prior literature informing our expectations about engineering students' occupational intentions at the college-careers interface. We first review the present state of supply-side explanations of students' occupational intentions, summarizing subject-specific characteristics that we expect to be associated with increased likelihoods of engineering career intentions among students. Next, we review key attributes of engineering work that the literature describes as either varying within the profession, or toward which there are documented trends of incongruence between societal perceptions and industry realities. Such attributes may constitute key areas of inconsistency in students' conceptions of engineering work. For the various attributes, we discuss our development of hypotheses reflecting how we expect subject-specific characteristics will interact with subjects' informedness of job attributes to influence job preference tendencies – hypotheses thus take the form of predictions about how certain subsets of students will tend to exhibit different preferences for particular job attribute variants compared to other student subsets. We then describe our research design and experimental results. We conclude by discussing our results' implications for both future researchers examining the composition of the engineering workforce, as well as for policymakers, educators, and employers aiming to influence career intention-forming processes in the engineering pipeline, so as to enhance candidate-career fit and increase diversity in the engineering workforce.

2.1 Supply-side processes and occupational intentions of engineering students

A recent wave of scholarship has examined processes underlying the formation of students' professional interests in engineering, aiming to understand why certain subsets of students emerge as

more likely than others to pursue engineering careers. Such supply-side-focused literature does not claim that supply-side processes act alone or independent of demand-side processes in influencing career outcomes; rather, this literature asserts that explanations limited to demand-side processes are insufficient to fully explain the career path sorting phenomena observed among students (see: Correll, 2004, p. 94-96). Indeed, studies have established that labor demand conditions substantively influence career intentions among students in the engineering pipeline (Ryoo & Rosen, 2004; Salzman & Lynn, 2010; Bardhan et al., 2013; Lynn et al., 2018), at times in systemically unequal ways across the candidate pool (Anker, 1997; Gray et al., 2007; Shu, 2016; Célérier & Vallée, 2017). Scholars of supply-side processes, however, are interested in how phenomena that act upon individuals – such as social and educational experiences of students before they arrive at their first full-time job – can explain a portion of the variance in students' career intentions, *ceteris paribus*.

Supply-side research has thus examined the role of social influences upon students' formation of beliefs pertinent to their sense of career fit in engineering. In this area, literature has analyzed the development of students' self-perception of their mathematics abilities, finding such ability beliefs to be associated with career intentions in engineering (Nauta et al., 1998; Correll, 2001; Eris et al., 2010; Litzler & Young, 2012), and finding that women are more likely to underestimate their math abilities compared to men, even when scoring the same on math performance measures or receiving similar grades in math classes (Correll, 2001; Ellis et al., 2016). Studies attribute this self-assessment bias to gendered cultural beliefs about abilities (Hyde et al., 1990; Correll, 2001; Correll, 2004). Further, research has found an association between perception of one's mathematics ability and anticipation of enjoyment of jobs or tasks involving math (Goetz et al., 2008; Sitzmann et al., 2010). Prior research thus leads us to expect that engineering students who anticipate enjoying an occupation involving the

use of mathematics are more likely, on average, to intend to work in engineering after graduation compared to their peers.

Additional literature has identified education-related social experiences tied to students' development of professional identity as engineers, for instance: students' experiences being accepted, respected, and engaged as participants in engineering project groups or class activities at school (Cech et al., 2011; Seron et al., 2016, 2018), and students' receiving of guidance and encouragement toward working in their field of study through interactions with mentors or faculty members (Lichtenstein et al., 2009, Amelink & Creamer, 2010). Here, the literature finds systemic variance, such as in women students' differing experiences with perceived fit and acceptance during engineering project or activity participation compared to men's (Cech et al., 2011; Seron et al., 2016, 2018), and in differences in engineering faculty-student interactions across university types (e.g., at technically-focused compared to non-technically-focused universities) (Lichtenstein et al., 2009). Meanwhile, the literature finds engineering students' likelihood of expecting to work in engineering after graduation to be associated with their strength of professional identity (Stevens et al., 2008; Matusovich, et al. 2010; Cech et al., 2011; Eliot and Turns, 2011; Ayre et al., 2013; Hatmaker, 2013; Cech, 2015).

Scholars also find that engineering carries an occupational reputation at a societal level that may influence students' conceptions of engineering careers, and in turn, their sense of career fit. Researchers of engineering practice have long highlighted incongruence between engineering's enduring reputation as an individualistic math- or science-centric occupation, and an industry reality where engineering roles routinely involve coordinative, collaborative, and leadership elements (Bucciarelli & Kuhn, 1997; Salzman & Lynn, 2010; Trevelyan, 2010; American Society for Engineering Education [ASEE], 2013; Hartmann et al., 2016) – and where entry-level roles frequently serve as pathways to managerial positions (Biddle & Roberts, 1994; Perlow & Bailyn, 1997; Herkert,

2001; Anft, 2013). Former National Academy of Engineering (NAE) president Charles Vest (2011) has described this incongruence as engineering's "image problem," whereby "engineers [are] perceived to be narrowly focused on technical details, rather than engaged with the social and human dimensions of projects" (p. 9). Baranowski (2011) suggests that an under-emphasis on social elements of engineering in engineering school may in part be responsible for engineering's difficulty in shedding its "'old' brand" of technical individualism (p. 14-15). Relatedly, several studies critique the engineering curriculum as insufficient in its demonstration of the integral social-technical components of engineering work to students (Bucciarelli & Kuhn, 1997; Trevelyan, 2007, 2010; Sheppard et al., 2009; ASEE, 2013). Researchers, moreover, have found that engineering students with stronger self-assessed interpersonal or leadership skills are more likely than their peers to intend to leave engineering at or soon after college graduation (Atman et al., 2010; Litchfield & Javernick-Will, 2016). This sorting behavior may relate, in part, to demand-side phenomena, such as prospects for comparatively higher returns on social skills in other fields of employment (see: Deming, 2017), but we also call attention to it here due to the literature's discussion of social propagation of skewed reputational beliefs about engineering work. Based on the literature, we expect that engineering students with comparatively high self-confidence in their leadership abilities are more likely, on average, to intend to work in non-engineering fields following graduation, while those with lower leadership self-confidence are more likely to persist from engineering school into engineering careers.

Economics literature, meanwhile, has examined family socioeconomic status as a factor associated with students' financial risk-taking orientation, which, consequently, has been shown to relate to the types of occupations students tend to pursue. Studies have found an association between low family wealth and financial risk-aversion in students – and have identified engineering as a field with comparatively low financial risk that risk-averse students are more likely to pursue compared to

their peers (Saks & Shore, 2005; Caner & Okten, 2009). Thus, all else equal, the literature suggests that financial risk-aversion constitutes a supply-side factor explaining variance in engineering occupational intentions.

Studies also call attention to learning mechanisms and educational content that students may experience during engineering school as factors associated with engineering career interests and intentions. Here, literature has examined educational innovations employed in undergraduate courses – such as active learning methods (Felder et al., 1998; Bernhold et al., 2007; Freeman et al., 2014) and project-based learning approaches (Dym et al., 2005; Zhou et al., 2012; Atadero et al., 2015) – as well as undergraduate interim work experiences such as co-ops or internships (Atman et al., 2010; Zhao & Linden, 2011; Malcom & Feder, 2016). Researchers have found active and project-based learning approaches to be associated with students' perception of opportunities to exercise creativity in engineering work (Bernold et al., 2007; Zhou et al., 2012); and, in turn, studies have found an association between perception of engineering's creative opportunities and students' persistence in engineering degree programs (Bernold et al., 2007; Atwood & Pretz, 2016). Meanwhile, the literature finds an association between engineering co-op or internship participation and an increase in students' likelihood of pursuing engineering careers (Atman et al., 2010; Zhao & Linden, 2011; Malcom & Feder, 2016). Much of the literature that examines educational experiences in relation to professional intentions in engineering is associational, and thus does not identify the specific causal mechanisms connecting these educational experiences to students' career intentions. Such experiences are sometimes voluntary, meaning that students who were already interested in engineering careers could have self-selected into the experiences. Nonetheless, we anticipate certain educational experience-related factors to correlate with students' career intentions in engineering based on this prior work – specifically, we expect students' perception of creative opportunities in engineering and students'

participation in engineering co-ops or internships to be positively associated with students' engineering career intentions. Since undergraduates' experiences can vary substantively across engineering schools (Chubin et al., 2005; Litchtenstein et al., 2009; Amelink & Creamer, 2010), the literature suggests the importance of measuring and controlling for such education-related factors, as well as controlling for students' universities of enrollment, in studies examining variance in career intentions among students.

Based on the literature examining supply-side influences on engineering students' career intentions, we conducted an analysis precursory to this chapter's investigation on conjoint job preferences; therein, we constructed and validated a unifying supply-side model of engineering students' occupational intentions (see: Chapter 1). Our model centers upon six factors from the prior literature whose expected relationships to students' career intentions were found to replicate in a survey of U.S. senior year engineering students. The model's dependent variable is students' intention to work in engineering as a first full-time occupation after college or graduate school. After controlling for demographics and students' universities, we found the following six subject-specific factors to be statistically significant and positively associated with the dependent variable in a multivariate logistic regression: enjoyment of work involving advanced mathematics, identification with a specific profession, anticipation of remaining an individual contributor through age 25 (e.g., anticipation of not taking on a formal leadership role by that age), aversion to financial risk-taking, satisfaction with creative opportunities at engineering jobs, and having had a positive engineering internship experience. We thus carry forward these six factors, as well as gender, into this study's central investigation of interactions between subject characteristics and job attributes.

2.2 Bringing the work in: Key dimensions of variance in engineering jobs

With origins dating to the mid-20th century, U.S. policy designed to strengthen the nation's science and engineering pipelines has primarily taken a generalized approach – one aimed at increasing student interest broadly across science and engineering fields (Hira, 2010; Teitelbaum, 2014). This generalized recruitment mindset continues in the 21st century, as is evident in key policy guidance and enacted legislation, for instance: the National Science Board's *Rising Above the Gathering Storm* report (Augustine, 2005), the *America COMPETES Acts* of 2007 and 2010 (Stine, 2009; Furman, 2012), and *Engage to Excel*, an executive branch report urging an overall increase in the nation's production of science, technology, engineering, and math (STEM) degrees (President's Council of Advisors on Science and Technology [PCAST], 2012). Policy in this area has provided substantive funding for programs aiming to increase diversity in the STEM pipelines (Stine, 2009; Furman, 2012). Among students in their pre-college years, interventions associated with this generalized "STEM push" have been effective at boosting students' confidence in relevant academic areas and at increasing their interest in pursuing degrees in STEM fields (Valla & Williams, 2012). But the broad campaign to increase STEM interest has been criticized for conveying overly vague career concepts to aspiring students (Cannady et al., 2014; Oleson et al., 2014), and STEM policy has often lacked strategies to promote and assess the effectiveness of candidate-career matching or candidates' career satisfaction at later stages in the pipeline (Hira, 2010; Xu, 2013; Teitelbaum, 2014). Such policy programs' success measures have often rested on counts of STEM degrees awarded and on measures of demographic diversification of degree cohorts, rather than on assessments of post-college career-related outcomes (Xu, 2013). The engineering profession, moreover, has struggled to convert underrepresented candidates' adolescent-age interests in the broad field of engineering into engineering career outcomes at the end of college. For instance, among engineering degree-earners,

women continue to be less likely than their male peers to work in engineering at or soon after graduation (Frehill, 2012; Ayre, et al., 2013; Glass et al., 2013). Further, engineering students possessing comparatively strong interpersonal skills – a group highly sought and found to be in short supply by engineering employers (Salzman & Lynn, 2010; Cappelli, 2015) – are less likely to take an engineering job at graduation compared to peers (Atman et al., 2010). While all workforce pipelines should generally expect candidate attrition as individuals learn more about themselves and about their fields (see: Lent et al., 1994; Ibarra, 1999), attrition at the college-career interface among engineering students remains systemic, with certain candidate groups exhibiting a higher propensity to depart engineering career paths than others. Given that engineering work can encompass a variety of job formulations (Perlow & Bailyn, 1997; Ranson, 2003; Goold, 2012; Brunhaver et al., 2013), it is challenging to understand which elements of engineering work constitute the most salient influences upon candidate subsets' propensities to remain in or depart from the field; such an analysis becomes especially difficult if one employs a broad and homogenized view of engineering work.

A growing literature has critiqued the generalized lens through which policymakers, educators, and researchers have often viewed engineering occupations. In a foundational study in this area, Perlow and Bailyn (1997) caution that ignoring the variety among engineering work amounts to a "senseless submergence of difference" (p. 230). Based on observations of practicing engineers over a three-year research program, these authors found that engineers "perform a wide range of occupational activities" (p. 231). Moreover, these authors state, "the acceptance of monolithic definitions of [engineering] work and career…serve to submerge existing and potentially valuable differences among individuals and their roles and activities" (p. 231). Perlow's and Bailyn's (1997) work documents how an engineering workforce that is markedly heterogeneous in its aggregate skills and interests serves to cover a variety of industry roles – yet, how traditional engineering job titles and

popularized role stereotypes hide this variety. Other more recent studies corroborate these observations. Based on an examination of the occupations of engineering graduates from four universities, Brunhaver et al. (2013) conclude: "many studies fail to address…the varying experiences of early career engineering graduates employed in different engineering sub-occupations," and, "[our] results showed several differences, specifically in graduates' perceptions of their work, current positions, and identities" (p. 1). Goold (2012), similarly, found that "engineers' work is diverse," noting that engineers in her research sample occupy an array of roles composed of elements from among: "process engineering; sales; engineering management; project management; people management; design; risk analysis; pricing; lecturing; research; consultancy; and quality engineering" (p.322). Other scholars more generally critique the literature's limited discussion on engineering work's varied components and substantially interdisciplinary nature (Bucciarelli & Kuhn, 1997; Bucciarelli, 2002; Trevelyan & Tilli, 2007; Trevelyan, 2010; Stevens et al., 2015); while, others, still, call attention to the varieties of career progressions among engineers (Allen & Katz, 1995; Igbaria et al., 1999; Tremblay et al., 2002; Ranson, 2003; Pons, 2015).

The literature on the variety of engineering work raises questions on whether engineering students are informed of this variety. Labor economists have observed that imperfect information flow in labor markets is prevalent, suggesting that candidates often lack pertinent knowledge about job possibilities (Autor, 2001; Manning, 2011). According to Autor (2001), "the labor market is replete with imperfect and asymmetric information…workers searching for a job are unlikely to be fully informed about job characteristics" (p. 25) – a phenomenon he posited might be ameliorated by an increase in job-related information conveyed via the internet; later studies, however, suggest that, despite growth in information quantity located online, candidates likely remain under-informed due to limitations in quality and comprehensiveness of such information (Manning, 2011). Further, research

has shown that the comprehensiveness of job-related information obtained by candidates is a factor associated with candidates' subsequent sense of fit toward their work outcomes (Saks & Ashforth, 1997; Saks, 2005). In a jobs landscape as complex and varied as that faced by engineering students, we suspect that students differ from one another in their informedness about engineering jobs and in their internalized conceptions of engineering work. We proceed by reviewing the literature on four dimensions of engineering work found to vary across jobs or to be commonly misunderstood, including: the use of mathematics in engineering roles, engineers' opportunities for growth into leadership roles, mobility restrictions and commitment durations at engineering positions, and the social components of engineers' work. This literature informs our construction of experimental job attribute manipulations for the purposes of testing for the effects of job attribute variation upon engineering students' attraction to jobs.

2.2.1 The use of mathematics in engineering roles

Engineering carries a reputation as a math-intensive profession (National Academy of Engineering [NAE], 2008) – a public impression likely tied, in part, to the math-heavy curricula of engineering schools (see: Winkelman, 2009). While engineering work certainly rests on principles of mathematics and science, analyses of engineering practice show that individuals' engagement with math – in terms of frequency and type of math employed – varies substantively across different engineering roles (Kent & Noss, 2002; Alpers, 2010; Goold, 2012). The literature identifies a broad distinction between specialist roles, requiring advanced expertise and frequent use of math, and generalist roles, requiring a more conceptual-level mathematics aptitude, and in which practitioners' math engagement is often limited to working with pre-established analysis software programs or leveraging consultation from specialists (Kent & Noss, 2002; Alpers, 2010; van der Wal et al., 2017). Research, meanwhile, reveals a sentiment among practitioners that mathematics experiences in

engineering school do not accurately reflect how mathematics is often used in industry, with industry contexts typically involving more support, tools, and collaboration compared to the way students are required to solve math problems in classes (Alpers, 2010; van der Wal et al., 2017).

Engineering specialists whose work centers upon computation and analysis play a distinct role in engineering projects (Kent and Noss, 2002; Alpers, 2010). Literature suggests such individuals often constitute dedicated expertise groups within larger organizations or are employed in specialty firms that provide an expert service (Kent & Noss, 2002; Alpers, 2010), for example, in areas such as structural engineering (Gainsburg, 2006). Researchers describe a "designer-specialist interface" (Kent & Noss, 2002, p. 3) in engineering project environments in reference to the interaction between generalist design engineers and specialty analysts. While the two roles routinely collaborate, the specialists have typically shown to be more individualistically involved in projects' advanced analysis work. Kent and Noss (2002) suggest that the generalist and specialist role distinction is a pragmatic aspect of engineering practice, where certain individuals necessarily focus on the bigger-picture aspects of projects, while others are needed to dive into the more rigorous computational details of particular supporting analyses.

Compared to the case of computational specialists, studies of other engineering practitioners reveal that many use mathematics comparatively less frequently (Goold, 2012) or engage in analyses as collaborators, rather than as dedicated experts (Alpers, 2010; Anderson et al., 2010). These types of engineers report using less intense math in their jobs compared to in their time in engineering school (Alpers, 2010; van der Wal et al., 2017).

Given the marked differences in mathematics usage across role types, engineering students' informedness about whether or not a particular engineering job encompasses that of a computational specialist could be a key factor influencing their attraction to the role. Yet, if uninformed of a particular

role's specialist or generalist characterization, we suspect that students' perceptions about the role will tend to skew toward beliefs of math-intensiveness, given engineering's general reputation. We suspect, however, that becoming more informed of a given job's actual mathematics intensiveness will impact different students' attraction to the job in different ways, depending on the students' internalized beliefs about working with mathematics. The prospect of having to work with math has been shown to elicit emotional responses in individuals (e.g., ranging from anticipated enjoyment to anxiety) contingent upon such factors as prior academic performance and the development of math self-confidence (Goetz et al., 2008; Sitzman et al., 2010; Goold, 2012). Based on the literature, we hypothesize that engineering students' beliefs about their enjoyment of working with mathematics interacts with their informedness about a given engineering job's mathematics intensity to influence their attraction to the job.

2.2.2 Engineers' opportunities for growth into leadership roles

The engineering profession has historically struggled to articulate the advancement and growth opportunities that compose engineering careers. A substantial literature traces this struggle to the challenge of codifying career paths that align with both the diverse goals of engineering professionals and the organizational goals of host corporations (Goldner & Ritti, 1967; Layton, 1971; Bailyn & Lynch, 1983; Shapira & Griffith, 1990; Watson & Meiksins, 1991; Biddle & Roberts, 1994; Allen & Katz, 1995; Perlow & Bailyn, 1997; Igbarria et al., 1999). Conceptualizing how individuals' professional identities as engineers endure or adapt during career advancement constitutes a central element of this challenge. Literature suggests that notions of engineering and management as distinct identities developed over the past century – inclusive of perceptions that one must depart engineering in order to enter management, or that one must choose between engineering or management (Biddle & Roberts, 1994; Perlow & Bailyn, 1997; Jemielniak, 2007; Trevelyan, 2007; Joseph et al., 2012). This dialectic view of engineering and management dissociates these two realms of work from each other

in a way that critics call misleading, given engineers' often-integral leadership or managerial job duties (Trevelyan, 2007, 2010; Trevelyan & Tilli, 2007) and engineers' common advancement trajectories from individual-contributor technical roles into technical management positions (Biddle and Roberts, 1994; Badawy, 1995; Mael et al., 2001; Hodgson et al., 2011; Joseph et al., 2012). Analyses suggest that such a binary view of the engineering-management distinction masks the existence of myriad role variations, hybridizations, and differences in advancement paths among engineers (Watson & Meiksins, 1991; Allen & Katz, 1995; Bailyn & Lynch, 1997; Treveylan, 2007; Paton & Hodgson, 2016).

The literature identifies at least three means by which leadership or managerial job components tend to manifest in engineering careers. First, studies describe common role transitions whereby engineers make a distinct jump from individual-contributor engineering roles into management positions – such transitions have been shown to lead to both people management positions as well as to project or product management positions (see, e.g., Biddle & Roberts, 1994; Badawy, 1995; Mael et al., 2001; Carbone & Gholston, 2004; Ebert, 2007; Hogdson et al., 2011; Joseph et al., 2012). Secondly, a related area of scholarship discusses evidence of career progressions marked by engineers' roles evolving into technical-managerial hybrid roles centered on project coordination in individuals' technical areas of expertise (see, e.g., Leonard-Barton, 1992; Allen & Katz, 1995; Causer & Jones, 1996; Petroni, 2000; Paton & Hodgson, 2016). In these cases, as Paton and Hodgson (2016) explain, "[practitioners see] project management as fundamentally an extension of a technical (engineering) role, which prioritises extensive knowledge of the product and technology" (p. 36). Lastly, a growing literature calls attention to leadership elements intrinsic to engineering practice itself, including during early-career roles. Such studies note that non-manager engineers must frequently coordinate the work of others, lead small groups, and leverage social skills

in order to contribute effectively on engineering projects (see, e.g., Kumar & Hsiao, 2007; Trevelyan, 2007, 2010; Farr & Brazil, 2009; Cox et al., 2012; Rottman et al., 2015; Hartmann et al., 2016). A general critique in the literature suggests that leadership, coordinative, and managerial aspects of engineering work and careers have historically been under-examined relative to their prevalence in practice (see: Trevelyan, 2007, 2010).

Among the literature examining those engineering careers marked by distinct transitions into management, a prominent subset describes the appointment of engineers to project management or product management roles (see, e.g., Carbone & Gholston, 2004; Ebert, 2007; Hodgson et al., 2011; Bredin & Soderlund, 2013; Nicholas & Steyn, 2017). Project management roles involve developing and managing project schedules and budgets, assessing and mitigating risks, and allocating resources based on priorities (DiVincenzo, 2006; Heagney, 2016); product management roles, meanwhile, center on discerning customer needs, defining product requirements, and creating product development plans and strategies (Ebert, 2007; Gorchels, 2012). Both project and product manager roles involve elements of leadership, such as establishing shared goals and visions, and inspiring teams and individuals to perform toward such aims (see: DiVincenzo, 2006; Gorchels, 2012). Gnanasambandam et al. (2017) estimate that engineering teams in industry typically operate with ratios of one project manager per every 4 to 5 contributing engineers or one product manager per 8 to 12 engineers – and, research indicates that the majorities of these project and product manager roles at engineering firms are filled by individuals with technical backgrounds (Carbone & Gholston, 2004; Ebert, 2007). Further, literature finds that some firms sponsor employee development programs to facilitate engineers' transition into these roles (Carbone & Gholston, 2004; Hodgson et al., 2011, Nicholas & Steyn, 2017). While the literature makes clear that career paths from engineering into project or product management are common in industry – and that many such roles maintain a distinct

association with engineering work – existing studies do not reveal how consistently aware engineering students are of these types of career trajectories, nor whether students consider such trajectories to fall within or outside of their concept of an engineering career.

More generally, we question the extent to which engineering students are informed about the variety of leadership and management opportunities that stem from careers in engineering, and question the extent of students' awareness that they may be called upon to exercise leadership in early-career engineering positions. If students are uninformed about such aspects of engineering work, we suspect, based on engineering's broad reputation described in the literature, that they will tend to under-estimate the opportunities to progress into leadership or management roles from entry-level engineering positions. Yet, we suspect that becoming informed of such opportunities will have different effects upon different subsets of engineering students: specifically, we expect that those with a higher self-appraised leadership ability will express greater attraction to a given job upon learning of its leadership opportunities, compared to their peers who assess themselves lower in leadership ability. We thus hypothesize that students' self-appraisal of their ability to fulfill leadership roles interacts with their informedness about a given engineering job's leadership growth opportunities to influence their attraction to the job.

2.2.3 Mobility restrictions and commitment durations at engineering positions

The restriction of engineers' career mobility, as influenced by employer policies, has received considerable attention in both scholarly literature and in the popular press in recent years (for overviews, see: Lobel, 2013; Hyde, 2015). This attention has centered upon employers' efforts to protect intellectual property and to preserve investments in employee training and development through various forms of restrictive covenants and terms of employment. These employment agreements have included both non-compete covenants restricting near-term employment at competing firms (Lester, 2001; Somaya

& Williamson, 2008; Marx, 2011; Marx & Flemming, 2012; Cappelli & Keller, 2014) and training repayment agreements that establish job commitment duration expectations (Lester, 2001; Long, 2005; VonBergen & Mawer, 2007; Cappelli & Keller, 2014; Hoffman & Burks, 2017). Marx (2011) finds that nearly half of U.S. "technical professionals" are asked to sign a restrictive covenant of some form. Meanwhile, some individuals have successfully challenged the legality of restrictive covenants in courts (Lester, 2001; Long, 2005), and some U.S. states have enacted prohibitive legislation against them (Marx et al., 2015). Legality notwithstanding, employer-designed restrictive policies have occupied a sizable place in the discourse on engineering work during the past several decades.

While non-compete covenants' effectiveness at building and retaining skilled engineering workforces has come under significant scrutiny in recent years (Samila & Sorenson, 2011; Amir & Lobel, 2013; Marx et al., 2015), their historic presence and attention in the popular press may have contributed toward shaping public conceptions of immobility or constraint associated with engineering careers (see: Lobel, 2013). Moreover, comparably less severe restrictions, such as training agreements tied to commitment expectations, generally endure as tolerated practices (Long, 2005; VonBergen & Mawer, 2007). When in place, training agreements specify a term of employment, usually between 1 and 3 years, during which an employee agrees to remain with an employer, lest they owe the employer repayment of a portion of funds contributed to their job training or employee development (Lester, 2001; Long, 2005; VonBergen & Mawer, 2007; Cappelli & Keller, 2014; Hoffman & Burks, 2017). From a legal standpoint, courts have upheld such agreements in cases where training was shown to have developed proprietary skills linked to companies' unique competitive competencies; cases have a greater precedent of being overturned, however, when training was shown to have primarily contributed to employees' development of general skills (Lester, 2001).

We posit that engineering students' awareness of expected commitment durations at engineering jobs (whether legally enforceable or not) is a factor potentially salient in shaping their attraction to such jobs – and, we generally question the consistency and accuracy of engineering students' informedness about commitment duration expectations across engineering jobs. Literature has shown that many engineering students' professional identities are still nascent at the time they prepare to graduate (Stevens et al., 2008). Thus, informedness of a given job's commitment duration expectation may shape job attraction differently for different subsets of students, depending on the state of development of the students' professional identities and whether such identities align with the job. For instance, we expect that engineering students who posses a strong professional identity in a given field will be less deterred by commitment duration expectations at jobs in that field, especially if such expectations are coupled with firms' investment in skills development in the area of individuals' professional interest. Benson et al. (2004), for example, find that firms' investment in skill development in employees' field of specialty can be motivating for employees and can encourage retention. Conversely, we expect that a job's imposition of a commitment duration expectation could reduce job attraction among individuals who are uncertain about their professional identity and developmental interests. We thus hypothesize that engineering students' strength of professional identity interacts with their informedness about a given engineering job's commitment expectations to influence their attraction to the job.

The literature on employers' mobility-restrictive policies has also examined the role of creative work in shaping individuals' reactions to such restrictive policies. Amir and Lobel (2013), for example, describe results of an experiment demonstrating that individuals' aversion to mobility-restrictive policies is reduced in cases where they perceive jobs' inherent work as creative, rather than rote. Studies also find students' attraction to the engineering profession is higher when they perceive engineering to

involve creativity (Bernold et al., 2007; Atwood & Pretz, 2016). This literature prompts us, again, to expect that different student subsets' attraction to a given job will be affected differently by knowledge of commitment expectations tied to the job. Here, we expect that students who are satisfied with creative opportunities perceived to be inherent in engineering work will react more positively to knowledge of a given job's commitment expectation compared to students who perceive engineering work as lacking in opportunities for creativity. We thus hypothesize that engineering students' perceived satisfaction with creative opportunities at engineering jobs interacts with their informedness about a given engineering job's commitment expectations to influence their attraction to the job.

2.2.4 Social components of engineering work

Substantive recent literature has examined the social characteristics of engineering roles in industry. Beginning in the late 20th century, studies began to contest engineering work's historic reputation as predominately rooted in individualistic problem solving, demonstrating, instead, that engineering work is often highly interactive and collaborative (see, e.g., Bucciarelli & Kuhn, 1997; Perlow & Bailyn, 1997; Bucciarelli, 2002; Trevelyan, 2007, 2010; Robinson, 2012; Stevens et al., 2015). Bucciarrelli (2002), for instance, has argued that the practice of engineering design "is not faithfully represented as simply the art of applied science pursued by an individual at a work station" (p. 220). Trevelyan (2010), moreover, observed that engineers typically spend more than half of their time interacting with others, concluding that "human performance and social interactions lie at the core [of engineering practice]" (p. 190). Yet, while contemporary literature generally makes clear that social interaction composes a central element of engineering work, studies also point out differences in the social components of engineering work across different types of roles. We find that studies discuss at least three general types of individual-contributor engineering roles among which social interaction manifests differently: individualistic technical specialist roles, marked by comparably large portions

of time spent on solitary work amidst periodic interaction; team-based collaborative roles, characterized by frequent or continuous interaction; and, inter-organizational coordinative roles, marked by substantial time spent coordinating technical work across functional or organizational boundaries.

A subset of the literature examines technical specialist roles that are comparatively individualistic relative to most other engineering roles (Kent & Noss, 2002, 2003; Anderson et al., 2010; Alpers, 2010). Anderson et al. (2010), for example, describes several circumstances of "individual level" work embedded within engineering practice, such as engineers working alone to design components using CAD programs, or to run computer simulations, or to review designs to ensure they meet standards, among other activities (p. 161). Meanwhile, certain computational specialty roles, as described in this chapter's Section 2.2.1, have also been shown to be substantially individualistic (Kent & Noss, 2002; Alpers, 2010), but, as Anderson et al. make clear, individualistic roles in engineering workplaces are not limited to math-heavy roles (2010).

A broad literature, meanwhile, emphasizes the prevalence of team-based collaborative roles in engineering (Bucciarelli & Kuhn, 1997; Bucciarelli, 2002; Trevelyan, 2010; Robinson, 2012; Stevens et al., 2015). Robinson (2012), for instance, finds peer collaboration to be integral to many engineers' routines, and Bucciarelli (2002), similarly, has observed: "engineering design is the business of a collective or team" (p. 219). Trevelyan (2007), however, draws a distinction between general forms of "teamwork" frequently referred to in descriptions of engineering practice, and a third common context of engineering work that centers on technical coordination across roles, functions, or organizational boundaries. As Trevelyan explains, "working in teams is a different experience [than extra-team coordination]. Most of the coordination reported in [this study] occurred outside the context of a particular team" (p. 198). Trevelyan characterizes this type of coordination as entailing elements such as: influencing members of other functions to perform needed tasks, monitoring and supervising the

work of contractors, engaging with external agencies, and interfacing with clients (see p. 197). Other studies provide similar examples of coordinative roles in engineering practice (see, e.g., Sheard, 1996; Twigg, 1998; Lakemond et al., 2006; Herbsleb, 2007; Stevens et al., 2015). Twigg (1998), for instance, discusses engineers' oversight and coordination of design activities among vendors in an automotive company's supply chain, and Herbsleb (2007) describes efforts required to coordinate technical work in globally distributed software projects.

In addition to describing variety in the social components across different engineering roles, literature has also documented trends of gendered sorting of individuals into such roles. Specifically, studies have observed that female engineers have exhibited a greater tendency than males to take on roles with comparably prevalent social and coordinative components, while males have been more likely than females to take on individualistic technical roles (Cech, 2013; Seron et al., 2016, 2018). Literature has described this phenomenon as "intra-professional gender segregation" (Cech, 2013), and has explored how such sorting trends are reproduced over time through supply-side processes of professional socialization experienced by students in engineering educational and pre-professional settings (Seron et al., 2016, 2018). Researchers find that these socialization processes can shape students' gendered notions of role fit and confidence – such as through initiation routines on student project teams involving competitive establishment of technical "pecking orders" among teammates, through interchanges that can undermine the formation of females' technical confidence (Seron et al., 2016). Researchers suggest that such socialization processes can influence women's tendencies toward social, coordinative, and administrative roles on engineering teams (Seron et al., 2016). While recent work has made strides in decomposing these socialization processes, opening them up to critique and reform (see, e.g., Seron et al., 2018), we expect that many of today's engineering students have nonetheless experienced elements of gendered professional socialization, and, correspondingly, we

expect that gendered trends in role preferences toward individualistically-centered or socially-centered roles will replicate in contemporary samples of engineering students.

Yet, given the nuanced variation in social components of different types of engineering roles, as described in the literature, we again question the comprehensiveness of engineering students' awareness of such variation. We expect, given the engineering profession's enduring reputation as centered upon individualistic technical work (Seron et al., 2018), that engineering students who are uninformed of the details of a particular engineering role's social aspects will tend to perceive the role as more individualistic than it actually is. We also expect that when students become informed of the details of a given engineering role's social components, that female and male students' attraction to the role will be impacted differently, with females reacting more positively than males to information about a role's social or coordinative components. We thus hypothesize that gender interacts with informedness about a given engineering job's social components to influence students' attraction to the job.

2.2.5 Summary

We proceed under the assumption that engineering students likely hold inconsistent and incomplete internalized conceptions of engineering work, given the variation in the work itself, the known gaps between the engineering educational experience and certain aspects of industry practice (Sheppard et al., 2009; ASEE, 2013), and the imperfections of information flow in labor markets (Autor, 2001; Manning, 2011). We next outline our experimental methods, which test the effects of job attribute informedness upon students' attraction to jobs. The job attribute differences tested are those corresponding with the variations in engineering work reviewed from the literature – differences in mathematics content, leadership growth opportunities, commitment duration expectations, and social characteristics of engineering jobs. We do not imply such variations in engineering work are the only ones present across industry; rather, we focus on these variations due to their notable presence in

the literature, and assumingly, their corresponding prevalence in industry. We outline our conceptualization and operationalization of these job attribute manipulations in Section 2.3.3 within the *Methods* section that follows.

2.3 Methods

2.3.1 Research setting

This chapter's empirical analysis centers on a conjoint survey experiment conducted at nine U.S. universities between November 2016 and April 2017. The experiment asked participants – engineering students in their senior year – to provide information about themselves and their career plans, and to rate the attractiveness of six different engineering job description profiles. Each job profile's content was randomized across four job attributes. Randomized profiles were presented to respondents in side-by-side pairs in accordance with a conjoint experimental method presented by Hainmueller et al. (2014). This scheme asked respondents to indicate a job choice preference toward one of the two from each pair, as well as to assign a job appeal scale rating to both job profiles in the pair. Such an approach is designed to simplify participants' decision tasks (Hainmueller & Hopkins, 2015, citing Krosnick, 1999), while acquiring redundant forms of preference information to enable robustness checks of experimental results (Hainmueller et al., 2014). The survey experiment took place in classroom settings and employed a paper-based survey form in order to maximize access to target participants and to integrate the survey task into participants' routines with minimal disruption.

We elected to sample all participants from a single academic major at a time in close proximity to when participants would face the engineering job market (or would face consideration of alternate plans, such as whether to continue directly on to graduate school). This sampling approach provided a means of experimental control for participants' exposure to transient job market factors that might influence their interest in working at an engineering job. For instance, students enrolled in

different academic majors might face differing job market prospects in their fields, and students within the same field could face different job market demand at different times due to market variations. Research has shown engineering students' career interests to be significantly associated with market conditions (Ryoo & Rosen, 2004; Bardhan et al., 2013; Lynn et al., 2018). We opted to sample exclusively mechanical engineering majors in light of that field's recent job market stability – the U.S. Bureau of Labor Statistics assesses mechanical engineering jobs growth as "average" relative to growth rates across all U.S. occupations (U.S. Bureau of Labor Statistics [BLS], 2018a). By contrast, some engineering job markets in computer software-related areas are experiencing sharp growth (BLS, 2018b). We know of no theoretic reasons why this experiment's examination of job preferences based on jobs' mathematics demands, leadership opportunities, commitment duration expectations, and social characteristics would not generalize across the broader population of engineering students. However, follow-on work is required to verify such generalization, as discussed in this chapter's Section 2.4.7 (*Limitations of results*).

We took steps to minimize participant self-selection biases in the sample, as engineering students' voluntary choice to participate in a study on job preferences could result in disproportionate representation (or exclusion) of those with certain attitudes toward the notion of working in their field of study. The mechanical engineering curriculum provides a unique opportunity to reach universities' entire senior year cohorts of mechanical engineering students at occasions of required attendance: senior capstone design course sessions. This study thus involved designing a survey experiment to be administered within these types of course sessions. Based on partnering negotiations with department chairs and capstone course instructors across the nine participating engineering schools, we reconciled the schools' unique constraints to arrive at a paper-based survey instrument designed to take respondents 12 minutes to complete, either at the

beginning or end of a scheduled senior capstone class session. At each class session in which the survey was conducted, instructors announced to students that a voluntary survey related to engineering careers would be part of the day's class. On-site research personnel then distributed and collected the paper survey forms in these class sessions. This short-duration, paper-based, in-class survey approach resulted in a near-90% participation rate among targeted respondents and garnered over 1,000 survey responses. The approach, however, necessitated use of a highly concise survey instrument, the development of which we discuss in Section 2.3.2 that follows.

In addition to establishing sampling requirements related to participants' academic major and proximity to the job market, we also targeted diversity in the types universities from which we drew participants. We attained participants from large and small engineering schools, public and private universities, and from across a broad geographical dispersion. We recruited the partner universities through an email campaign, distributed to achieve such institutional diversity, to department chairs and capstone course instructors at various accredited mechanical engineering programs. The campaign resulted in agreements to conduct the survey at Boston University, Carnegie Mellon University, Massachusetts Institute of Technology, Penn State University, Santa Clara University, Texas A&M University, Tufts University, the University of Connecticut, and the University of Michigan. This mix of universities consists of four public and five private institutions from six U.S. states. Public university students constituted the majority (59%) of the resulting participant sample. The sample's institutional composition, inclusive of a large public school component, provided a participant base reflective of how at least 80% of the nation's engineering graduates earned their degrees (Cech et al., 2011). As part of our partnering agreements with the nine universities, we agreed not to publish results in a manner that conveyed university-to-university comparisons. We obtained Independent Review Board (IRB) approvals or concurrences for the survey experiment from all participating institutions before beginning data collection.

2.3.2 Development of a survey instrument with embedded conjoint experiment

This study's survey instrument contained three distinct types of questions: those associated with participant-specific independent variables, those constituting the embedded conjoint experiment, and those constituting post-experiment manipulation checks. Questions were laid out on a five-page survey form. The form's first and last pages were identical for all participants and were dedicated to the collection of participant-specific data and post-experiment checks, while the middle three pages contained experiment content that was randomized across participants. Each survey form was marked with a unique identification number.

The survey included measures for participant-specific independent variables in the following areas: key theoretic variables pertinent to engineering students' career interests, demographic variables, and additional variables related to empirical control. The complete set of survey questions for all independent variables employed in this study is presented in Table 2-A1 of this chapter's Appendix. The development and validation of these survey questions, including approaches taken to minimize question count and response time, are discussed in Chapter 1, which documents an earlier stage of this research project. Meanwhile, Table 2-1, below, lists definitions for six key theoretic variables from among the independent variables set shown to be associated with engineering students' interest in engineering careers based on the multivariate occupational sorting model presented in Chapter 1. In this current study, some of these key variables are employed in our empirical analysis of job preference interaction effects between participant characteristics and job attributes. Beyond those variables listed in Table 2-1, the survey instrument also collected participant-specific data on: career intentions, expected salary, gender, race, student loan debt status, extracurricular activities participation, graduation date, and verification of undergraduate major.

Table 2-1. Definitions of key participant-specific independent variables measured in the survey

Variables and definitions
Had a positive engineering internship experience Subject has held at least one engineering internship or co-op position that they consider as a positive overall experience.
Averse to financial risk-taking Subject seeks income stability and job security in an occupation, and seeks to avoid occupations that have prospects for outsized financial windfalls that come at the expense of income stability or job security.
Would enjoy working at a job involving advanced mathematics Subject would enjoy a job that regularly required the use of advanced mathematical concepts that they experienced as part of their undergraduate engineering curriculum.
Identifies with a specific profession Subject envisions their ideal career as one that is based upon a specific profession.
Anticipates promotion into formal leadership role by age 25 Subject believes it to be likely that they will be appointed to a formal leadership position by age 25.
Sastisfied with creative opportunities at engineering jobs Subject is satisfied with the availability of job opportunities in engineering that allow one to engage in creative design work.

The portion of the survey instrument dedicated to the conjoint experiment followed the layout shown in Figure 2-1, whereby pairs of randomized job profiles were presented, followed by associated rating questions. This layout generally follows a configuration developed and tested by Hainmueller et al. (2014). By convention, each pair of profiles is referred to as one experimental "round." As Hainmueller et al. (2014) discuss, conjoint methods allow respondents to rate multiple rounds of profiles in order to increase a study's effective observation count; standard errors of job preference measurements are then clustered to account for the origination of multiple measurements from the same individual respondent. We assessed participant response timing by conducting pilot testing of the survey instrument with student volunteers to determine a tenable number of experimental rounds to embed in the instrument, given our 12-minute overall survey completion time target. We elected to include three rounds (e.g., six total profiles for respondents to rate) based on the pilot evaluations. Development of the job profiles' content, including definition of their fixed and variable features, is described in detail in Section 2.3.3 (*Job attribute manipulations*); as discussed therein, certain features

such as the jobs' title and benefits information, remain constant across all profiles, while other elements are varied as part of the experimental manipulations.

Below you will find several pairs of job descriptions.
Please read each pair, compare the two jobs, and answer the questions that follow each pair.
As you answer, **assume** that each job is located somewhere that is desirable to you,
and that the type of product(s) the company makes are of interest to you.

	Job A	Job B
	Mechanical Design Engineer	**Mechanical Design Engineer**
Salary	$78,950 /year	$78,990 /year
About the Company	19 year-old company, 500 employees	20 year-old company, 400 employees
Credentials	B.S. in Mechanical Engineering required Strong skills required in differential equations and mechanical analysis (e.g., fluids, thermal, structural, dynamics)	B.S. in Mechanical Engineering required
Responsibilities	You'll work on a design team in new product development. You'll develop concepts, collaborate on design details, choose components and materials, and verify the design through modeling and test. We are seeking an expert comfortable with computation and analysis (both hand calculations and FEA), given the tight margins for error in this product. You'll spend most of your time working on your own tasks, while a small portion of your time will involve collaborating with peers.	You'll work on a design team in new product development. You'll develop concepts, collaborate on design details, choose components and materials, and verify the design through modeling and test. You'll work alongside an engineering analysis group that will run any detailed computation necessary to support your design work. You'll spend most of your time in collaborative team environments, communicating and coordinating about designs.
Other	This highly selective opportunity is with the company's Advanced Projects Division, where a minimum of a 3-year commitment to remain with the company is expected due to the specialized and proprietary skills set you'll develop.	This position includes a leadership "fast track" option for those interested in transitioning into product or project management (PM) roles. Qualified candidates can achieve PM roles within 1-2 years, if desired. A salary increase accompanies advancement.
Benefits	Generous year-end bonus, Best-in-class healthcare, 401(k), free gym membership, flexible hours.	Generous year-end bonus, Best-in-class healthcare, 401(k), free gym membership, flexible hours.

If you had to choose to work at one of these two jobs, which would you select?

☐ Job A ☐ Job B

Based on the limited information in the job descriptions,
please indicate the **potential appeal** of each of the jobs to you:

1	2	3	4	5	6	7
Little/no potential appeal			unsure			Potentially very appealing

1	2	3	4	5	6	7
Little/no potential appeal			unsure			Potentially very appealing

Figure 2-1. Layout of a single conjoint experiment round: job profile pair comparison

Post-experiment manipulation checks, meanwhile, were employed on the last page of the survey form to assess participant's cognition of the intended job attribute manipulations. Such checks allowed us to verify that job preference effects measured in the experiment were non-spurious, and, instead, could be assumed associated with respondents' reactions to the presence of manipulated information in the job profiles. The manipulation checks are described in Section 2.3.4 (*Data collection, verification, and analysis*), following a description of the job attribute manipulations themselves in the next section (Section 2.3.3).

2.3.3 Conceptualization and operationalization of job attribute manipulations

Based on our review of literature examining differences among engineering jobs, we developed a set of job attribute manipulations that entailed presenting experimental participants with different sets of job profile information in the format shown in Figure 2-1. We tested the effects of four such manipulations, each based upon variation in one of the following attributes: mathematics intensity, leadership growth opportunities, commitment duration expectations, and social characteristics. Each manipulation involved imparting differences within one or more of the following information categories from among those shown in Figure 2-1: "credentials," "responsibilities," or "other." We refer to the variants of a particular manipulated job attribute as the "states" of that attribute; thus, attribute manipulations entailed presenting different attribute states to participants in a randomized manner. Table 2-2 lists the full set of job attribute manipulations. As shown, we tested manipulations encompassing two different states of the mathematics intensity, leadership growth opportunities, and commitment duration attributes; meanwhile, we tested three states of the manipulation encompassing the social characteristics attribute.

Table 2-2. Job profile differences associated with experimental job attribute manipulations

Job Attribute	Job Profile Content Differences across Attribute States		
	State 0	**State 1**	**State 2**
Mathematics intensity:	***Non-intensive with support emphasized***	***Intensive with individual ability emphasized***	*N/A*
	Credentials: "B.S. in Mechanical Engineering required"	Credentials: "B.S. in Mechanical Engineering required Strong skills required in differential equations and mechanical analysis (e.g., fluids, thermal, structural, dynamics)"	
	Responsibilities: "You'll work alongside an engineering analysis group that will run any detailed computation necessary to support your design work"	Responsibilities: "We are seeking an expert comfortable with computation and analysis (both hand calculations and FEA), given the tight margins for error in this product."	
Leadership growth opportunity:	***No opportunity discussed***	***Opportunity discussed***	*N/A*
	Other: N/A	Other: "This position includes a leadership 'fast track' option for those interested in transitioning into product or project management (PM) roles. Qualified candidates can achieve PM roles within 1-2 years, if desired. A salary increase accompanies advancement."	
Commitment duration expectation:	***No duration discussed***	***Duration and skill development discussed***	*N/A*
	Other: N/A	Other: "This highly selective opportunity is with the company's Advanced Projects Division, where a minimum 3-year commitment to remain with the company is expected due to the specialized and proprietary skills set you'll develop"	
Social characterization of work:	***Individualistic role***	***Collaborative team-based role***	***Inter-organizational coordinative role***
	Responsibilities: "You'll spend most of your time working on your own tasks, while a small portion of your time will involve collaborating with peers"	Responsibilities: "You'll spend most of your time in collaborative team environments, communicating and coordinating about designs"	Responsibilities: "You'll spend most of your time interacting with vendors, interpreting specifications, and/or updating design details on drawings. As designs are completed, you'll have on-call responsibility to help keep production running smoothly"

While the "credentials," "responsibilities," and "other" job profile information categories contained variable elements associated with the job attribute manipulations, other aspects of the job profile were held consistent across all profiles evaluated by experimental participants. These consistent job profile elements are shown in Table 2-3. For instance, all profiles had an identical job title, "Mechanical Design Engineer," all profiles listed an identical set of "benefits," and all contained identical core language within the "responsibilities" category as follows:

> *You'll work on a design team in new product development. You'll develop concepts, collaborate on design details, choose components and materials, and verify the design through modeling and test.*

Meanwhile, "salary" and "about the company" were also designed to be consistent job elements, but we imparted miniscule variations in this information across job profiles to heighten participants' sense that each job profile was unique, thus encouraging participants to read all profiles in their entirety. For example, the posted salary was varied by +/- $50 around a mean of $78,940. The small variations in salary and company information were intended to be meaningless to participants, a notion that we empirically confirm as part of the experiment's results verification. Further, instructions printed above the job profiles advised participants to "assume each job is located somewhere that is desirable to you, and that the type of product(s) the company makes are of interest to you." All of the job information not involved in the experimental manipulations was strategically designed to make the jobs appear neutral or modestly attractive to the participants, so that participants' focus would be on the manipulated differences, and that worries about other key aspects of the jobs would be eased. The salary, for example, was set to be slightly higher than the anticipated average salary offered to an entry-level mechanical engineer – so that salary concerns would not be at the forefront of participants' minds – but not so high as to be startling. The elevated salary reflects a 10-15% increase over reported U.S. average starting salaries of mechanical engineers, depending on location (Glassdoor, 2016).

Meanwhile, company size and age were set so that the company would neither appear to be a young start-up, nor an old, large company. In the remainder of this section, we describe the attributes of the jobs that were intentionally manipulated, outlining the theoretical bases behind our conceptualization of each manipulation, and describing each manipulation's operationalization in the experiment.

Table 2-3. Job attributes not subject to experimental manipulation

Job Attribute	Content
Job title	"Mechanical Design Engineer"
Salary	$78,940 (+/- $50)
About the company	Company age: 20 years (+/- 1 year) Company size: 450 employees (+/- 50 employees)
Responsibilities	"You'll work on a design team in new product development. You'll develop concepts, collaborate on design details, choose components and materials, and verify the design through modeling and test"
Benefits	"Generous year-end bonus, best-in-class healthcare, 401(k), free gym membership, flexible hours"

We conceptualized the manipulation of jobs' mathematics content in terms of a difference between roles involving non-intensive mathematics in a supportive environment, and roles involving intensive mathematics requiring advanced individual abilities. We operationalize this manipulation in the survey experiment through the two contrasting attribute states shown in the first row of Table 2-2. In the case of the non-intensive mathematics attribute state, no mention is made of requisite credentials in mathematics beyond a bachelor's degree in engineering; meanwhile, the job's responsibilities include "[working] alongside an engineering analysis group that will run any detailed computation necessary to support your design work." This language reflects the industry-realistic scenario of a designer-specialist interface, as described by Kent and Noss (2002), and suggests that this particular role embodies that of a generalist design engineer, rather than a computational specialist. In contrast, the alternate job attribute state suggests a specialist role. As such, the alternate state emphasizes individual math ability by listing several field-representative math skills among

requisite credentials, and makes the analytical nature of the role clear in the job's list of responsibilities.

The leadership growth opportunity manipulation was conceptualized in a binary manner: a job would either convey a clear pathway into a future leadership role, or such information would be absent. The discrepancy between these states captures the inconsistent and often under-articulated manners in which engineers' growth paths have historically been presented to those in the engineering pipeline, as discussed in the literature review. We operationalize this manipulation through a difference between attribute states' posted content within the "other" job profile category, as shown in the second row of Table 2-2: in one attribute state, nothing is posted under "other," in the alternate state, specific information about growth opportunities into project management or product management roles is provided. Project or product management roles were selected due to evidence from the literature suggesting that such roles compose common career trajectories of engineering graduates, and toward which some engineering employers sponsor internal professional development. Meanwhile, the job profile information on the growth opportunity suggests it is neither guaranteed, nor required (e.g., the opportunity is for "qualified candidates…if desired"). Further, a timeline for realization of the opportunity, "1-2 years," is provided, along with an acknowledgement that increased compensation accompanies advancement. These latter features provide specific and pragmatic details of the opportunity.

Similar to the leadership growth opportunity manipulation, we also conceptualized the manipulation of jobs' expected commitment duration in a binary manner. Here we acknowledge a divide in the manner in which engineering employers carry out policies related to employee development and retention: some enact explicit policies to retain those in whom they will invest in specialized skill development, while others do not (see, e.g., Marx, 2011). We therefore

conceptualized the manipulation of commitment duration expectation to encompass a difference between an attribute state where no mention of commitment duration is made, and a state that outlines specific terms of employee development and associated commitment expectation. According to the literature, such employer policies that tie commitment expectations to proprietary, specialized skills development in areas of firms' competitive advantage have a greater precedent for legal legitimacy compared to policies unlinked to specialized skill development (Lester, 2001). Here, we thus couple commitment expectations with notions of specialization and advanced work. The third row of Table 2-2 depicts the commitment duration job attribute manipulation. This manipulation is operationalized through differences in language posted within the "other" job information category. The first state of this attribute consists of nothing posted within the "other" category, while the alternate state contains language conveying a specific job commitment duration expectation. In this latter case, the job profile emphasizes the role's positioning within the company's "Advanced Projects Division" and states: "a minimum 3-year commitment to remain with the company is expected due to the specialized and proprietary skills set you'll develop." While this manipulation embodies a compound set of job elements (e.g., notions of both advanced skills development and commitment expectations), the reviewed literature suggests realism and legitimacy of such a combination.

Finally, we conceptualized a three-state job attribute manipulation pertaining to the social characterization of jobs. Based on our review of literature examining engineering practice, we established the three attribute states as follows: one that encompasses individualistic work with occasional collaboration, one composed of predominately team-based collaborative work, and one entailing substantial coordination across functions or organizations. We operationalized this manipulation through three distinct sets of wording, each of which corresponded with one of the three attribute states, and which were conveyed within the "responsibilities" information category of the job

profile. Details of this manipulation are presented in the last row of Table 2-2. Language from the first attribute state, that corresponding with an "individualistic environment," conveys: "you'll spend most of your time working on your own tasks, while a small portion of your time will involve collaborating with peers." The second attribute state contains language emphasizing a team-based work environment: "you'll spend most of your time in collaborative team environments, communicating and coordinating about designs." Meanwhile, the third state emphasizes communication beyond the confines of a specific engineering team, through language such as: "you'll spend most of your time interacting with vendors," and "you'll have on-call responsibility to help keep production running smoothly."

2.3.4 Data collection, verification, and analysis

Following survey collection at the nine participating universities, an author of this study and a research assistant independently conducted data entry from the paper survey forms, then reconciled results to ensure accuracy of the digitized dataset. Data were then imported into the statistics program Stata v.15 for analysis. The fundamental analysis approach for this study's experiment involved computing Average Marginal Component Effects (AMCEs) for each of the manipulated job attributes, as outlined by Hainmueller et al. (2014). In the case of this study, an AMCE represents the average difference in probability of a job being preferred between two different states of a specific job attribute, with this average taken over all possible combinations of the remaining manipulated job attributes. For instance, the AMCE for this experiment's mathematics intensity job attribute represents the average difference in probability of participants expressing preference for the math-intense job variant compared to the math non-intense job variant, with all other job attributes assumed to exist in random combinations across all jobs. This analytical approach provided a means of quantifying the effect that each unique attribute manipulation had upon participants' expressed job preference.

AMCEs can either be computed for the full participant sample, or for specific sub-samples of interest; we present both full sample and conditional AMCEs in this study's results. Further, Hainmueller et al. (2014) demonstrate that AMCEs are non-parametrically identified through linear regression of the outcome variable (in this case, job preference) upon sets of indicator variables representing the manipulated attribute states, provided that the attributes are independently randomized and manipulation effects are independent of each other. We computed the AMCEs reported in this study using Hainmueller et al.'s technique, and we followed those authors' verification steps to confirm independence of the attribute manipulations. Tests for manipulation effects' independence involved verifying that regression coefficients for attribute state variables remained statistically similar when the outcome variable was regressed upon one state variable at a time, compared to when the outcome variable was regressed upon the full set of state variables together. Similar tests verified that attribute state variables' coefficients were independent from variables indicating job profile positions within the survey form. Randomization of the attribute states across the sample of participants was checked by verifying that the mean of attribute state indicator variables was at or very close to 0.5 for two-state manipulations, and at or close to 1.0 for the three-state manipulation, for all key participant subsets (e.g., demographic subsets and subsets associated with the key-theoretic variables listed in Table 2-1). Meanwhile, also in accord with Hainmueller et al.'s approach, we computed confidence intervals for the AMCEs using clustered standard errors by participant to account for the fact that multiple observations (e.g., job preference results) are obtained from each participant.

Several additional checks were conducted to validate this study's AMCE results. First, we performed a robustness check, as demonstrated by Hainmueller and Hopkins (2015), to confirm the full-sample AMCEs are substantively similar when computed in two different ways: from the survey experiment's forced-choice measure of the outcome variable (e.g., binary job preference measure),

and second, from the appeal scale measure of the outcome variable. In the latter analysis, the job appeal variable was dichotomized from a 7-pt scale into a 0-1 binary variable by setting scale responses that were above the scale midpoint equal to one, and the others equal to zero; AMCEs were then computed in the same manner described above. This robustness check provides confidence that the forced choice construction of the job preference measure did not introduce constraint that skewed participants' expression of job appeal relative to its measurement on an unconstrained scale.

We next conducted a realism check on the design of our job profiles: since all of this experiment's job profiles represented engineering jobs, we expected that those participants who planned to work as engineers in the real-world would, on average, rate profiles higher than those participants not planning to work as engineers. To check this expectation, we conducted a test for the significance of the difference in mean job appeal responses between these two groups. Confirmation of higher average job appeal ratings from those pursuing real-world engineering jobs gives confidence that the overall randomized set of job attributes conveyed a balanced and realistic perspective of the profession: while some respondents are likely better informed than others about industry jobs, and some attribute combinations likely appeal more than others to those not pursuing engineering, we deemed it important that the broad set of job profiles not introduce an artificial appeal that compromised the general concept of the engineering profession among participants. Similarly, in another test of realism, we computed the full-sample mean job appeal ratings for all 24 possible combinations of job attributes in the experiment: here we sought to confirm that no one specific job profile configuration was found to be near-universally unappealing to participants. For instance, verifying that even the least popular among the job profile configurations was appealing to a substantive subset of participants would suggest realism; by contrast, a universally unappealing job would suggest an industry-unrealistic job configuration. While this test does not carry absolute

meaning, it allowed us to qualitatively confirm that we did not create unrealistically unappealing job profiles.

Finally, we conducted manipulation checks to verify that participants recognized the job profile differences that were intended to be conveyed by the job attribute manipulations. Here, following the three rounds of job profile rating tasks in the survey form, we presented participants with a series of manipulation check measures as shown in Table 2-A2 of this chapter's Appendix. The manipulation check question heading reads, "Place a check next to any/all of the attributes that differed meaningfully among the different jobs," and was followed by a list of eight attribute options, four of which were intentionally manipulated in the experiment, and four of which were not. We then ran statistical tests to confirm that correct responses differed significantly from false-positive responses, both overall, as well as for each of the four intentionally manipulated attributes separately.

The AMCE computation and verification procedures outlined above allowed us to establish a baseline set of ACMEs for the four job attribute manipulations for the full sample. Once this baseline was established, we proceeded to investigate the hypothesized interactions between subject-specific characteristics and job attributes put forth in Sections 2.2.1 – 2.2.4 of this chapter. We carried out this interaction analysis in two stages. First, we compared relevant participant subsets' mean conditional job preference results at different job attribute states, testing for significant differences between the subsets. As Hainmueller et al. (2014) discuss, significant differences detected here should also indicate significance of associated interactions in a regression model where attribute state indicator variables, subject characteristic variables, and interaction terms are tested together. Thus, as the second stage in this interaction analysis, we formally test for the significance of the hypothesized interactions in regression models.

We present this study's results in the section that follows, beginning with summary and descriptive statistics characterizing the participant sample. Next, we present AMCEs for job attribute

manipulations at the full sample level, followed by evaluations of the individual hypothesized interaction effects. We then present a multivariate model of job preference with both job attribute manipulations and subject characteristic-job attribute interactions included, and we conclude the section with a discussion of results interpretation and limitations.

2.4 Results

2.4.1 Description of sample

Conducting the survey at the nine host universities resulted in a sample of 1,061 participants. The average institution-specific participation rate among target respondents was 86.9%; this rate ranged from 81.9% to 92.0% across the individual universities. Table 2-4 shows summary statistics for the sample, beginning with statistics for the key supply-side independent variables theoretically associated with engineering students' career outcomes (e.g., those variables defined in Table 2-1). Table 2-4 then presents information on participants' expected career plans, demographics, institution type, and graduation date. All participants expected to complete their undergraduate degrees in the year 2017 (an inclusion criteria for this study), with most set to graduate at traditional spring semester commencements (91.0%) and a small number of participants scheduled to receive their degrees following their institution's summer or fall terms of that year. Meanwhile, 70.5% of participants expected to work as an engineer in their first full-time job after college or graduate school.

As shown among statistics for key supply-side independent variables in Table 2-4, the majority of participants expressed that they had experienced a positive engineering internship (69.3%). Most rated themselves as averse to financial risk-taking (78.0%). Smaller majorities stated that they would enjoy working at a job involving advanced mathematics (55.9%) and identified with a specific profession (54.8%). Meanwhile, approximately half of the candidates anticipated being

appointed to a formal leadership role by age 25 (50.0%), and approximately half expressed satisfaction with creative opportunities at engineering jobs (49.9%).

Table 2-4. Summary and descriptive statistics on survey participant sample

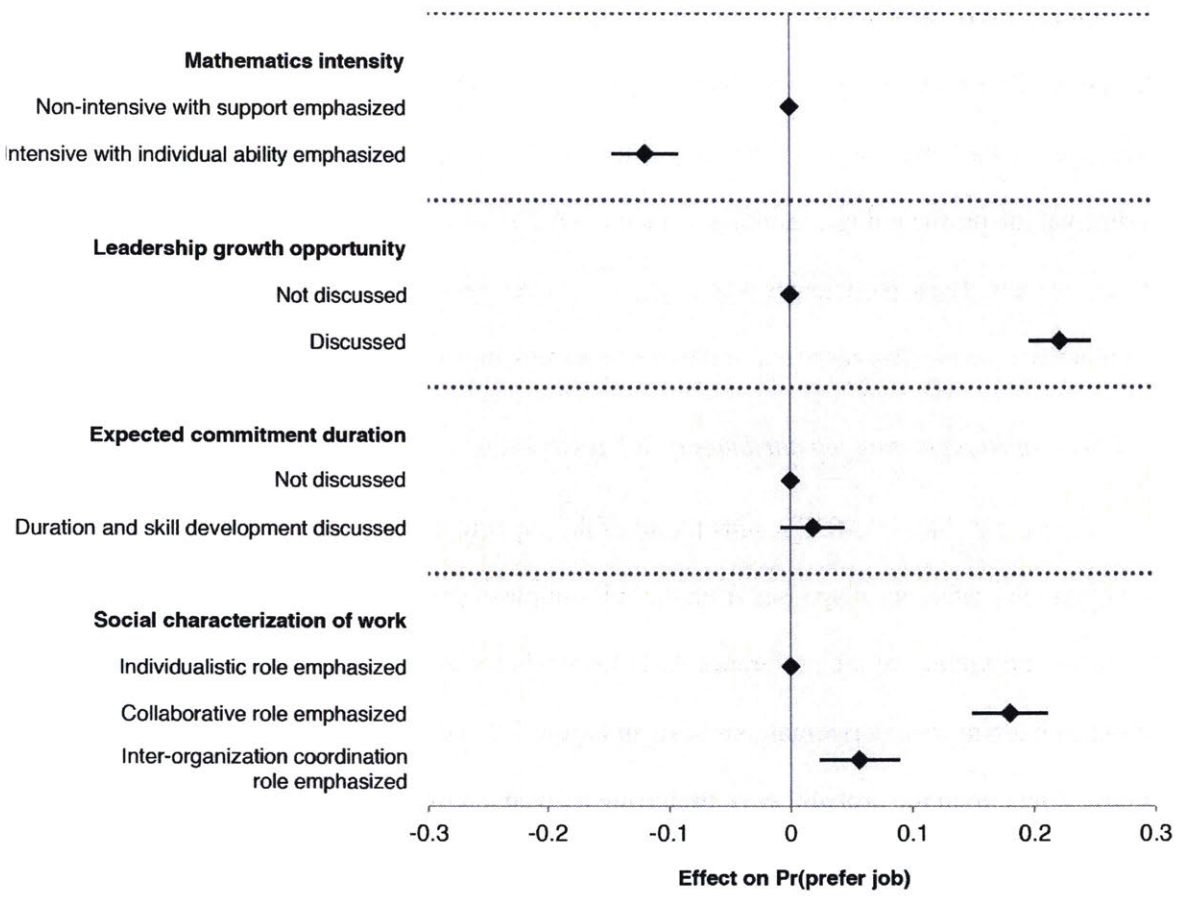
	Mean	(SD)	Number of Observations	Percentage
Total participants in sample:			1,061	
Key participant-specific independent variables (supply-side factors):				
Had a positive engineering internship experience			735	69.3
Averse to financial risk-taking			828	78.0
Would enjoy working at a job involving advanced mathematics			593	55.9
Identifies with a specific profession			581	54.8
Anticipates promotion into a formal leadership role by age 25				
7-pt scale assessment	4.61	(1.37)		
Subject rates self above scale midpoint			531	50.0
Satisfied with creative opportunities at engineering jobs				
7-pt scale assessment	4.47	(1.29)		
Subject rates self above scale midpoint			529	49.9
Participant career plans:				
Expected first full-time job:				
Engineering[1]			748	70.5
Non-engineering			255	24.0
Military service[2]			19	1.8
Expects to attend graduate school directly after college[3]			230	21.7
Salary expectation at first full-time job	$70,142	($13,740)		
Participant demographics:				
Female			245	23.1
White			752	70.9
Asian			205	19.3
Hispanic or Latino/Latina			87	8.2
Black or African American			40	3.8
Other (non-White)			24	2.3
Other participant information:				
Institution type:				
Public university			624	58.8
Private university			437	41.2
Graduation term:				
Spring 2017			965	91.0
Summer 2017			21	2.0
Fall 2017			75	7.1

Notes:
1. "Engineering" refers to traditionally categorized engineering jobs. Related jobs, such as in project management, are counted as "non-engineering" here.
2. Those who indicated military service as their first full-time job are not counted in either of the "engineer" or "non-engineer" career categories above.
3. Those who indicated that they expected to attend graduate school directly after college are also counted in the "engineering" and "non-engineering" career categories above based on their expected occupation immediately following graduate school.

Of the 1,061 participants who submitted a survey form, 1,054 (99.3%) contributed responses to the job profile assessment questions that composed the survey's embedded experiment. Of those who engaged in the survey experiment to any extent, 98.4% completed all three rounds of experimental job profile ratings, resulting in a total of 6,220 job preference observations from these 1,054 individuals. These participants who engaged with the survey experiment assessed an average of 5.9 randomized job profiles each (out of the maximum possibility of assessing 6 profiles).

2.4.2 Effects of manipulating job attributes on job preferences

Figure 2-2 shows AMCE results for all of the experiment's job attribute manipulations based upon job preference responses from the full sample of participants. In Figure 2-2, dots indicate point estimates of job preference AMCEs, while horizontal bars show each estimate's 95% confidence interval. The horizontal axis scale in Figure 2-2 is demarked in the following unit of measure: effect upon the probability of preferring a given job over the other possible job configurations. One state for each job attribute is designated as a reference state, as indicated by a dot without confidence interval bars around it located on the zero intercept line of the horizontal axis; thus, job attribute manipulations' effects on probability of job preference are shown in Figure 2-2 as the difference on the horizontal axis between an attribute state's point estimate and its reference. For instance, in the case of the mathematics intensity attribute, the point estimate for "intensive with individual ability emphasized," compared to the reference state of "non-intensive with support emphasized," denotes a -0.12 effect on preference probability, meaning that the estimated probability that engineering students will prefer a given job is reduced by 0.12 if the job entails mathematics characterized as "intensive with individual ability emphasized" compared to if the job entails mathematics characterized as "non-intensive with support emphasized."



Notes:
This plot shows estimates of the Average Marginal Component Effects (AMCEs) of randomly manipulated job attributes on the probability of a job being preferred. Horizontal bars represent 95% confidence intervals. The points without horizontal bars denote the attribute state that is the reference category for each attribute. The plot is based on the study's full sample, consisting of 6,220 observations from 1,054 unique participants.

Figure 2-2. Job attribute manipulations' effects upon probability of job preference – full sample

The set of AMCEs shown in Figure 2-2 were estimated by regression of the dependent variable, job preference, upon a set of dichotomous indicator variables for the attribute states, with standard errors clustered by participant, per the method discussed in Section 2.3.4. The regression model underlying the AMCE results in Figure 2-2 is presented later in this chapter as Model 1 in Table 2-6 in Section 2.4.4 (*Interactions analysis: development and evaluation of an integrated model of job preference*). As shown in Figure 2-2, four statistically significant job attribute manipulations at the full-sample level were identified in this analysis: manipulation of mathematics intensity from

"non-intensive" to "intensive" was found to have a significant negative effect on probability of job preference ($p < 0.001$); manipulation of leadership growth opportunity from "not discussed" to "discussed" was found to have a significant positive effect on probability of job preference ($p < 0.001$); manipulation of social characterization of work from "individualistic" to collaborative" was found to have a significant positive effect on probability of job preference ($p < 0.001$); and, manipulation of social characterization of work from "individualistic" to "inter-organization coordination" was found to have a significant positive effect on probability of job preference ($p < 0.01$). These significant effects represent general trends in job configuration preferences observed at the full-sample level.

After establishing the baseline set of AMCEs shown in Figure 2-2, we conducted verification and robustness checks upon these results, as outlined in Section 2.3.4. We began by verifying the mutual independence of attribute manipulation effects by evaluating the statistical similarity of attribute state indicator variables' regression coefficients computed in two different ways: first, by separately regressing the dependent variable on each attribute state indicator variable by itself, and, second, by regressing the dependent variable on the full set of state indicator variables together. We employed Stata's *suest* post-estimation command to test the null hypothesis that specific attribute states' coefficients, when computed in these two different ways, were equal. We found we could not reject this null hypothesis for any of the attribute state indicator coefficients ($p > 0.1$ for all tests) in support of the notion that the survey experiment's attribute manipulation effects are mutually independent from one another. Next, we verified that attribute manipulations' effects were independent of job profiles' physical position within the survey form – specifically, the left and right side positions on a given page, and the first, second, and third page positions across the experiment's three pages. To accomplish this test, we again evaluated the statistical similarity of job attribute state

indicator coefficients computed in two ways: first, by regressing the dependent variable on the set of state indicator variables (e.g., our baseline model), and, second, by regressing the dependent variable upon the set of attribute state indicators variables along with indicator variables for left/right and first/middle/last page positions, as well as the full set of interaction terms between the position indicator variables and the attribute state indicator variables. Interaction terms are necessary for this test because attribute states are randomized with respect to job profile positions; thus, these terms allow us to detect whether there are undesirable interactions between job profile positions and attribute states influencing the dependent variable. Again, we used Stata's *suest* command to conduct this test, where the null hypothesis was that attribute state indicator variables' coefficients were equivalent when computed in these two different ways. We again could not reject this null hypothesis for any of the coefficient equivalency tests ($p > 0.1$ for all tests), indicating support for the notion that job attribute manipulation effects are independent of job profile position. This latter test also verified that the non-experimental job profile parameters listed in Table 2-3 (e.g., information on "salary" and "about the company") had no appreciable effect on job preference, since these parameters were set to vary consistently by job profile position.

We next conducted a robustness check, as outlined by Hainmueller and Hopkins (2015), to assess the sensitivity of this study's job preference results to differences between forced-choice and appeal scale measurement approaches. As shown in Figure 2-1, both of these types of measures followed each of the experiment's job profiles within the survey forms. The analyses conducted thus far in this section have utilized the forced-choice data. In carrying out the robustness check, we first dichotomized the appeal scale data by coding all responses above the scale midpoint as "1" and all remaining responses as "0." We then ran the same regression analysis used to generate Figure 2-2, above, except that we employed the dichotomized appeal scale variable as the dependent variable,

resulting in a set of AMCEs for the job attribute manipulations that are similar to those shown in the baseline model in Figure 2-2. We report these results in Figure 2-A1 in this chapter's appendix. Because the substantive meanings of the forced-choice job preference measurements and the appeal scale measurements are not identical, the results cannot be formally compared. However, as Hainmueller and Hopkins (2015) suggest, robust results should convey the same general conclusions about preference behavior across the two measurement methods, as we show to be the case in Figure 2-A1; here, we observe that the same job attribute manipulations that are shown to be statistically significant in Figure 2-2 are also significant in Figure 2-A1, each with the same effect directionality. This robustness check suggests that the forced-choice measure did not unrealistically constrain participants' ability to express job preference.

Once the experiment's results were confirmed to uphold conjoint analysis assumptions and measurement conventions, we conducted realism checks, as outlined in Section 2.3.4, for the job attribute manipulations. As discussed, we expected the mean dichotomized job appeal ratings from participants expecting to work as engineers to be higher than those of participants expecting to work outside of traditionally categorized engineering roles. Results support these expectations: a clustered chi-square test indicates a significant association between job appeal and engineering career intent (chi-square = 27.62; $p < 0.001$), where mean appeal among those with engineering career intent was 0.77 and that from among those with non-engineering career intent was 0.66. A second realism check assessed the full-sample mean job appeal ratings for all 24 combinations of job attributes composing the set of experimental job profiles. Here we checked to ensure that no specific job profile was rated as near-universally unappealing by participants. Figure 2-A2 in this chapter's appendix shows the mean job appeal values (with 95% confidence intervals) for all job profile configurations; as indicated, the least-appealing job profile configuration was found to have a mean appeal value of 0.57

(e.g., meaning that it was rated as appealing 57% of the time), while the most-appealing job profile configuration had a mean appeal rating of 0.91. Hence, substantive subsets of participants found the overall least- and most-appealing jobs to be appealing and unappealing, respectively, suggesting that neither generated universal sentiment among participants. These realism checks provide confidence that the set of experimental job profile configurations contains substantial but reasonable variation in attractiveness for the purposes of examining job preference sorting patterns among engineering students.

Next, we conducted manipulation checks, as described in Section 2.3.4, to assess participants' recognition of job attribute differences across job profiles in the experiment. Here, we asked respondents to assess whether they felt various aspects of jobs differed meaningfully across job profiles (see Table 2-A2 in this chapter's Appendix for manipulation check questions). Participants assessed eight questions about job differences, four of which referred to attributes that were in fact manipulated across the experimental job profiles, while the other four referred to attributes of that were not part of the experimental manipulations. As expected, participants' responses indicating they detected meaningful variation were significantly higher for the intentionally manipulated attributes (0.63/1 mean response) compared to for the non-manipulated attributes (0.11/1 mean response). We proceeded to formally test whether the manipulation checks for each intentionally manipulated attribute produced significantly higher recognition responses from participants compared to the checks for each non-manipulated attribute. We accomplished this assessment by running pairwise Wilcoxon signed-rank tests for each of the 16 possible comparisons: for each check of participants' recognition response to an intentionally manipulated attribute, we test whether the recognition response is significantly higher in comparison to their responses for each of the four non-manipulated attributes. Table 2-A3 of the appendix presents the results of these tests, showing a Z-statistic and significance level for each pairwise comparison – in all

cases, the mean recognition responses are found to be significantly higher for the intentionally manipulated attributes than for the non-manipulated attributes.

Based on the tests and checks described in this section, we deemed the baseline model, as shown in Figure 2-2, to represent a valid baseline model of job preference for our sample of engineering students (for the limited set of job attribute states examined). With this baseline established, we proceeded to examine preference differences across different participant subgroups of interest. Such subgroup analysis can be carried out in two ways: by repeating the type of regression analysis used to generate Figure 2-2 (e.g., regressing the job preference dependent variable upon the job attribute state indicator variables) for conditional subgroups among the sample, or, by formally testing for interaction effects between subject characteristics and job attribute manipulations within a full sample model. We present the former type of analysis, conditional modeling, in the next section (Section 2.4.3 – *Job attribute manipulation effects upon conditional subgroups' job preferences*) and present the latter type, interaction effects analysis, in Section 2.4.4. These two approaches provide alternate means of observing the same phenomena – differences in job attribute manipulations' effects on job preferences across different subgroups – with each approach offering convenient means of conducting different types of comparisons. For instance, the conditional modeling approach allows for simultaneous comparison of full sets of job attribute manipulation AMCEs across different subgroups. We employed this approach to generate a comprehensive table of conditional AMCEs for numerous theoretically relevant subgroups in our sample, as presented in the next section. Meanwhile, we employed analysis of interaction terms within full sample models in order to formally test for such terms' ability to explain additional variance in job preference behavior at the full sample level – an investigation aligned with the central question of this chapter. In the interactions analyses presented in Section 2.4.4, we first graphically examine the individual interaction effects of

interest associated with the specific hypothesized interactions we presented in Sections 2.2.1 – 2.2.4, as based upon the pertinent literature. After examining these interactions individually, we then tested them together in a full-sample regression model in order to verify that their statistical significance held and that their addition to the model improved overall model fit.

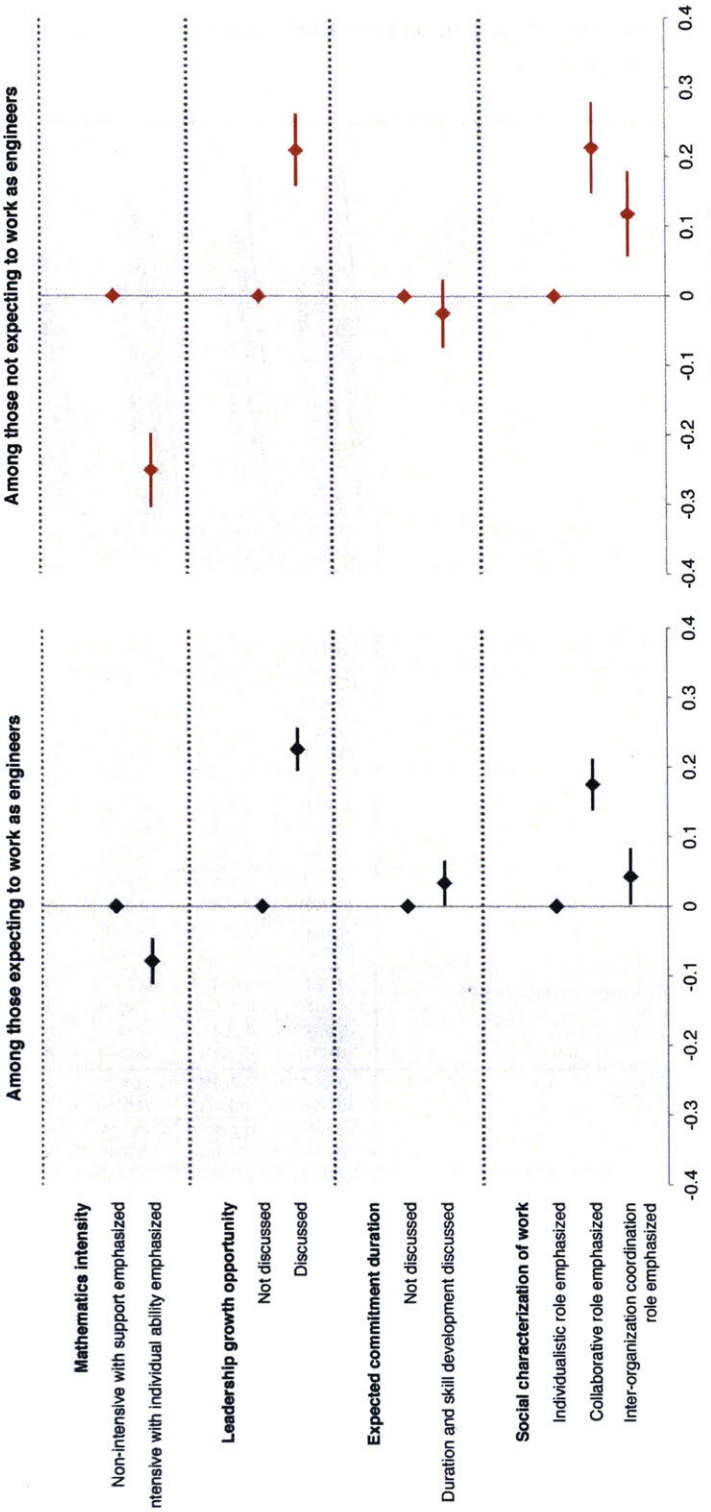
2.4.3 Job attribute manipulation effects upon conditional subgroups' job preferences

This survey experiment's primary dependent variable, dichotomous job preference, has, by definition, an overall mean value of 0.5 for any particular subgroup of participants, provided that the subgroup is identified by a variable not associated with the experiment's job profile attribute manipulations. This is true because the experiment's pairwise forced-choice measure of job preference counts any participant's choice of preferred job profile from among a given pair as a choice against the other profile from the pair. Thus, a comparison, for example, of females' and males' overall means of the job preference variable yields an identical value of 0.5 for both groups. In order to meaningfully compare females' and males' job preferences, one must therefore assess the subgroups' differences in their allocation of job preference choices across different job attribute states. One way to facilitate such an assessment is by regressing the job preference variable upon the job attribute manipulation indicator variables, as was described in the full sample analysis of the preceding section, conditionally for each subgroup, and then observing differences in job preference AMCEs across job attribute manipulations for each subgroup. Figure 2-3 shows an example of such a comparison of conditional regressions, in this case showing the job attribute manipulation AMCEs for participants expecting to work as engineers (in the left side plot) alongside such AMCEs for participants not expecting to work as engineers. Comparing these models reveals significant differences between the expectant engineers' and non-engineers' AMCEs for three attribute manipulations: mathematics intensity ($p < 0.001$), expected commitment duration ($p < 0.05$), and emphasis of inter-organization coordination ($p <$

0.05). The significance levels for these differences in manipulation effects were determined analytically by running post-estimation coefficient comparison tests in Stata between the conditional regression models. The results suggest that an increase in a job's mathematics intensity has a significantly greater negative effect on estimated probability of job preference for the expectant non-engineers (-0.25) compared to the expectant engineers (-0.08). This result is congruent with recent findings that individuals' enjoyment of working with mathematics correlates significantly with their expectation to work as engineers (see: Chapter 1). Smaller differences in manipulations' effects on job preference probability were observed for the other two significant manipulation differences. For instance, the imposition of job commitment duration expectations produced a significant positive effect on job preference probability among expectant engineers (+ 0.03), but not for expectant non-engineers (-0.02; not significant). Expectant non-engineers, meanwhile, exhibited a more positive job preference probability when inter-organization coordination was emphasized in jobs (+ 0.12) compared to expectant engineers (+ 0.04).

Conditional model comparisons, like that shown in Figure 2-3, can be conducted for any subgroups of interest among the experiment's sample of engineering students. We present results from a series of such model comparisons, in tabulated form, rather than graphical form, in Table 2-5 for subgroups pertinent to the six key supply-side career-related independent variables presented in Table 2-1, as well as for gender. Table 2-5 thus provides a broad overview of job preference trends among engineering students. While an exhaustive analysis of similarities and differences among student groups is beyond the scope of this study, we proceeded to formally evaluate the five particular subgroup-specific differences in job preference behaviors hypothesized in Sections 2.2.1 – 2.2.4. We first examined these hypotheses by observing subgroup differences in AMCEs between the conditional models shown in Table 2-5. For instance, we hypothesized that those engineering students who

anticipated enjoying work involving advanced math would respond differently to informedness about jobs' mathematics intensity compared to other engineering students; data shown in Table 2-5 implies support for this assertion based on the subgroups' differences in magnitude and statistical significance levels for the conditional AMCEs for the mathematics intensity attribute manipulation. We found these differences in the subgroups' AMCEs to be statistically significant ($p < 0.001$) by conducting a coefficient comparison test in Stata. Similarly, results in Table 2-5 suggest support for our four other hypothesized differences in job preference behavior by student subsets; specifically: students with different levels of anticipation of promotion into early-career leadership roles appear to respond differently to information about jobs' leadership growth opportunities; students with different levels of strength of professional identity appear to respond differently to information about jobs' commitment duration expectations; students with different levels of satisfaction with creative opportunities at engineering jobs appear to respond differently to information about jobs' commitment duration expectations, and females appear to respond differently than males to information about engineering jobs' social characteristics (in both of the two different experimental manipulations of jobs' social characteristics). We again employed coefficient comparison tests, based on the conditional model data shown in Table 2-5, to examine each of these observed differences in job preference behavior, and found each to be statistically significant at $p < 0.05$ or better. In the next section, we individually analyzed each of the interaction effects underlying these observed differences in subgroups' job preference behavior; there, we formalize our conclusions about empirical support for each of the effects' associated hypotheses.



Notes:
These plots show estimates of the Average Marginal Component Effects (AMCEs) of randomly manipulated job attributes on the probability of a job being preferred. Horizontal bars represent 95% confidence intervals. The points without horizontal bars denote the attribute state that is the reference category for each attribute. The plot on the left is based upon a subsample of 4,404 observations from 745 unique participants; the plot on the right is based upon a subsample of 1,482 observations from 252 unique participants.

Figure 2-3. Job attribute manipulations' effects upon probability of job preference – comparison between participants expecting to work in engineering and non-engineering roles

Table 2-5. Job attribute manipulations' effects upon probability of job preference – comparisons across key sample subgroups

Participant characteristics (conditional subgroups):	Job attribute manipulations[1]: **Mathmatics intensity:** non-intensive with support **to** intensive and individualistic	**Leadership growth opportunity:** not discussed **to** discussed	**Expected commit. duration in role:** not discussed **to** discussed	**Social characterization of work:** individualistic **to** collaborative	**Social characterization of work:** individualistic **to** inter-organization coordinative
Full sample (n = 1,054)	-0.119*** (0.014)	0.222*** (0.013)	0.018 (0.013)	0.180*** (0.016)	0.056** (0.017)
Expecting to work as an engineer (n = 745)	-0.078*** (0.017)	0.225*** (0.015)	0.034* (0.016)	0.175*** (0.019)	0.043* (0.020)
Not expecting to work as an engineer (n = 252)	-0.251*** (0.027)	0.210*** (0.026)	-0.025 (0.025)	0.213*** (0.033)	0.118*** (0.031)
Male (n = 802)	-0.111*** (0.016)	0.233*** (0.015)	0.032* (0.015)	0.157*** (0.018)	0.026 (0.019)
Female (n = 244)	-0.148*** (0.030)	0.181*** (0.027)	-0.026 (0.028)	0.262*** (0.033)	0.161*** (0.032)
Had a positive engineering internship experience (n = 730)	-0.114*** (0.017)	0.220*** (0.015)	0.017 (0.016)	0.174*** (0.019)	0.065** (0.020)
Otherwise (n = 288)	-0.130*** (0.026)	0.221*** (0.025)	0.023 (0.024)	0.179*** (0.031)	0.029 (0.033)
Averse to financial risk-taking (n = 824)	-0.116*** (0.016)	0.218*** (0.015)	0.031* (0.015)	0.184*** (0.018)	0.059** (0.019)
Otherwise (n = 215)	-0.128*** (0.030)	0.236*** (0.027)	-0.023 (0.030)	0.162*** (0.034)	0.056 (0.034)
Would enjoy working at a job involving advanced math (n = 590)	-0.026 (0.018)	0.229*** (0.017)	0.038* (0.018)	0.159*** (0.021)	0.053* (0.023)
Otherwise (n = 452)	-0.233*** (0.021)	0.204*** (0.020)	-0.001 (0.020)	0.206*** (0.024)	0.061* (0.025)
Identifies with a specific profession (n = 578)	-0.078*** (0.019)	0.225*** (0.017)	0.052** (0.018)	0.184*** (0.022)	0.044 (0.023)
Otherwise (n = 473)	-0.165*** (0.020)	0.223*** (0.019)	-0.023 (0.020)	0.178*** (0.023)	0.074** (0.024)
Anticipates promotion into a formal leadership role by age 25[2] (n = 529)	-0.150*** (0.020)	0.267*** (0.017)	0.033 (0.018)	0.178*** (0.021)	0.074** (0.022)
Otherwise (n = 516)	-0.086*** (0.020)	0.176*** (0.019)	0.005 (0.020)	0.1863*** (0.024)	0.039 (0.025)
Satisfied with creative opportunities at engineering jobs[2] (n = 527)	-0.095*** (0.021)	0.233*** (0.018)	0.051** (0.018)	0.156*** (0.022)	0.061* (0.024)
Otherwise (n = 512)	-0.141*** (0.019)	0.216*** (0.019)	-0.015 (0.020)	0.205*** (0.023)	0.051* (0.024)

Notes:

1. The values in each cell are estimates of Average Marginal Component Effects (AMCEs) on the probabilities that subjects from conditional subgroups will prefer a job based on differences in specific job attribute states. Robust standard errors are in parentheses under AMCE values. Subgroup sample sizes are shown next to subgroup labels in the left most columns; these values are sometimes lower than these subgroup sizes reported in the overall study because participants needed to have responded to both subgroup categorization survey questions and job assessment questions to be counted here.
2. These variables were dichotomized from 7-pt scale variables for the purposes of subgroup comparison; this split distinguishes those who responded with values above the scale midpoint from the others.

***p<0.001; **p<0.01; *p<0.05 (two-tailed tests)

2.4.4 Interactions analysis: development and evaluation of an integrated model of job preference

We examined each individual hypothesized job preference interaction effect graphically, and then assessed the significance of all such effects together in a combined job preference regression model. We graphically inspected interactions by plotting estimates of conditional job preference probabilities, with 95% confidence intervals, for participant subsets of interest at two different attribute states. Figure 2-4 shows such an analysis for the mathematics intensity attribute manipulation for two subsets of participants: those who anticipate enjoying work involving mathematics, and those who do not. Figure 2-4 shows an asymmetric job preference effect across the subsets – those who do not anticipate enjoying work involving advanced math exhibit a significant drop in job preference probability when informed that jobs entail intensive math, while those who anticipate enjoying work involving advanced math exhibit no statically significant change in preference probability between the job attribute states. In this latter case, participants' probability of job preference was near 0.5 for both math intensity job attribute states, suggesting that these individuals' attitudes toward jobs are minimally impacted by differences in jobs' math intensity. For the other subset of individuals, however, we observe a drop in estimated probability of job preference of 0.23 between jobs entailing non-intensive math and jobs that are math-intensive. We formally test for the significance of this interaction by comparing the math intensity attribute state indicator variables' coefficients between conditional regressions for these two participant subsets, and find the coefficients to be significantly different ($p < 0.001$). This result indicates support for our hypothesis of a significant interaction between individuals' perception of math enjoyment and their informedness of jobs' math intensity.

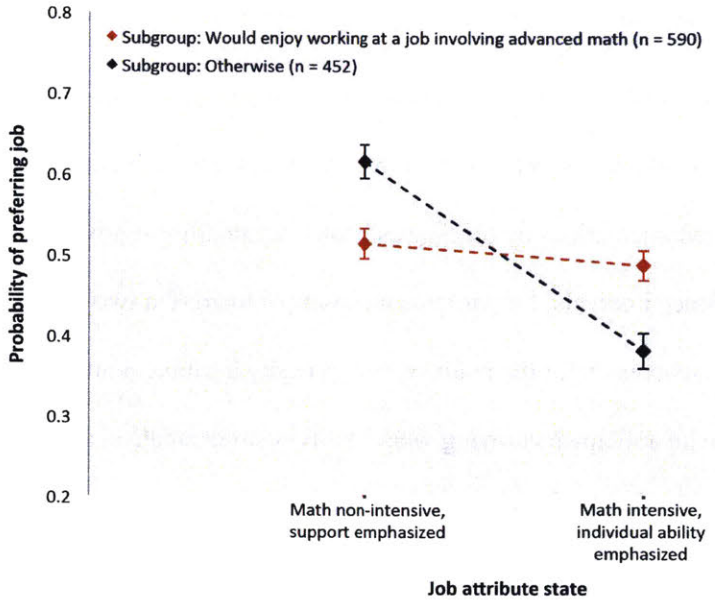


Figure 2-4. Interaction analysis – Individuals' anticipation of enjoying work involving advanced mathematics and jobs' mathematics intensity

We next examined the hypothesized interaction between individuals' anticipation of promotion into early-career leadership roles and their informedness about leadership growth opportunities at engineering jobs. Figure 2-5 shows plots of conditional job preference probabilities for the subsets of participants who anticipate promotion to a formal leadership position by age 25, and those who do not. For both subsets, probabilities of job preference were estimated for two job attribute states: cases where jobs' leadership growth opportunities are not discussed, and cases when such opportunities are discussed. Figure 2-5 shows that those participants who anticipate early-career promotion into leadership positions demonstrate a more substantial increase in job preference probability when informed about leadership growth opportunities at engineering jobs compared to the other participants. In the former case, participants' estimated probability of job preference increases from 0.37 to 0.63 upon becoming informed of leadership growth opportunities at jobs (a probability increase of 0.26), while in the

latter case, estimated job preference probability increases by a more modest 0.18. We again assess the statistical significance of this interaction by comparing coefficients for the leadership growth attribute state indicator variable between conditional regressions for the two participant subsets, and find the difference to be significant ($p < 0.001$). This result indicates support for our hypothesis of a significant interaction between individuals' anticipation of promotion into a formal leadership role by age 25 and individuals' informedness of jobs' leadership growth opportunities.

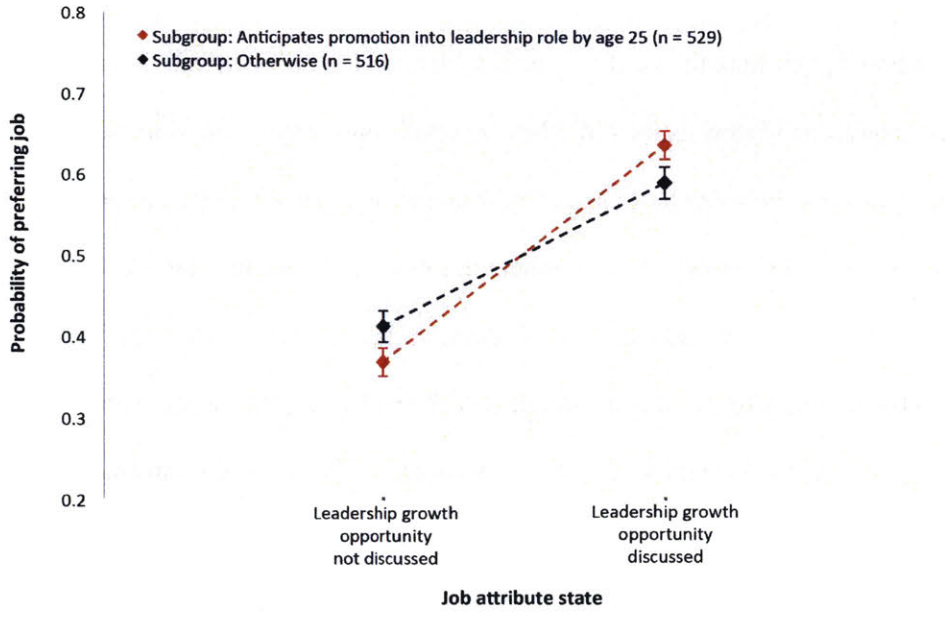


Figure 2-5. Interaction analysis – Individuals' anticipation of promotion to a leadership role by age 25 and jobs' leadership growth opportunity

We examined two interaction effects between participant characteristics and jobs' expected commitment duration. First we assessed the interaction of participants' strength of professional identity with manipulation of this job attribute. Figure 2-6 shows conditional job preference probabilities for those who identify with a specific profession and for those who do not; here, both subsets' probabilities of preferring jobs were estimated for jobs with expressed commitment duration expectations, and for

jobs without such expectations. Figure 2-6 shows differences in the job attribute manipulation effect upon these two subsets, indicating that those with a strong professional identity reacted more positively to informedness of an expected commitment duration (a 0.05 increase in preference probability) compared to those with a comparatively weak professional identity (a statistically insignificant negative response). This difference in job attribute manipulation effect upon these groups was found to be statistically significant in a comparison of coefficients for the commitment duration attribute state indicator variable between conditional regressions for the two participant subsets (at $p < 0.01$), supporting our hypothesis of a significant interaction between individuals' strength of professional identity and informedness of jobs' expected commitment duration. Secondly, we assessed the interaction between participants' satisfaction with creative opportunities at engineering jobs and jobs' expected commitment duration, as shown in Figure 2-7. Here we again found a difference in the expected commitment duration job attribute manipulation's effect upon participant subsets, where those who are satisfied with creative opportunities at engineering jobs exhibited an 0.05 increase in estimated probability of job preference when informed of commitment duration expectations, and those who are unsatisfied with creative opportunities at engineering exhibited a near-flat response. This difference in the job attribute manipulation effect upon these groups was also found to be statistically significant in a comparison of coefficients for the commitment duration attribute state indicator variable between conditional regressions for the two participant subsets (at $p < 0.05$), supporting our hypothesis of a significant interaction between individuals' satisfaction with creative opportunities at engineering jobs and informedness of jobs' expected commitment duration.

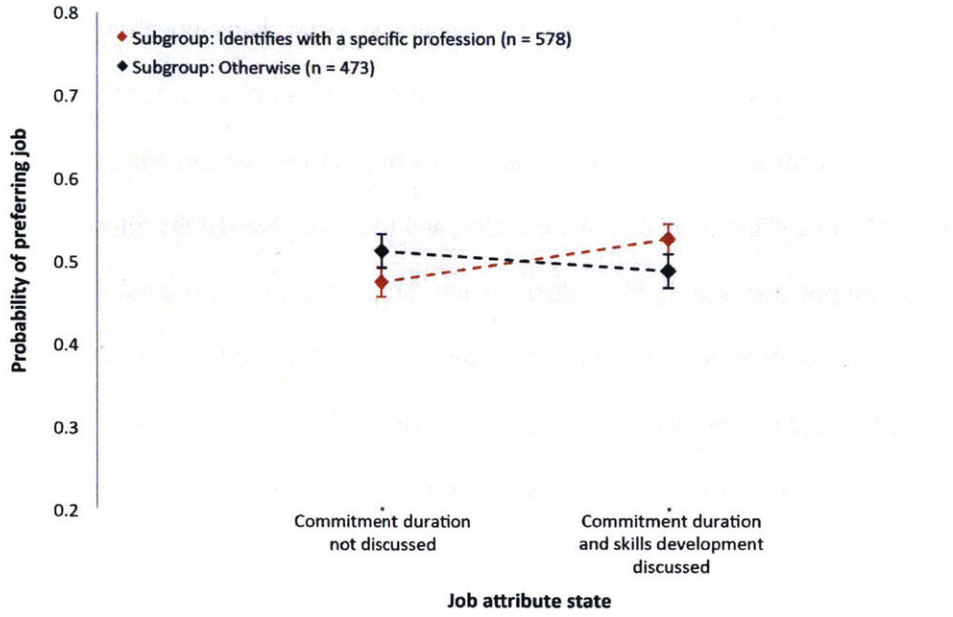


Figure 2-6. Interaction analysis – Individuals' strength of professional identity and jobs' expected commitment duration

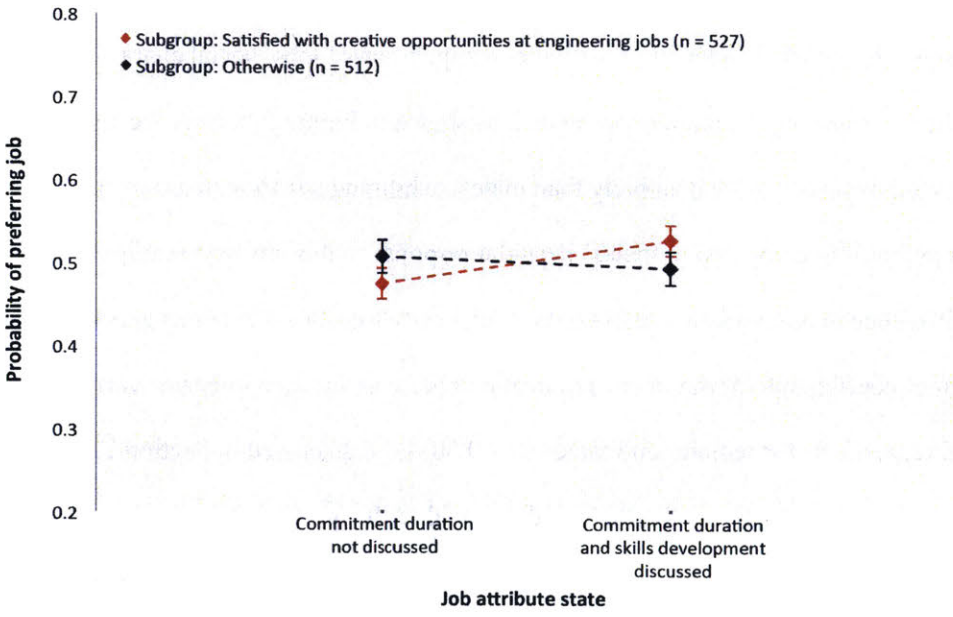


Figure 2-7. Interaction analysis – Individuals' satisfaction with creative opportunities at engineering jobs and jobs' expected commitment duration

Finally, we examined interactions between gender and social characterization of engineering jobs. Here, we ran two analyses corresponding with two distinct manipulations of the social characterization job attribute: first, we assessed the interaction between gender and the manipulation from individualistic to collaborative team-based roles, and next, we assessed the interaction between gender and the manipulation from individualistic to inter-organization coordinative roles. Figure 2-8 shows conditional job preference probabilities for females and males, and for jobs that are largely individualistic compared to jobs that are largely collaborative. This figure shows that both females and males reacted positively to this job attribute manipulation, but that females reacted distinctly more positively than males: females exhibited a 0.27 increase in estimated job preference probability as jobs' social characterization is shifted from individualistic to collaborative, while males exhibited a 0.16 increase. This difference in manipulation effect upon females and males was found to be statistically significant in a comparison of coefficients for the collaborative role attribute state indicator variable between conditional regressions for females and males ($p < 0.01$). Next, we ran a similar analysis for gender's interaction with the manipulation of jobs' social characterization from individualistic to inter-organization coordinative, as shown in Figure 2-9. Here we again see that females reacted distinctly more positively than males, exhibiting a 0.16 increase in estimated job preference probability compared to males' near-flat response to this attribute manipulation. We again find this difference in manipulation effect to be statistically significant between genders based on a comparison of coefficients for the inter-organization coordination state indicator variable between conditional regressions for females and males ($p < 0.001$). As discussed in Section 2.2.4, we generally hypothesized, based on the literature, that gender would react significantly to informedness about social components of engineering work in shaping engineering students' attraction to jobs. Here we tested two types of interactions between gender and manipulation of jobs' social components, and the

results of both tests find support for the general hypothesis that gender and knowledge of engineering jobs' social characteristics influences students' expressed job preference.

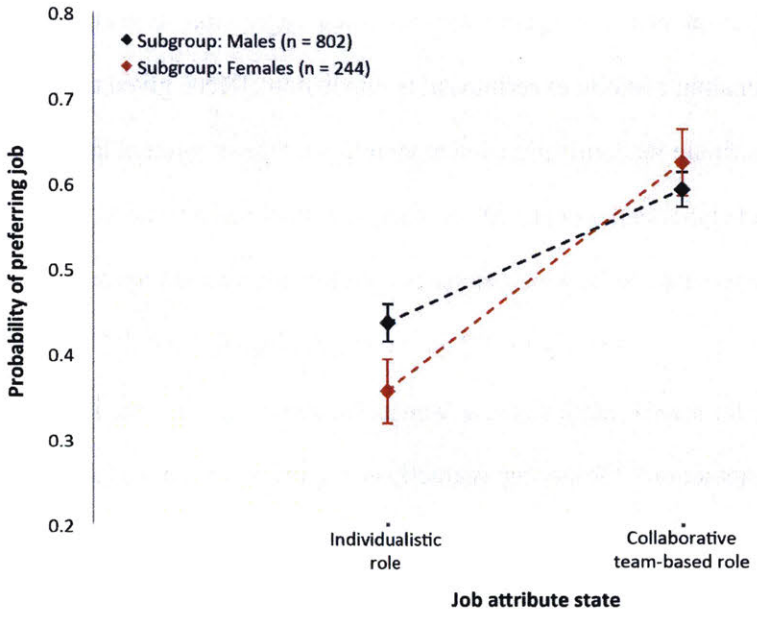


Figure 2-8. Interaction analysis – Gender with jobs' social characterization (individualistic vs. collaborative roles)

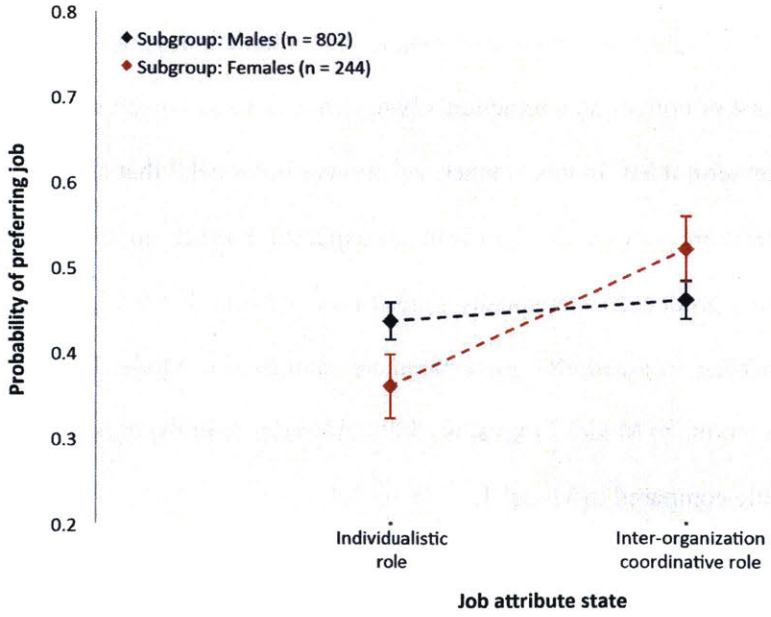


Figure 2-9. Interaction analysis – Gender with jobs' social characterization (individualistic vs. inter-organization coordinative roles)

We proceeded to construct an integrated job preference model that encompassed all six of the interaction effects between job attribute manipulations and participant-specific characteristics that we assessed graphically in this section. Here, we again employed linear regression, as such provides a non-parametric means of estimating conjoint experimental manipulation effects, given the assumptions previously discussed about attribute randomization and manipulation effects' mutual independence (see Section 2.3.4, herein, and Hainmueller et al., 2014). Table 2-6 shows construction of the integrated model. Model 1 within this table, which includes only job attribute manipulation terms, represents the baseline model introduced in Figure 2-2 earlier in this chapter. Model 2 in Table 2-6 includes the interaction terms for the six interactions, as well as the participant-specific independent variables involved in these interactions. Observing interactions' significance is not as straightforward in this context as it was in our graphical inspection of individual interaction effects; here, a given interaction's effects can manifest in the coefficients for any of the independent variables involved in an interaction: attribute manipulation indicator variables (e.g., manipulation base terms), participant-specific independent variables (e.g., participant characteristic base terms), and in the interaction terms themselves. Thus, we expected that the introduction of a significant interaction would result in significant coefficients for one or both of an interaction's base terms, or would result in a significant coefficient for the interaction term itself. In this manner, we observe in Model 2 that all six of the incorporated interaction effects are statistically significant, as expected. Further, an incremental F-test between Model 1 and Model 2 produced a statistically significant F-statistic ($F = 9.37$, $p < 0.001$), and Model 2 shows a relative increase in pseudo R-square parameter compared to Model 1, suggesting that the introduction of these terms to Model 2 explains additional variance in the experiment's job preference dependent variable compared to Model 1.

Table 2-6. Models of job attribute manipulations' effects on job preference – with and without interaction effects

Dependent variable: job preference		
Independent variables	**Model 1**	**Model 2**
Job Attribute A, Mathematics intensity	-0.119***	-0.419***
	(0.014)	(0.041)
Job Attribute B, Leadership growth opportunity	0.222***	0.083
	(0.013)	(0.048)
Job Attribute C, Commitment duration expectation	0.018	-0.118*
	(0.013)	(0.056)
Job Attribute D1, Social characterization as collaborative and team-based	0.180***	0.159***
	(0.016)	(0.018)
Job Attribute D2, Social characterization as inter-organization coordinative	0.056**	0.024
	(0.017)	(0.019)
Would enjoy working at a job involving advanced mathematics		-0.062***
		(0.008)
Identifies with a specific profession		-0.015
		(0.008)
Anticipates promotion into a formal leadership role by age 25		-0.013**
		(0.005)
Satisfied with creative opportunities at engineering jobs		-0.010
		(0.005)
Female		-0.067**
		(0.022)
(Would enjoy working at a job involving advanced mathematics) x (Job Attribute A)		0.130***
		(0.017)
(Anticipates promotion into a formal leadership role by age 25) x (Job Attribute B)		0.030**
		(0.010)
(Identifies with a specific profession) x (Job Attribute C)		0.032*
		(0.015)
(Satisfied with creative opportunities at engineering jobs) x (Job Attribute C)		0.015
		(0.010)
(Female) x (Job Attribute D1)		0.093*
		(0.038)
(Female) x (Job Attribute D2)		0.140***
		(0.038)
Constant	0.359***	0.657***
	(0.016)	(0.044)
Incremental F-test		9.37***
pseudo R^2	0.086	0.102
Total observations	6,220	6,000
Clusters	1,054	1,014

Notes:
All models are linear regression models; robust standard errors are in parenthesis. Reductions in observation count between successive models is due to the addition of variables to the models: only participants who completed all corresponding survey questions are included, and some respondents did not respond to certain survey questions about participant-specific information.
***p < 0.001; **p < 0.01; * p < 0.05 (two-tailed tests)

The results of this study's conjoint survey experiment suggest that interaction effects between engineering students' individual characteristics and jobs' attributes influence engineering students' job

preferences. These results lend support to the study's central investigation: as suspected, we find empirical evidence that the general trends in job preferences exhibited by a broad sample of engineering students contain variance that can be further explained by accounting for differences in how key subsets among such students uniquely react to differences across engineering jobs.

2.4.5 Limitations of results and considerations for future work

Research design limitations should be taken into consideration when interpreting the generalizability of this study's findings. First, though we were interested in examining mechanisms underlying job preferences among all types of engineering students, we note that our research sample was limited to a specific subset of engineering students: mechanical engineering majors. This sampling choice reflects an intentional tradeoff in research design. Specifically, the constrained sample allowed us to minimize and control for potential confounding effects on attitudes toward engineering jobs that could have been present among participants if the sample had been exposed to the varied job market conditions of differing engineering fields. This choice to constrain participants' degree field also allowed the study's experimental job profiles to include a realistic, rather than generic, job title and to include realistic supporting information. The experimental job profile manipulations we tested were drawn from the broad literature on engineering practice and pertain to job choice considerations faced by students in a wide array of engineering fields; however, this study's survey dataset does not allow us to empirically confirm that these results will generalize across a broader sample of engineering students from diverse disciplines. Follow-on work that replicates these findings among engineering students from different degree fields would increase confidence in the generalizability of the findings.

We next acknowledge that participants' stated preferences toward (or against) the simulated job profiles in our experiment cannot be confirmed to directly map to real-life job choice behaviors.

Critics have highlighted the importance of survey question wording (Berinsky, 2017) and choice of research context (Kagan, 2017) to the validity of findings from studies attempting to predict human attitudes or behaviors toward real-life situations. Berinsky (2017), for instance, discusses that achieving correct survey question interpretation often involves adjusting the level of specificity or abstractness of wording to a level most appropriate for the sample of participants. In this regard, we designed the experimental job profile wording specifically for the audience of U.S. senior year mechanical engineering students, and piloted the survey experiment with several student volunteers in the year prior to the main study to assess whether wording was being interpreted correctly. Kagan (2017), meanwhile, cautions against conducting studies on human attitudes or behaviors in contexts where research participants are far removed from the real-life phenomena being investigated – for instance, asking participants to express how they feel about a threat that is not real, or asking participants to envision how they would respond if they were someone or someplace they were not – citing potentially poor external validity of findings from such studies. Here, we selected our sample and research context conscientiously to mitigate this type of concern. We did not ask participants to envision being anyone they were not – our approach was to measure participants' job preferences whilst in their own shoes: as senior year engineering students at a timeframe when the engineering job market was likely near the forefront of their minds. Follow-on research, however, could further increase our confidence that the preference effects identified in this study translate to real-life job pursuit behaviors by aligning experimental data collection and real-life job pursuit contexts even more closely. For instance, future research could test for engineering students' job preferences toward actual positions in real job search-related situations, such as at university career fairs. This type of research design would require partnerships with industry employers, and could test the effects of randomized interventions implemented in the way that real engineering positions were advertised in

the promotional materials used at the career fairs. Researchers could measure relative job pursuit rates of career fair visitors in response to the various randomized versions of jobs' promotional materials – provided that materials sufficiently matched real positions associated with them – meanwhile, research-pertinent information about individuals could be collected upon the individuals' visits to career fair booths. Such an arrangement could be repeated at career fairs at multiple universities. This type of research design, while logistically intensive, could provide additional empirical support toward the findings of this study.

Finally, we call attention to the particular job attribute manipulations we chose to incorporate into this study's experiment. While the states of the attributes that we examined in the experiment – in areas of mathematics intensity, opportunities for growth into leadership positions, commitment duration expectations, and social characteristics of work – are discussed prevalently in the literature, we lack information on the specific proportions of real entry-level engineering jobs that embody each attribute state (for instance, the proportion of engineering jobs best characterized as mathematics-intensive computational specialist roles). The implications of this study's findings could be strengthened by research that assessed these proportions in industry, such as through surveys of engineering employers or through mining of job posting data. While we assume, based on the presence of supporting literature, that each of this study's job attribute states composes at least a substantive minority of engineering positions, such research could verify this assumption. Further, this type of follow-on research could help identify whether there existed any notable gaps between proportions of engineering job types preferred by engineering students and such jobs' availability in the labor market – this information could be of use to employers in their design and marketing of future positions. Finally, engineering jobs characterization research could be useful in identifying

additional key dimensions of variance among jobs, in areas beyond the four examined in this study, to determine whether follow-on studies should incorporate additional pertinent attribute manipulations.

2.5 Discussion and conclusions

This study's experiment allowed us to examine how engineering students' stated preferences for particular engineering jobs are shaped by differences in certain key attributes across such jobs. Further, the study facilitated an analysis of how engineering jobs' attributes interact with individual-level characteristics – engineering students' career-related beliefs and expectations – to influence such job preferences. Our findings carry implications for those who are involved in developing and recruiting future engineering workforces. For instance, results suggest that heightening students' awareness of the variety among engineering work could improve job matching at the college-careers interface; thus, we call attention to collegiate educators' potential for enhancing students' awareness of this variety as part of the engineering educational experience. Our results also shed light on how differences in the detailed information conveyed about engineering jobs during employers' recruiting and hiring processes could shape engineering students' attraction to jobs, and, in turn, could influence the sorting of various candidate subsets into pursuit or non-pursuit action choices relative to certain available positions. Finally, this study contributes empirical evidence in support of implications of past analyses: that differences across engineering jobs could be a significant source of variance in job preferences among those in the engineering pipeline (see, e.g., Perlow & Bailyn, 1997; Brunhaver et al., 2013).

Among a broad sample of senior year mechanical engineering students, we detected general preference trends suggesting that students tend to favor certain engineering jobs over others: jobs that are comparably lower in mathematics intensity; jobs that are tied to specific leadership growth paths, as opposed to those with unstated growth paths; and those that are more socially collaborative or

coordinative, as opposed to those that are primarily individualistic. These broad trends must be interpreted with caution: they are generalizations at our full-sample level, and should not be taken to imply, for instance, that few engineering students are attracted to jobs involving intensive mathematics, or that few students prefer individualistic work. Quite the contrary: in instances where the randomized survey experiment presented participants with pairs of job profiles where one profile featured intensive math, and the other featured non-intensive math, participants expressed preference for the profile with intensive math 37.3% of the time; and, in situations where participants were presented with job profile pairs where one profile featured individualistic work, and the other emphasized collaborative or coordinative work, participants expressed preference for the profile with individualistic work 36.9% of the time. Thus, while it may be useful to know what types of jobs majorities of engineering students prefer, this study's primary research contribution lies in identifying the nuanced job preference patterns of student subsets that underlie these broader trends. We conclude this chapter by discussing these patterns and their implications relative to key engineering workforce development issues.

We found, for instance, that differences in students' stated job preferences in response to manipulation of jobs' mathematics intensity showed notable asymmetry between student subsets (Figure 2-4). Those students who anticipated enjoying work involving advanced math (55.9% of the sample) exhibited an insignificant difference in job preference probability between jobs featuring low and high mathematics intensity, while those students who did not anticipate enjoying work involving advanced math (42.6% of the sample), exhibited a significant relative drop in job preference probability when informed that jobs involved intensive math. This asymmetric effect is notable because it suggests that under-informedness among students about jobs' mathematics content may not merely introduce random error in student-job matching; rather, such under-informedness could cause a

skewed mismatching of students to jobs. Literature suggests that engineering work carries a general reputation as math-intensive (NAE, 2008); yet, studies also indicate that engineering positions differ substantively among each other in terms of actual math intensity (Kent & Noss, 2002; Alpers, 2010; Goold, 2012), and that positions often do not involve the same forms of mathematics work students grow accustomed to in engineering school (Alpers, 2010; van der Wal et al., 2017). Thus, if students are under-informed about jobs' mathematics intensity, they may default to anticipating that a given engineering job is more math-intensive than it really is. In turn, our findings suggest that those less assured of their enjoyment of working with math could be more likely than their peers to avoid engineering jobs that they might actually be a good fit for – an implication potentially salient toward gender diversity in light of prior research. For instance, prior studies have found that, net of actual math ability, women students possessed lower mathematics confidence, on average, compared to men (Correll, 2001, 2004) – a phenomenon of self-assessment bias believed to be tied to gendered cultural beliefs about roles and abilities (Hyde et al., 1990; Correll, 2001; Correll, 2004). If such a phenomenon persists, our findings suggest women could be disproportionately dissuaded from considering engineering positions if under-informed about the details of positions – until such a gendered confidence gap is closed. Based on this study's survey data, we indeed found that the females in our sample reported significantly lower anticipated math enjoyment, on average, compared to the males ($p < 0.05$; based on a bivariate Pearson chi-square test). We also found that the experiment's math intensity manipulation's AMCE was more negative for females (-0.148) compared to males (-0.111), as shown in Table 2-5, though this difference in AMCE was not statistically significant in our sample – we call attention to it simply because of its theoretical relevance and its congruence with the statistically significant difference between females' and males' anticipated math enjoyment. Yet, the concern about potential mismatching of students and jobs due to under-informedness about jobs' math

intensity is not limited to gender equity considerations. All participants in this study's sample were on track to successfully complete an accredited engineering degree, and thus possessed sufficient mathematics aptitude for that accomplishment – our results suggest that any of the sample's substantial subset of candidates who did not express anticipation of mathematics enjoyment could be more susceptible to dissuasion from pursuing engineering jobs due to under-informedness about jobs' math intensity than their peers. These findings imply that educators should act to make better connections between how math is used in engineering school compared to in industry, as has been suggested (Winkelman, 2009), and should continue working to close mathematics confidence gaps due to self-assessment biases. Meanwhile, results suggest an imperative for employers to express math requirements accurately in job descriptions. Certainly, employers aspiring to hire computational specialists should be clear about the mathematical obligations of such comparably math-intensive roles, but employers looking to hire generalists should be cautious that they may inadvertently push away highly qualified candidates if job descriptions include boilerplate language about mathematical or analytical requirements beyond what are needed. Employers, in short, should take steps to create job descriptions that are unique for computational specialist and generalist roles in ways that appropriately distinguish the roles from each other.

The job preference patterns identified in response to experimental manipulation of jobs' leadership growth opportunities carry notably different implications compared to those found for the manipulation of jobs' math intensity. Here, although key student subsets exhibited statistically significant differences in their average stated preferences toward jobs depending on whether leadership growth opportunities were or were not expressed, all of the examined student subsets reacted positively and significantly (e.g., in terms of increased probability of job preference) when jobs were manipulated to include opportunities for growth into leadership roles (see: Figure 2-5 and Table 2-5). This finding

is important in light of recent literature suggesting engineering employers seek an increase in candidates with leadership abilities and aspirations (Salzman & Lynn, 2010; Cappelli, 2015). The finding thus suggests that heightening students' awareness of leadership growth opportunities at engineering jobs could support a key workforce development need for many employers, and could enhance job attractiveness, on average, across the candidate pool. This is not to say that all students should be pushed toward leadership roles – recall, the experiment's job attribute statement for "leadership growth opportunities" framed the opportunities as "[for] qualified candidates…if interested"; rather, our findings suggest there appears to be little downside to a campaign aimed at increasing students' awareness of leadership opportunities at engineering jobs. We suggest, again, that both educators and employers can contribute to this increased awareness. First, we note that the growing contemporary movement among engineering schools to include engineering leadership courses or programs (see: Klassen et al., 2016) appears to be well-founded, not only in response to the literature on employers' needs, but also as a general mechanism for increasing students' cognizance of the association between leadership and engineering careers. And, second, we again point to an implication for employers' job descriptions and recruitment processes: our findings suggest that job descriptions that do not mention opportunities for future growth into leadership roles are likely at a general disadvantage in attracting candidates in the labor market compared to those descriptions that do. We are not suggesting employers should falsely advertise such opportunities if they do not exist. Rather, employers should consider incorporating these growth opportunities into both the design of positions themselves, as well as into the marketing strategies for positions, in light of this study's findings on such information's positive effect on candidates' attraction to positions.

Patterns in students' stated job preferences in response to the experimental manipulation of jobs' expected commitment durations suggest that distinct student groups respond differently to the

manipulation (see: Figures 2-6 and 2-7). Here, two key subsets among students – those with strong professional identities and those satisfied with perceived opportunities for creativity at engineering jobs – reacted positively and significantly to job profiles that included both an expected commitment duration coupled with training and development of "specialized skills." Meanwhile, those students who did not belong to either of these groups did not exhibit a positive response to such information; rather, such students' responses were statistically similar between manipulated job attribute states.

We hypothesized that subsets of students with strong and weak professional identities would react differently from one another upon being made aware of job commitment duration expectations, and, similarly, hypothesized that subsets who were satisfied with creative opportunities at engineering jobs would react differently from those who were not (see: Section 2.2.3). However, we were surprised not to have measured more of a negative response to the commitment duration expectation attribute state from those student subsets with weak professional identities and who were not satisfied with creative opportunities at engineering jobs, given literature documenting negative impacts of employer-imposed mobility constraint upon job appeal (Marx et al., 2015), and the ostensible lack of a theoretic reason for these groups' to be ambivalent to such constraint. We note that our commitment duration expectation job attribute manipulation, as operationalized, was in fact a compound manipulation: not only did the manipulation impose an expected role commitment duration, but it also mentioned that the job would involve skills development tied to work on advanced projects. As explained in Section 2.3.3, the choice to include both such features in this manipulation was intentional based on the literature: studies suggest that employer-imposed commitment expectations were more legally viable when coupled with specialized skill development and work related to firms' competitive advantage (Lester, 2001). We find it plausible, however, that including both such elements in the attribute manipulation could have tempered negative responses to the manipulation,

especially in light of literature that finds an association between employers' sponsorship of skills development and increased retention at jobs (Benson et al., 2004). Thus, in future iterations of this experiment, we recommend incorporating three job attribute states into this manipulation – such a three-state manipulation could test for the effect of imposing a commitment duration expectation upon students' job preference, both with and without the additional attribute elements related to specialty skills development. Meanwhile, in this present study, our test of the commitment duration expectation manipulation more generally implies that imposition of a commitment duration expectation can produce significant differences in job attraction among student subsets.

Finally, we observed differences in the ways that females and males responded to information about jobs' social characterizations, as was expected based on literature reviewed in Section 2.2.4. Specifically, we found that female students exhibited a greater increase in probability of preferring engineering jobs, compared to males, upon being informed that such jobs were rooted in collaborative or coordinative work, rather than in individualistic work (see: Figures 2-8 and 2-9). These findings carry potentially salient implications toward improving gender equity in the engineering workforce, given engineering's historic reputation as centering on individualistic technical work (Seron et al., 2018) despite substantive literature that contests that reputation's merit, finding, instead, that most real-world engineering jobs contain substantial social, collaborative, and coordinative elements (Bucciarelli & Kuhn, 1997; Perlow & Bailyn, 1997; Bucciarelli, 2002; Trevelyan, 2007, 2010; Robinson, 2012; Stevens et al., 2015). Researchers associate the endurance of this reputation to longstanding professional socialization experiences endemic to engineering schools that continue to "valorize" individualistic technical work as a core element of what it means to be an engineer (Seron et al., 2018, p. 133), and to an engineering professional culture that persists in under-valuing social elements of engineering work relative to their centrality to engineering project success (see literature reviewed by Cech, 2015, p. 63). Yet, due to this enduring reputation, we suspect that if students are

under-informed about the details of particular engineering jobs, they might default to assuming such jobs are more individualistic than they really are. Such a tendency, in turn, suggests a disproportionate negative impact on females' interest in engineering jobs, given females' more negative view of individualistic engineering jobs compared to males. Our results thus offer support to several courses of action that could increase women's attraction to engineering jobs. First, educators should continue refining the engineering educational experience, inclusive of student project team experiences, to reinforce a broader conception of what it means to be an engineer – one that celebrates social, collaborative, and coordinative roles as existing at the heart of engineering (see, e.g., Cech, 2015). Second, educators should continue to work to identify and mitigate processes that produce gendered technical confidence gaps during engineering school (see, e.g., Seron, et al., 2018). Employers, meanwhile, should highlight collaborative and coordinative aspects of roles during recruiting and hiring processes for engineering positions. While our findings indicate that females responded more positively to information about these aspects of roles than males did, our results do not indicate a negative response from males to this information – in fact, none of the key subsets of engineering students we examined exhibited a negative reaction to such information (see: Table 2-5) – thus, there appears to be little downside to a general recommendation that engineering employers' recruitment efforts should highlight engineering jobs' social elements.

This study's findings underscore the importance of considering both individuals' characteristics and engineering jobs' unique attributes when examining individuals' attitudes toward working at engineering jobs. Through the use of a randomized survey experiment, we were able to make causal inferences about job attributes' effects on engineering students' stated job preferences, and were also able to assess the joint significance of interaction effects between student characteristics and job attributes on such preferences. We observed that differences in job attributes explained variance in engineering students' job preferences, but also found that such interaction effects between

student characteristics and job attributes explained additional variance in job preferences beyond what was explained by job attribute differences alone. It is our hope that these findings will influence future research on engineering students' career outcomes, and will help shape education and recruitment efforts to better facilitate the matching of students with satisfying, well-fitting jobs and career paths at the education-careers interface. Recent studies examining processes shaping the composition of the U.S. engineering workforce have focused largely upon supply-side explanations of students' career outcomes – explanations centered on students' individual-level preferences, beliefs, and goals as independent variables tied to career choices – and these works have largely assumed engineering work to be homogenous. The findings described herein suggest that research in this area could potentially expose greater detail in student-job sorting mechanisms if variety across engineering jobs is accounted for in research designs. Similarly, recent federally-funded U.S. education policy efforts have largely focused on pushing students toward engineering or "STEM" careers, while focusing little on the effectiveness of post-education matching between students and specific sub-occupations within these career umbrellas. Here, too, our results suggest that enhanced student-job fit could be attained if such programs included means to better inform candidates about the substantive differences that exist across specific roles in engineering. Our findings, in sum, indicate that accounting for differences across engineering jobs, while continuing to account for differences among students, may be a critical next step in advancing education and recruitment efforts aimed at strengthening the engineering workforce – in terms of the workforce's demographic diversity, the satisfaction of its workers, and the satisfaction of its employers.

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Chapter Appendix

Table 2-A1. Survey questions for participant-specific independent variables

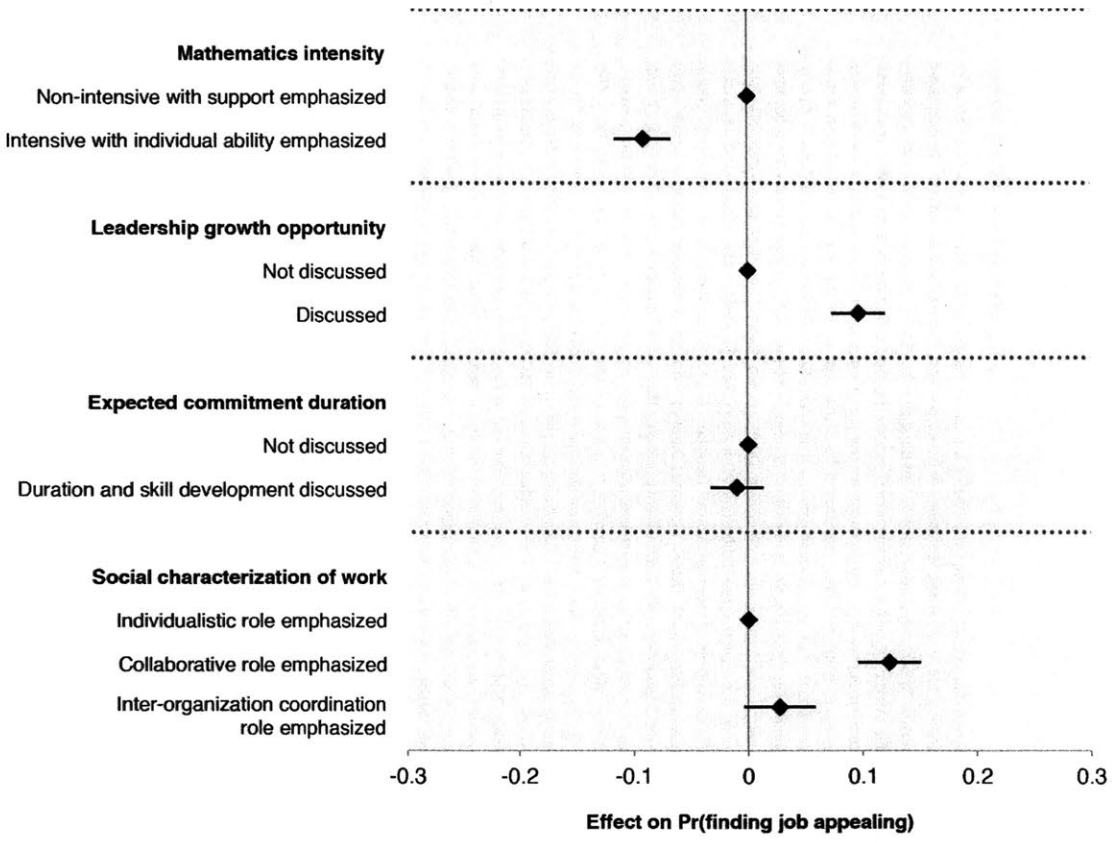
Survey questions: **Key independent variables from engineering student occupational intentions model (Magarian and Seering, 2018a)**
Had positive or negative engineering internship experience(s) Have you ever worked at an engineering internship or co-op? (either at a company or at a government/non-profit organization; this question does not refer to university labs) [Yes] [No] If yes, please check one or both of the following: [At least one internship/co-op was a positive experience] [At least one internship/co-op was a negative experience]
Averse to financial risk-taking If you had to choose between either of the following compensation schemes, which appeals more to you? (please check only one) [Guarantee of a consistent upper-middle class salary, but with no chance of additional large monetary payouts] [A chance for large non-salary monetary payouts, but with high uncertainty in your annual salary and/or job security]
Would enjoy working at a job involving advanced mathematics Which of the following better describes your relationship with mathematics? (please check only one; assume "advanced mathematics" is within the bounds of your major's curriculum) [A job that regularly requires use of advanced mathematics concepts would be enjoyable for me] [A job that regularly requires use of advanced math would not be enjoyable for me] [I'm unsure]
Identifies with a specific profession When you envison your ideal career, is it based upon a specific profession? (e.g., doctor, engineer, lawyer, consultant, artist, etc.) [Yes] [No] [Unsure/can't envision ideal career]
Anticipates promotion into formal leadership role by age 25 How likely is it that you will be appointed to a formal leadership position early in your career? (e.g., by age 25) Please circle the appropriate number on the scale: [7-pt scale: very unlikely, unsure, very likely]
Satisfied with creative opportunities at engineering jobs How satisfied are you with the availability of job opportunities that allow graduates to engage in creative design work in engineering jobs after college? Please circle the appropriate number on the scale: [7-pt scale: entirely unsatisfied, unsure, entirely satisfied]
Survey questions: **Other participant-specific independent variables**
Expected occupational outcome Which one of the following represents how you will most likely begin your career journey after undergraduate graduation? (please check only one) [Work as an engineer] [Work in product management, project management, technical consulting, or quantitative analysis] [Work in management consulting, finance, or venture capital] [Work other: _____] [Grad school, then work as an engineer] [Grad school, then work in product management, project management, technical consulting, or quantitative analysis] [Grad school, then work in management consulting, finance,or venture capital] [Grad school, then pursue a career in academia] [Grad school, then other: _____] [Other: _____]

Table 2-A1. Survey questions for participant-specific independent variables [Continued]

Survey questions: **Other participant-specific independent variables [continued]**
Salary expectation at first full-time job after college or graduate school At whatever point in life you take your first full-time job after college or graduate school, what starting salary do you expect to earn? (in $/year in today's dollars) [_____]
Gender What is your gender? [Female] [Male] [_____]
Race How do you identify yourself by race and/or ethnic origin? [American Indian or Alaska Native] [Asian (Incl. Indian subcontinent)] [Black or African American] [Hispanic or Latino/Latina] [Native Hawaiian or Pacific Islander] [White] [_____]
Student loan debt status Please indicate true or false for the following statement: Following undergraduate graduation, I will personally owe $10,000 or more in student loan debt that I'll need to repay. [True] [False] [Unsure]
Varsity athletics participation status Have you participated in a collegiate varsity athletics program? [Yes] [No] If "Yes," how many seasons wil you have participated in before graduating? [_____]
Greek life participation status As an undergraduate, were you a member of a fraternity or sorority? [Yes] [No] If "Yes," did you hold an elected leadership position within the fraternity or sorority? [Yes] [No]
Undergraduate major Are you a Mechanical Engineering student? (either by degree major or by home department) [Yes] [No] If "No," then what is your home department? [_____]
Degree completion date/status When do you expect to complete your bachelor's degree? Please indicate the month and year you will earn your degree: [Month: _____] [Year: _____]

Table 2-A2. Survey questions for experimental manipulation checks

Survey questions: **Conjoint experiment manipulation checks**
Please tell us about any meaningful differences that existed among the above job postings in any of the attributes below. Place a check next to any/all of the attributes that differed meaningfully among the different jobs: [ ] Company size [ ] The amount or intensity of mathematical work associated with the job [ ] Company age [ ] Expected commitment duration in the role (e.g., how long you will stay at the role you're hired into) [ ] The degree of solitary work versus collaborative work [ ] Salary [ ] Opportunity to be promoted into leadership positions [ ] Other; please specify: _____



Notes:
This plot shows estimates of the Average Marginal Component Effects (AMCEs) of randomly manipulated job attributes on the probability of a job being found to be appealing. Horizontal bars represent 95% confidence intervals. The points without horizontal bars denote the attribute state that is the reference category for each attribute. The plot is based upon this study's full sample (6,112 job appeal ratings from 1,056 unique participants).

Figure 2-A1. Robustness check: job attribute manipulation effects based on dichotomized appeal scale data

Figure 2-A2. Mean job appeal ratings for the exhaustive set of experimental job profile formulations

Notes:
This plot shows estimates of mean job appeal ratings for each job profile formualtion. Data from a dichotomous variable for job appeal was used, where appeal was set to equal one if participants rated appeal above the scale midpoint, and was set to zero otherwise. The job profile formulations shown here represent the exhaustive set of profiles tested in this study (e.g., the profiles set encompasses all possible job attribute state combinations in the study). Horizontal bars represent 95% confidence intervals. The plot is based on the study's full sample of participants who submitted job appeal ratings (6,112 observations from 1,056 unique individuals)

Table 2-A3. Results from survey experiment manipulation checks

Z-statistics from pairwise comparisons of responses to attribute manipulation recognition checks

	Non-manipullated attributes:			
Manipulated attributes:	*Company size*	*Company age*	*Salary*	*Other*
Mathematics intensity	18.51***	21.87***	13.38***	20.48***
Leadership growth opportunity	23.96***	26.07***	20.72***	24.74***
Commitment duration expectation	18.16***	21.27***	13.40***	19.82***
Social characterization of work	24,51***	26.71***	20.89***	28.82***

Notes:

Z-statistics are presented from Wilcoxon signed-rank tests of differences. The tests compare recognition responses between attributes that were actually manipulated and placebic attributes that were not manipulated. Positive and significant Z-statistics indicate significantly higher recognition of the manipulated attributes over the placebos.

***p<0.001; **p<0.01; *p<0.05 (two-tailed tests)

3. Characterizing engineering work in a changing world: Synthesis of a typology for engineering graduates' occupational outcomes

3.1 Introduction and background

The 21st century has brought an expansion in the variety of occupational roles associated with product, service, and technological development. As a result, it has become more challenging to assess the occupational choices of engineering graduates over time. This paper introduces an engineering graduates' occupational outcomes typology designed to facilitate consistency among researchers who employ occupational outcome as a dependent variable in original research examining engineering graduates' occupational outcomes. The typology is synthesized from the results of a systematic literature review aimed at establishing which work attribute(s) have most consistently united those practicing engineering. Based on the review, we present a series of propositions that underpin general definitions of three types of occupational outcomes – engineering work, engineering-related work, and other work. These definitions serve as the foundation for the typology's categorization of occupations' engineering-relatedness. We conclude by discussing how utilization of this new approach for categorizing engineering graduates' occupational outcomes can enhance transparency and consistency among studies that examine such outcomes. By building the typology upon fundamental job responsibilities, rather than upon job titles, it is our hope that the typology can serve in a meaningful, enduring occupational benchmarking capacity as new job titles, role formulations, or entire technology areas, come and go.

3.1.1 Engineering work – The case for a unifying framework

At a time when engineering educators strive to align student aspirations with engineering careers, we notice a concurrent call to clarify what working as an engineer really means in the 21st

century. Achieving this alignment is challenging, if not intractable, if we lack an accurate means for measuring and describing what students do after graduation. Educators and policymakers who envision an enhanced engineering educational system – one aimed at diversifying the engineering workforce and assuring student preparedness – depend upon a feedback loop that informs about graduates' occupational outcomes.

Yet, measuring these occupational outcomes and their congruence with familiar engineering roles has become increasingly difficult. The turn of the 21st century brought an expansion in the breadth of role types embedded in the product, service, and technological development workforces – an effect dubbed "the rise of the project workforce" (Melik, 2007), which manifests as substantial variation on project and product analytical, coordinative, and customer-liaison-type roles (see: Hong et al., 2005, Van de Weerd et al., 2006; Van der Linden et al., 2007; Rauniar et al., 2008; Salzman & Lynn, 2010; PMI, 2013). These often cross-disciplinary jobs blur the boundaries of engineering and strain our existing ability to measure engineering occupational participation (see: DiVincenzo, 2006, as an example of categorization challenge). Existing measurement systems range from the U.S. Bureau of Labor Statistics' *Occupational Employment Statistics* program (U.S. BLS, 2016), to the National Science Foundation's *Characteristics of Recent Science and Engineering Graduates* program (U.S. NSF, 2016), to individual universities' alumni surveys.

Changes in the occupational landscape have compounded society's already-fragile understanding of engineering work at the turn of this century, prompting top leaders in engineering education to call for renewed clarification. Former National Academy of Engineering president Charles Vest (2011) concluded: "engineering as a profession has done a poor job of communicating what engineers really do" (p. 8) and "years of effort to create an accurate, compelling image of engineering have fallen far short of that goal" (p. 9). A branding expert called on by the NAE to study

the matter referred to engineering work as "decentralized," adding that: "engineers themselves do not always agree on what engineering is" (Baranowski, 2011, p. 15). Current NAE president C. Dan Mote (2015) recently listed building a public understanding of engineering as one of the top strategic goals of the Academy.

While this "decentralization" is, on the one hand, a testament to the profound reach engineering has had across industries and organizations, it has also produced a vexing challenge: engineering roles have become more difficult to pinpoint and, thus, graduates' participation and engagement more difficult to measure. Historians and education researchers who have studied the unfolding of our present state have been bold in asserting: "engineering is undergoing…[an] expansive disintegration" (Williams, 2002, p. 30); or in asking: "are engineers losing control over technology?" (Downey, 2005, p. 584); or in simply questioning whether engineers suffer reduced visibility amidst an increasingly complex network of workplace roles (Newberry, 2009).

This study inquires into the most fundamental core of engineering work by identifying unifying attribute(s) that have endured as consistent markers of engineering. We then examine how this core of engineering work is nested within the network of related roles in today's product, service, and technological development workforces. These results allow for synthesis of an objective and communicable scale of occupations' engineering relatedness that is meaningful to students, educators, and researchers alike. We are cautiously aware of categorization challenges posed by engineering's continued evolution – Williams (2002), for instance, warns that engineering's expansion away from well-defined profession and toward a "hybrid" identity makes attempts to bound engineering futile, given that "[engineering] is most dynamic at its peripheries, where it is most engaged with science and with the marketplace" (p. 80). Consequently, this study seeks not to bound the extremities of

engineering. It instead identifies engineering's simplest enduring center while allowing for the continued outgrowth of modern occupations.

We conceive of an occupational outcomes typology for engineering graduates that avoids imposing value judgment on any of graduates' wide-ranging job choices. Rather, the typology is a tool for standardizing feedback for education programs working to increase diversity and engagement in engineering, and for those aiming to assess alignment of the curriculum with graduates' changing occupational outcomes. Educators, we presume, are concerned with whether students' professional interest in engineering is waxing or waning, or, if curricula are sliding further into or out of alignment with graduates' realized occupational trajectories. Capturing these trends demands a means of consistent measurement. This consistency would also enable more meaningful comparison across future published engineering education research that examines occupational outcome. If there exists a core to engineering work, such a typology will help researchers elucidate whether graduates are gravitating toward or away from it.

3.1.2 A history of engineering identity crises

Our present period is by no means the first characterized by an identity crisis in engineering. In the U.S., engineering's modern era spans from the humble beginnings of a niche occupation – one with fewer than 1,000 practitioners by the midpoint of the 19th century (Sobek, 2001) – through the birth of engineering professional societies in the late 19th century (Grayson, 1980), through the infusion of "engineering science" into the engineering curriculum in the early-to-mid-20th century (Grayson, 1980; Seely, 1999; Downey, 2005; Crawley et al., 2014), to the 20th and 21st centuries' rises of high tech, the internet, and globalization. Throughout this complex history, scholars have observed waves of "identity politics" at play as engineers grappled with how to define their field (Downey and Lucena, 2004). When craft practitioners banded together to form engineering's primary professional

societies between 1852 and 1908 in the U.S., they worked to standardize arcane knowledge and fought to establish credentialed privilege. These efforts marked the first serious attempts toward forging a stable engineering professional identity (Layton, 1971; Grayson, 1980; Meiksins, 1988). Yet, such formal efforts at professionalization were also spurred by serious safety, quality, and ethical concerns associated with rapid technological evolution. The American Society of Mechanical Engineers, for example, traces its coming of age to the aftermath of a major boiler explosion (ASME, 2016a). The historic shaping of engineering identity has included a complex blend of both strategic and reactive elements.

Historians describe a pronounced push toward formal professionalization in the late 19th and early 20th centuries, perhaps peaking during the period Layton famously called "the revolt of the engineers" in reference to the years surrounding World War I (Layton, 1971). Many consider this era a pinnacle of professional strength and solidarity among engineers, after which dispersion and decentralization of professional identity have continued to this day (Layton, 1971; Meiksins, 1988; Seely, 1995). As Seely (1995) explains, "engineers…had been determined to achieve the recognition, prestige, and professional status that society accorded to law, medicine, and other professions." And, while the details surrounding the actual strength and potential of this "revolt" have been debated (see: Meiksins, 1988), evidence points toward corporatization of engineering careers as a key factor in the movement's dissolution: many top engineers were happy with the prospects of being promoted out of engineering roles, perhaps as far as into the executive ranks of their companies (Layton, 1971; Meiksins, 1988). Though the dissent dissipated, one can argue that engineers achieved the path to prestige they sought – it so happened that this path led outboard of the then-ostensible professional bounds of engineering.

The time period surrounding World War II and the dawn of the Cold War prompted engineers, again, to advocate for professional recognition reflective of the unique value they felt they provided to

society as designers and problem solvers – especially in light of the attention and credit granted to scientists for wartime accomplishments (Seely, 1995). Kemper (1967) summarizes a telling perspective: "Every rocket firing that is successful is hailed as a scientific achievement; every one that isn't is regarded as an engineering failure" (p. 84). The "physics envy" (Seely, 1995, p. 747) that followed the Second World War corresponded with a shift toward endorsing engineering science as a backbone of engineering education (Grayson, 1980; Seely, 1995, 1999, & 2005; Crawley et al., 2014). Leaders among engineers began embracing undergraduate curricular reforms that introduced more science among required subjects – a move they thought would prove legitimizing for the profession, yet one that may have gone too far, weakening the connection between practitioners and the educational system (Seely, 2005).

A less unified practitioner base eventually paralleled an expansion in scope and variety of engineering work, which proceeded to branch and morph throughout the remainder of the 20th century (Williams, 2002; Downey, 2005). On the one hand, the general public began to confuse scientists and engineers (Bush, 1965; Petroski, 2010; Vest, 2011), while on the other hand, previously unforeseen engineering-marketing and engineering-business hybrid roles began to emerge, as well as roles uniquely tuned to computing and software realms (Sheard, 1996; Van de Weerd et al., 2006; Rauniar et al., 2008). Some may consider this evolutionary flexibility a boon to our era's blossoming product development activity; others may feel unease about dilution of professional integrity in engineering (see: Cunningham et al., 2013). Either way, we have witnessed the bounds of engineering work strained in at least two dimensions: first, in the diversity of capabilities called upon across varied roles (Williams, 2002; Downey, 2005), and second, in the emergence of natural career role progressions tending toward a variety of managerial roles following individual contributor roles (Bailyn & Lynch, 1983; Rynes et al., 1988; Biddle & Roberts, 1994). Engineers also began embracing hybrid technical-project coordinator roles as long-term career identities, solidifying an alternate perspective to an

engineering-management dialectic (Watson & Meiksins, 1991; Allen & Katz, 1995). Generally speaking, we now observe diverse expectations about roles befitting engineers in industry and about the range of experiences soon-to-be engineering graduates can aspire toward in their careers.

Yet, throughout the dramatic broadening of society's conception of "engineering," the original professional societies have endured with consistent missions (e.g., ASCE, ASME, AIChE, IEEE, and others), professional engineering licensure remains a requisite credential in certain areas of practice, and engineering honor societies espousing century-old values continue to have a presence in the engineering educational and professional scenes (see: Seely, 2005; AIChE, 2016; ASCE, 2016; ASME, 2016b; IEEE, 2016; NPSE, 2016; TBP, 2016). Scholars of engineering practice point out that social and coordinative processes are intrinsic to carrying out engineering design and should be embraced, not solely as evidence of novel role formulations, but as endemic to the practice of engineering itself (Bucciarelli, 2002; Trevelyan, 2007). Where some historians see evidence of disintegration, others sense an impetus to identify binding ties and to construct a robust 21st century engineering identity. Many engineering educators, policymakers, and researchers, for example, have responded to this impetus through initiatives that affirm key attributes of 21st century engineers and refine engineering curricula and pedagogy for a new era (for example: NAE, 2004 and 2005; Sheppard et al., 2009; Atman et al., 2010; NSB, 2010; Crawley, 2014; ASEE, 2016). We do not diminish or reinvent such valuable work; rather, we limit our scope to the development and presentation of a succinct career paths typology to provide a dependent variable for studies of engineering graduates' occupational outcomes.

3.1.3 Reconciling key competing perspectives

Prominent engineers and educators have offered no shortage of general occupational descriptions over the past century: "scientists study the world as it is; engineers create the world that never has been" (Von Kármán, as quoted in: U.S. NSF, 2012); "engineering is the creative application

of scientific principles used to plan, build, direct, guide, manage, or work on systems to maintain and improve our daily lives" (National Society of Professional Engineers, 2006); "engineers create products and processes...to enhance...our everyday lives" (Martin & Schinzinger, 2005). These generalizations have served the noble purposes of inspiring individuals to pursue engineering and of boosting public support, but they offer little assistance in discerning engineering work among contemporary job listings.

An attempt to distill a most basic unifying criterion of the engineering workforce – a rudimentary threshold of commonality among those practicing engineering – quickly reveals incongruence between two prominent camps in the literature. Specifically, sociologists and the scholars of engineering ethics offer differing conclusions on whether engineering is in fact distinctly identifiable as a profession. Bailyn and Lynch (1983, citing Kerr et al., 1977, and Child & Fulk, 1982) summarize a sociological perspective: "engineering, even though it is based on technical expertise, [is not] a profession. It is subject to organizational rather than occupational control" (p. 264). Meiksins (1988) adds: "what was missing...was any serious commitment to the idea of the engineering profession as a whole as an independent, organized force." (p. 224). Goldner and Ritti (1967) suggest that engineers have eschewed a united professional identity in exchange for greater career mobility. Bailyn and Lynch (1983, citing Ritti, 1971, and Bailyn, 1980) add: "practitioners have been shown, as a group, to subscribe more to organizational than professional values" (p. 264). Williams (2002) offers an even broader view: "Engineering has evolved into an open-ended Profession of Everything...with no strong institutions to define an overarching mission" (p. 70). This scholarly community asserts that, following shared engineering educational experiences, many engineers subsequently relinquish control of career specifics to corporate entities whom, in turn, adjust the definition of engineering work as needed to fit their operational contexts. Today we thus see a

perpetual outgrowth of diverse job titles, hybrid roles, and role progressions that strain the concept of engineering as a distinct and unified work activity.

Before discussing how the social scientists' and engineering ethicists' arguments differ, it is first worth noting the common practice, if not near-universality, that engineering ethics textbooks include a decomposition of factors supporting (and challenging) engineering's status as a cohesive profession (see: Fleddermann, 2004; Martin & Schinzinger, 2005; Whitbeck, 2011; Harris et al., 2013). Such analysis in this area of the literature is expected for two reasons. First, applied ethics texts conventionally describe a "professional ethics" lens, which differentiates the unique ethical obligations of certain sets of practitioners from those obligations of all humans (e.g., "general morality"); thus, it follows that these texts also conventionally analyze the parameters unifying their subject set of practitioners (see: Wueste, 1994; Robinson, et. al, 2007; Harris et al., 2013). Second, a part of the EC2000 revision of the ABET engineering accreditation criteria, Outcome (k), "an understanding of professional and ethical responsibility," is prescribed as a general component of engineering education in the U.S. and in other locales recognizing this governance (ABET, 2015). Assuming that many engineering ethics texts aspire to be part of accredited curricula, it is unsurprising that these texts address the issue of professional definition and associated responsibilities. What is of chief interest, more so than conclusions about engineering's status as a profession, are commonalities in these scholars' rationales for the existence of engineers' shared professional bonds – and, in particular, whether key components of these rationales are supported in the separate literatures describing engineering practice. The latter question is explored in detail in the literature review in Part 2 of this paper.

To understand scholarly disciplines' differing perspectives on engineering's status as a distinct profession, it is necessary to consider definitions posited for what constitutes a profession. At least

three defining criteria for professions emerge in similar forms across popular ethics texts: 1) requisite advanced skills and knowledge, 2) self-regulation (e.g., the profession dictates its own standards for membership and operation), and, 3) an embrace of duty toward public good (see: Fledderman, 2004; Martin & Schinzinger, 2005; Whitbeck, 2011). As Didier (2010) points out, professional definitions can vary globally. And as Davis (1997) discusses, social scientists, compared to engineering ethicists, tend to focus more heavily on membership and self-regulation criteria of such definitions; this conclusion is consistent with Meiksins' and Smith's (1993) review of social scientists' definitions-in-use , and with the observation that some engineering ethics texts soften or leave out the self-regulation criterion (Baura, 2006; Harris et al., 2013). Davis (1997), alternatively, presents a case for an engineering professional definition primarily rooted in members' commitment to serve a specific moral ideal. These differing foci of professional definitions – those focusing on a commitment to serve a particular moral function versus those rooted in self-regulation – help explain key differences in scholars' conclusions about engineers' professional unity.

While the set of constituent factors governing professions' bounds may not be universally agreed upon, our review nonetheless reveals instances of relatively wide support for certain sub-factors' salience as indicators of cohesion among engineers. Such support does not prove anything by itself, but it can, if corroborated via a broad, systematic review of the engineering practice literature, help us build reasonable propositions about definitions of engineering work. One such example, related to the *public duty* professional dimension, is seen reiterated across engineering ethicists' accounts: that an engineer holds *responsibility* for the safety, quality, and efficacy of the products (or processes, services, or systems) he or she designs and implements (Fleddermann, 2004; Martin & Schinzinger, 2005; Whitbeck, 2011; Harris et al., 2013). These scholars purport that the consequence of a given product's design falls within the responsibility bestowed upon individuals working in the role of engineer.

We call attention to this *design responsibility* aspect of the ethicists' analysis for several reasons. First, it stands out as a factor that social scientists do not appear to refute in their accounts of engineers' roles or in their critiques of engineering professional status. Second, it is a potential node of cohesion at the center of what it means to be an engineer. And third, it is an attribute that may manifest explicitly in engineers' job roles (e.g., it has the potential to be connected to visible, measurable activities of jobs). Meanwhile, social scientists and engineering ethicists also appear to generally agree about *specialized knowledge or skill* dimensions of engineering. Social scientists, however, explicitly reject the *professional self-regulation* criterion – in fact, engineers' cession of job, career, and career path definitions to organizational or market control is the primary basis of their denial of professional unity of engineering (e.g., Layton, 1971; Bailyn & Lynch, 1983; Meiksins, 1988; Williams, 2002).

It is not the goal of this paper to demonstrate whether engineering is a profession – as Van de Poel (2010) discusses, such determination may be close to impossible. It is, however, our goal to discern engineering's most-recognized center of gravity, so as to establish an occupational relatedness scale grounded upon such. Our analysis begins with a review of the published analyses and critiques of engineering's professional cohesion in order to uncover pertinent relational factors among engineers; then, having recognized *design responsibility* as a unifying characteristic prevalently supported by the literature, our analysis proceeds to review the engineering practice literature with an aim to identify whether, and in what manner, ostensible markers of this attribute may exist prevalently in practice contexts. Finally, we review occupational data to assist with contextualizing core and related roles in order to build out the typology.

3.1.4 Why Refine the categorization approach? The pragmatic challenges of categorization

Recent decades' proliferation of new job roles and titles has had an unfortunate, and presumably unintended, side effect: decreasing the transparency and precision of legacy workforce

statistics and participation tracking systems. In the case of the U.S. Bureau of Labor Statistics' *Occupational Employment Statistics*, the system attempts to account for every working individual in the U.S. by means of establishing a standardized list of occupations (e.g., the *Standard Occupation Classification (SOC) codes*), by surveying a subset of employers about their workforces, and by extrapolating to (theoretically) categorize every working American into one of 840 occupation codes in order to construct a proportionally-accurate workforce cross-section. The SOC list is updated relatively infrequently, at approximately 8-year intervals. The BLS openly acknowledges that the 840 job codes are far too sparse to cover most individuals' exact job titles – particularly those in hybrid roles – yet because of the organization's imperative to provide proportionally accurate workforce descriptions, it is essential that they do not double-count the same individual in multiple job categories (U.S. BLS, 2010). Other nations' labor statistics bureaus likely face a similar dilemma. This single-counting imperative manifests in the BLS's avoidance of cross disciplinary and hybrid-type job categories among the SOCs, which directly challenges our ability to understand the number of individuals who work in these types of roles. While it is simple enough to count workers with the word "engineer" in their title, as a BLS Labor Economist explains, individuals in roles such as "project manager" are not as easily categorized. No such SOC currently exists for project managers, so they must be counted elsewhere – distributed into categories that more neatly fit under specific disciplines, such as in construction management or information systems management (DiVincenzo, 2006). Thus, this system neither informs us of how many project managers there are, nor does it provide consensus on how many among them should be considered as working in roles close to or encompassing "engineering." The U.S. BLS is not the only organization that attempts to account for the number of working engineers – the U.S. Census Bureau attempts to do so (U.S. Census Bureau, 2014), as does the National Science Foundation's Center for Science and Engineering Statistics'

Characteristics of Recent Graduates program (U.S. NSF, 2016) – but a review of each of those organizations' results suggests the presence of similar issues related to generalization of roles.

This categorical imprecision impairs educators' and education policymakers' abilities to understand attrition and career engagement among engineering graduates. For example, a recent U.S. Census report indicates that approximately 50% of engineering graduates, averaged across all ages, now work outside of "engineering" or "STEM," but it is unclear where these individuals actually work – especially given that over one third of those who've ostensibly left engineering are categorized in the report as "Managers, non-STEM" (U.S. Census Bureau, 2014). Similarly, data released by the U.S. Department of Commerce concludes that the U.S. has accumulated a pool of 2 million working-age degreed engineers currently engaged in "Non-STEM Employment" (Langdon et al., 2011). Could a substantial portion of these roles in fact be engineering-related hybrid roles that are labeled as "non-STEM"? Lowell et al. (2009) discuss that it is likely that categorical obfuscation occurs throughout workforce statistics pertaining to engineering graduates.

Government agencies understand these categorization challenges and are working to reduce the vagueness of legacy methods – yet as hybrid roles continue to proliferate, this will be an ongoing, perhaps endless, uphill battle. The U.S. Department of Labor recently sponsored the development of a large, detailed occupations database (e.g., *Occupational Information Network*, or, *O*Net*) that provides descriptive details on over a thousand job titles (Peterson et al., 2001). Similarly, the Bureau of Labor Statistics periodically issues a job title-mapping file that links over 6,000 job titles to their closest match from among the 840 standard SOC titles (U.S. BLS, 2013). These helpful tools add clarity, yet are not linked to occupational participation statistics. In other words: *O*Net* may provide detailed descriptions of "sustainability specialists," "systems analysts," or "information technology

project managers" (O*Net, 2017), but we have little consensus on the engineering-relatedness of these roles, nor do we know how many engineering graduates land at them.

We hereafter propose a categorization approach designed expressly for those conducting original research tied to occupational outcomes of engineering graduates. The approach centers on discerning occupational roles' association with engineering's widely acknowledged core – what we recognize as design responsibility – not by means of job title, but by intrinsic work attributes.

3.1.5 The purpose and criteria of a new occupational outcomes typology

The exploration of connections between educational and social factors and engineering students' career outcomes constitutes a vibrant research area in our present time. In engineering education, various recent studies, both qualitative and quantitative, have related educational experiences, curricular reforms, and pedagogical innovations to student occupational aspirations or occupational outcomes (for example: Chubin et al., 2005; Lichtenstein et al., 2009; Lord et al., 2009; Atman et al., 2010; Eris et al., 2010; Dasgupta et al., 2015; Godwin et al., 2016). Similarly, in sociological and inter-disciplinary work, researchers have explored the salience of diverse factors in predicting students' and graduates' persistence in engineering occupations (for example: Correll, 2004; Cech et al., 2011; Herman, 2015; Hunt, 2016; Seron et al., 2016). All such studies, which contribute toward the important goals of increasing women's and minorities' representation in engineering jobs and to boosting overall interest in engineering careers, require researchers to choose a means of conceptualizing and measuring what counts as engineering work. Occupational outcome is often the dependent variable of interest in these works, yet researchers' ability to conceptualize and measure it in a manner consistent with the rest of the research community can be challenging in the absence of either a unifying framework or gold-standard governmental database.

Summary of design criteria

With this research community's needs in mind, and in consideration of the complex historic factors that have shaped engineering professional identity, we employ the following criteria to guide the construction of a typology aimed at categorizing engineering graduates' occupational outcomes in meaningful relation to discerned core attributes of engineering work:

- The typology shall provide a means of categorizing occupations being pursued or obtained by engineering students and graduates in terms of the occupations' engineering-relatedness.
- The typology shall be an occupational role-based (rather than professional membership-based) categorization system; the typology shall not attempt to designate engineering professional status.
- The typology shall accommodate a temporal dimension – it shall be robust to the changing nature of what engineering work may mean over the life of a working individual. For example, it shall provide a means of measuring engineering-relatedness of occupations held at various points in graduates' lives, encompassing entry-level roles and advanced career roles.
- Engineering-relatedness of occupations need not be forced into binary categorical designation (e.g., "engineering" vs. "non-engineering"). Therefore, more than two engineering-relatedness strata may compose the typology.
- Categorical label assignment shall avoid implicit or explicit value judgment of occupations (e.g. language employed in labels shall not imply one occupation group is more important than others).

Concept of use

We focus on original research as the use case for this typology. For reasons discussed, competing methodological constraints currently prevent existing occupational categorization schemes from achieving greater accuracy and precision in their discernment of careers' engineering-relatedness (e.g., the U.S. BLS's single-counting imperative). The typology is envisioned as a tool for engineering education researchers (and others) engaged in such efforts as longitudinal studies, tests of interventions, or alumni or workforce surveys. When researchers have their own opportunity to query individual respondents about details of their occupations (or aspired-to occupations), this typology can

assist in gauging engineering-relatedness. In particular: for studies employing occupational outcome as dependent variable, this typology aims to help facilitate consistent definition of the variable.

3.2 Systematic exploration: Discerning the core and extended network of engineering work in the 21st century

3.2.1 Overview of sequential literature review approach

We employed a series of nested systematic literature reviews to discern unifying attributes of engineering work and, subsequently, to situate such work among the broader set of documented present-day employment contexts. Content analysis from initial review rounds informed search terms for later reviews in order to complete a four-part serial thread of inquiry: (1) *what attribute(s)* are most consistently discussed in the literature as unifiers of work characterized as "engineering"? (2) *What job functions* are involved in carrying out these unifying attribute(s) of work? (3) *What specific types of activities* compose these engineering job functions? And finally, (4) *what occupations* involve similar or related activities to various extents? In sum: we aimed to establish a basic, conventionally-recognized core of engineering work expressed in terms of specific observable role markers, the presence (or lack of presence) of which could meaningfully categorize real-world jobs. Once established, this engineering core (and other roles' comparison to such) informed the construction of the engineering graduates' career outcomes typology (see: *Part 3: Typology Synthesis and Discussion*).

Methods employed for each round of systematic literature search and results qualification were informed by documented best practices summarized by Borrego et al. (2014, 2015) and Petticrew and Roberts (2006). The section that follows discusses our application of these methods to each round of search and literature review. Though differing sets of search terms and logic were established for each round, all rounds followed similar guidelines for repeatability and reliability, as outlined by Borrego et al. (2014): construction of clear research questions and scope, definition of

specific result inclusion criteria, identification of specific databases upon which to conduct the searches, establishment of critique and appraisal criteria (e.g., to qualify results), establishment of a means of results synthesis, and identification of limitations, validity, or reliability concerns of the search method.

Searches 1 through 3 considered sources from academic journal articles, as well as books, identified through two search portals. The first portal was an EBSCO Host-powered meta-search engine configured to simultaneously search a broad set of leading databases, including *Education Source*, *Academic Search Complete*, *Business Source Complete*, *ERIC*, *PsycARTICLES*, and the e-journal sets from several major publishers (Elsevier/Science Direct, Wiley, Springer, Taylor and Francis, and Sage). EBSCO Host provides a complete list of databases included in the search portal that we utilized (see: EBSCO Host, 2016). A second portal, WorldCat, was utilized specifically for book searches, allowing for broad search through the catalogs of over 10,000 worldwide libraries (WorldCat, 2016). Between the EBSCO Host and WorldCat portals, a deliberately broad search capability was established to accommodate the likelihood that pertinent results would be found in databases across disciplines, such as sociology, history, business/management, education, and engineering. We did not limit the country of origin of the results. While such a broad search naturally produces large initial results lists requiring substantial further processing, we believe such a search was necessary due to the cross-disciplinary nature of this topic. Search 4, on the other hand, was conducted specifically within the U.S. Department of Labor-sponsored *Occupational Information Network (O*Net)* database in order to access its refined and consistently formatted catalog of detailed occupation descriptions (Peterson et al., 2001).

Following acquisition of raw search results for each search, we next conducted manual qualification review and filtering based upon specific sets of inclusion criteria established for each round of search (see: Petticrew & Roberts, 2006). As part of the manual review, we introduced a small

number of titles (e.g., less than 5% of the result count) from among our awareness into the results lists that did not turn up by automated search. No titles were added that did not fully comply with the search logic. Any added titles were either 15 years old or older, or came from chapters or proceedings embedded within larger works – in such instances, incomplete source indexing and/or limited digitization are probable causes for these sources' failure to be retrieved automatically. For each of Searches 1 – 3, the manual processes of result qualification were accomplished in multiple passes through the documents sets that were initially identified via systematized search. The first-pass review was based on within-document key word searches, as well as reviews of document abstracts and tables of contents to ascertain topic areas. Any source that did not explicitly violate qualification criteria was retained for a second-pass analysis. The second-pass review entailed ascertaining context in which key words were used from body text review – for example, was the keyword used as part of a critique or discussion related to the specific search question, or was it merely used as a common noun casually in a discussion about something else? Sources that passed both the first- and second-pass manual qualification reviews were retained for the purposes of in-depth content analysis, while summary lists of excluded source topics were recorded.

Once qualified search results sets were established, content analysis methods, as presented by Krippendorff (2004), were employed to draw summative themes from content clusters identified from each of the results sets. Content analysis was carried out uniquely for each of Searches 1, 2, 3 and 4; the specific content analysis methods and results associated with each round of search and review are discussed in detail in the following section.

3.2.2 Search-specific questions, methods, and literature review results

Figure 3-1 illustrates the overall flow of the sequential literature review process, indicating how outcomes from preceding search rounds informed the search criteria employed in subsequent searches.

In keeping with the sequential flow of our investigation, we present the results from each search round immediately following the description of its methods. Thus, for each round, we describe its specific search question, means of search systemization and qualification, content analysis method, and results synthesis.

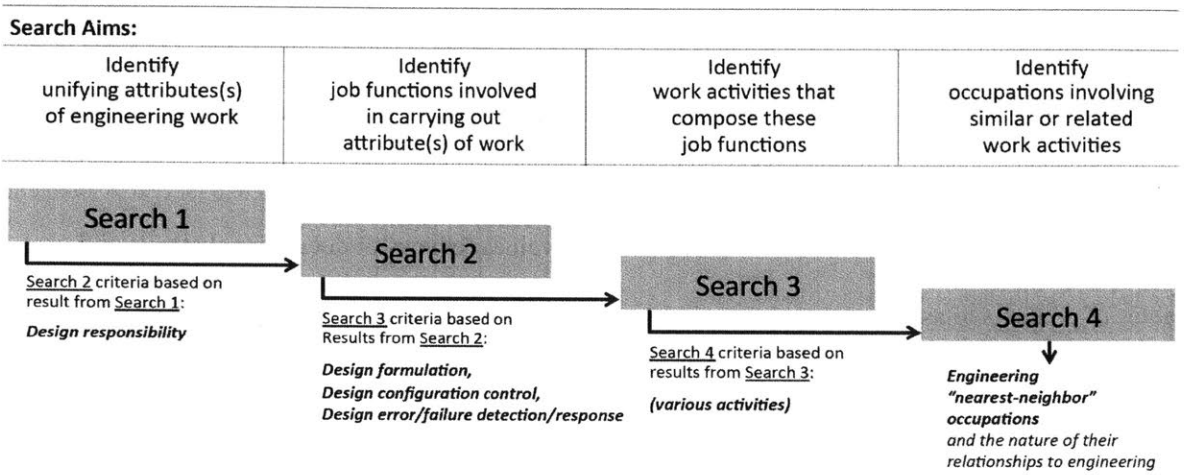


Figure 3-1. Sequential nature of searches employed in systematic literature review

Search 1 – Identifying unifying attribute(s) of engineering work

> **Search question:** *Among literature that analyzes engineering's status as a distinct profession, what attributes(s) are discussed as unifiers of work characterized as "engineering" (or, if applicable, are discussed as evidencing dis-unity of "engineering")?*

In Search 1 we elected to search the wide date range from 1966 – 2016 in order to trace the historic critique of the professional unity of engineers. Within that date range, we ran 5 sub-rounds of search with unique criteria designed to cover a wide range of topic areas within which scholars may have explored the questions of whether and how engineering is unified as a profession. Aware of the differences between engineering ethicists' and social scientists' published conclusions about this question, we designed the sub-rounds of Search 1 to ensure coverage, at a minimum, of both of those areas. Each sub-round of Search 1 featured specific subject terms, text terms, and Boolean

combinatory logic as summarized in Table 3-1. Qualification review of the Search 1 raw results sought to verify that sources specifically commented on the professional status of engineering, and that they provided discussion or analysis on factors uniting (or straining the unification of) engineers. A total of 144 sources were retained for inclusion in the qualified results set. The qualification criteria employed and the resultant topic areas of excluded sources are also summarized in Table 3-1.

Content analysis of Search 1 results began with high-level source topic area binning to categorize the unique areas of scholarship from which each of these sources were drawn. Based on a review of the indexed subject terms associated with the articles and books, we established 6 broad topic bins as follows: (1) historical reviews of engineering practice and the educational system, (2) analyses of organizational aspects of engineering work and careers, (3) literature on gender and engineering professional identity, (4) analyses of the development of engineering norms and standards, (5) discussion on societal and occupational expectations of engineers, and (6) engineering ethics textbooks. We allowed for sources to be binned into multiple topic areas. We then proceeded with clustering analysis to discern key themes supported by groups of sources within each of the bins (Krippendorf, 2004). This analysis first entailed a review of the body texts of each source to identify substantiating argument(s) made within the texts in support of or against the case of professional unity among engineers. Once each source had been reviewed and its specific critique of professional unity identified, cluster statements were generated that encompassed the arguments of related or complimentary sources. We first identified the clusters pertaining to support for unity among engineers; we next discerned clusters suggesting dis-unity among engineers. Table 3-2 summarizes the content analysis for the Search 1 results – in order to present these findings compactly, we have arranged the results in groups so that "unifying" and "dis-unifying" thematic conclusions could be presented side-by-side when possible.

Table 3-1. Criteria and results count for Search 1 – Sources analyzing engineering's status as a distinct profession

	Sub-rounds of Search				
	1	**2**	**3**	**4**	**5**
Subject Search Terms	engineer* OR technolog*	engineer*	engineer* OR technolog*	engineer*	engineer*, ethics
Text Search Terms (all terms required)	engineer*, profession, work, occupation, career, organization	engineer*, profession, history, ideology	engineer*, profession, history, change	engineer*, profession, history, "engineering education"	engineer*, ethics
Excluded Subject Terms	"K-12", counseling, immigration, "high school", legal, marketing, operations, parent*				
Media	<----- academic journal articles and books ----->				
Date Range	1966 - 2016				
Raw Result Count	367	167	316	347	426
Qualification:					
Inclusion Criteria	<--- Source must specifically comment on the professional status of engineering Source must provide discussion or analysis on what unites (or strains the unification of) engineers --->				
Excluded Topics	curriculum, graduate student issues, job counseling, job search, pedagogy, STEM policy, specific engineering design issues, faculty	design ideology, early education, faculty, specific engineering design issues	curriculum, design ideology, early education, faculty, history of specific products or technologies, pedagogy, science-specific issues, specific engineering design issues	curriculum, engineers' salaries and job markets, faculty, job counseling, job search, life-long learning, offshoring, pedagogy, STEM policy, graduate student issues	ethics learning activities, pedagogy, ethics in experiments, ethics of communication, ethics of specific sub-disciplines, ethics of war, nation or culture-specific discussions, specific ethics case studies, student assessment in ethics, theology, ethics workshops
Qualifying Result Count	29	15	10	24	38

Table 3-2 thus reveals a collection of discussions substantiating or contesting engineering's professional cohesion. While the underlying attributes of engineering work that these arguments cite vary across the six source categories, one substantiating attribute uniquely stands out as both being discussed recurrently and being met with scant contestation among the overall literature set. Specifically, engineers' *design responsibility* – their responsibility for the outcomes of design implementation, inclusive of safety, ethicality, and general effectiveness of designs – emerges as a fundamental characteristic of engineering occupational identity. It is important to note that the literature review methods employed herein cannot prove there is *no* counterargument to this assertion – only that there does not appear to be a substantial or cogent one among the sources identified in our search. As such, we do not seek to *prove* what unifies engineers, but rather, to recognize conventionality and prevalence of a means for unifying engineering work based on the literature. Example statements from among sources in Table 3-2 illustrate this theme of design responsibility:

- "Responsible engineers are expected to foresee…consequences [of design decisions]" (Whitbeck, 2011, p. 178).
- "…when something goes wrong on an engineering project, the responsibility falls heavily on engineers" (Basart & Serra, 2013, p. 181).
- "Engineers can expect to be held accountable, if not legally liable…for caused harms" (Harris et al., 2013, p. 50).
- "Attention to detail is a watchword of the engineering profession" (Dias, 2014, p. 545)
- "The engineer thus assumes a responsibility to determine which dangers are pertinent to each [design]…to decide how to best deal with them…" (Schmidt, 2014, p. 998)

Other key attributes involved in the discussion about engineering cohesion include: specialized knowledge or skill, established standards, common educational experiences, and

conventional work artifacts or protocols – none, however, are as straightforward and uncontested as the notion of design responsibility. We proceed assuming that design responsibility is a recognized hallmark of what it means to belong to an engineering occupation, though we do not contend it is the sole factor uniting engineering practitioners. We do, however, make the assumption that it is a widely acknowledged "necessary condition" of engineering work, and can thus reasonably serve as a central identifier of engineering practice for the purposes of anchoring an occupational outcomes typology.

Table 3-2. Results from Search 1 – Attributes that unify and dis-unify engineering professionals

Source Topic Area	Supporting Sources	What attributes of engineering are discussed as unifying or dis-unifying it as a profession?	
		Unifying	Dis-unifying
Historical reviews of engineering practice and the education system	Layton (1971); Noble (1977); Meiksins (1988); Reynolds (1991); Meiksins and Smith (1993); Kemper and Sanders (2001); Lawson (2002); Pursell (2006); Auyang (2004); Kline (2008); Jones (2011); Verin and Gouzevich (2011); Diogo and de Matos (2012)	- Formalization of craft practices into codified practices - Campaigns for professional unity - Broad societal need for services	- Lack of consensus understanding of engineering work in society - Lack of universal recognition of professional bounds by society, employers, and practitioners - Societal confusion about roles of scientists versus engineers
	Ferrall (1995); Thom (1998); Williams (2002); Downey and Lucena (2004); Downey (2005); Sorensen (2009); Jamison (2013)		- Technological change prompting hybridization and reformulation of work - Dynamic expectations of engineers' duties or required skills
	Grayson (1980); NRC (1985); Dreicer (1995); Seely (1995); Vest (1995); Thom (1998); Seely (1999); Downey and Lucena (2004); NAE (2005); Lucena et al. (2008); Heywood (2009); Sheppard et al. (2009); Atman et al. (2010); Grasso and Burkins (2010); Jamison (2013); Crawley et al. (2014)	- Attempts to establish (national, global) standards and approaches for engineering education	- Ongoing discourse about the need for improved engineering curricular alignment (e.g., reconciliation of academia, practitioner, industry leader perspectives) - Ongoing debate about missing, over-, and under-represented curricular components
Analyses of organizational aspects of engineering work and careers (20th - 21st century)	Burke (1969); Meiksins and Watson (1989); Yip and Rowlinson (2009)	- Job and task standards in place (e.g., that engineers have bought into) - Acknowledged need to stay current with disciplinary, project, or product knowledge	- Job, role, task, and project definition sometimes formulated outside the control of engineers (e.g., such as project schedules)
	Ferrall (1995)	- Ostensible and structured role and responsibility designations among engineers	
	Ritti (1968); Perrucci and Gerstl (1969); Kerr et al. (1977); Child and Fulk (1982); Bailyn and Lynch (1983); Rynes et al. (1988); Bacharach et al. (1990); Reynolds (1991); Meiksins and Smith (1993); Igbaria et al., (1999); Holt (2001)	- Specialized knowledge and skill requirements tied to job roles	- Organizations, rather than a centralized engineering profession, define job details and expectations - Career advancement paths are often established by individual organizations rather than by an overarching profession
	Watson and Meiksins (1991); Perlow and Bailyn (1997); Newberry (2007)	- Specialized knowledge and skill requirements tied to job roles	- Engineers identify with their (varied) work or technology specialty itself, rather than with a unified professional identity
	Goldner and Ritti (1967)	- Specialized knowledge and skill requirements tied to job roles	- Engineers face career mobility incentive to avoid professional unification
Literature on gender and engineering professional identity (21st century)	Morgan (2000); Jorgenson (2002); Faulkner (2009); Cech et al. (2011); Ayre et al. (2013); Herman (2015); Cech (2015)	- Perceived need for entry/acceptance - Specific job expectations perceived as associated with engineering (e.g., level of commitment at job, capabilities required)	- Career identity as personally, rather than professionally, defined - Career identity as construed through a variety of positionings, rather than through a centralized profession

Table 3-2. Results from Search 1 – Attributes that unify and dis-unify engineering professionals [continued]

Source Topic Area	Supporting Sources	What attributes of engineering are discussed as unifying or dis-unifying it as a profession?	
		Unifying	Dis-unifying
Analyses of the development of engineering norms and standards	Gerstl and Hutton (1966); Noble (1977); Lawson (2002); Auyang (2004); Keltikangas and Martinsuo (2009); Gainsburg et al. (2010); Kedrowicz and Sullivan (2012)	- Responsibility for producing specific artifacts (e.g., technical drawings, software code) in accordance with standardized practices - Adherence to engineering design standards - Socialization of unique ways of thinking and communicating as engineers	
Discussion on societal and occupational expectations of engineers	Johnson (1991); Davis (2001); Herkert (2001); Kemper and Sanders (2001); Spier (2001); Martin (2002); Vesilind (2002); Antoniou et al. (2007); Frey and O'Neill-Carillo (2008); Downey et al. (2007); Harris (2008); Son (2008); Lucena and Schneider (2008); Stovall (2011); Diogo and de Matos (2012); Didier and Derouet (2013); Michelfelder and Jones (2013)	- Responsibilities to one's community, nation, and/or world for public safety, health, welfare, and the environment	- Sense of social obligation not consistent across all groups of engineers or time periods; not consistently integrated into engineering education
	Kemper and Sanders (2001); Auyang (2009); Trevelyan (2010); Dias (2014); Gainsburg et al. (2010); Schmidt (2014)	- Responsibility for documenting, communicating, and collaborating about designs and associated risks, issues, and concerns with stakeholders, other engineers, and/or adjacent functions	
	Lynch and Kline (2000); Kemper and Sanders (2001); Auyang (2009); Delahousse (2009); Basart and Serra (2013); Hayes (2015); Schmidt (2014); Lurie and Mark (2016)	- Responsibility for outcomes and consequences of design / development projects (e.g., accountability for failures of designs)	
	Kiepas (1997); Gotterbarn (1999); Kemper and Sanders (2001); Harris (2008); Dias (2014); Lurie and Mark (2016)	- Responsibility for (and attention to) minute details, and the associated risks and broader implications of such details	
	Gotterbarn (1999); Kemper and Sanders (2001); Martin (2002); Downey et al. (2007); Walesh (2012); Brauer (2013); Schmidt (2014); Michelfelder and Jones (2013); Schlossberger (2016)	- Formal codes of professional ethics published by engineering disciplines' societies	- Ethics codes may be incomplete, inconsistently revered, inconsistently integrated into engineering education

Table 3-2. Results from Search 1 – Attributes that unify and dis-unify engineering professionals [continued]

Source Topic Area	Supporting Sources	What attributes of engineering are discussed as unifying or dis-unifying it as a profession?	
		Unifying	Dis-unifying
Engineering ethics textbooks	Schlossberger (1993); Unger (1994); Beder (1998); Vesilind and Gunn (1998); Fleddermann (2004); Martin and Schinzinger (2005); Robinson et al. (2007)	- Professional societies are in place representing the major engineering sub-disciplines	- Professional societies are weaker than those of other established professions (e.g., medicine and law) - Incomplete adoption of licensing or society memberships among engineers - Societies' memberships not limited to specific job types or areas of practice
	Unger (1994); Pinkus et al. (1997); Vesilind and Gunn (1998); Armstrong et al. (1999); Humphreys (1999); Fleddermann (2004); Martin and Schinzinger (2005); Robinson et al. (2007); McCuen and Gilroy (2010); Whitbeck (2011); Bowen (2014); Catalano (2014); Harris et al. (2013)	- Areas of commonality across published codes of engineering ethics, such as: -- Acceptance of responsibility to protect safety, health, and welfare of the public -- Commitment to practice only in areas of competence; to defer to experts otherwise -- Commitment to honesty and objectivity in statements made to the public	
	Unger (1994); Pinkus et al. (1997); Beder (1998); Fleddermann (2004); Govindarajan et al. (2004); Martin and Schinzinger (2005); Baura (2006); Pfatteicher (2010); Whitbeck (2011); Harris et al. (2013)	- Responsibility for (and attention to) minute design details, and the associated risks and broader implications of such details (e.g., discussed as 'preventative ethics' in these texts)	

Search 2 – Identifying job functions involved in carrying out attribute(s) of engineering work

> **Search question:** *Among literature that discusses design responsibility of engineers, which of engineers' job functions does this literature identify as being involved in carrying out design responsibility?*

In basing the design of Search 2 upon the content analysis results from Search 1, we sought to discover evidence of *where* engineers' design responsibility manifests in practice (e.g., through which engineering job functions does this design responsibility manifest?). We narrowed the search date range to 1990 to 2016 to capture the discussion of engineering practice surrounding the turn of the 21st century. Within this date range, we ran two sub-rounds of search, as differentiated by the first's broad inquiry into literature describing the practice of engineering design and the second's focused inquiry into ethnographic accounts of engineering workplaces. Both sub-rounds of Search 2 featured specific subject terms, text terms, and Boolean combinatory logic as summarized in Table 3-3. Qualification review of the Search 2 raw results sought to verify that sources described engineers' job responsibilities and referenced real-world practice contexts. A total of 63 sources were retained in the qualified results set. Search 2's qualification criteria and the resultant topic areas of excluded sources are summarized in Table 3-3.

Search 2's content analysis was carried out to broadly identify areas where design responsibility appears in engineering practice – an approach designed to set the stage for the follow-on search's narrower focus on finding detailed examples of design responsibility (e.g., at the task or activity level) within these broadly defined areas. For each of the 63 qualified sources identified in Search 2, we searched the body text to locate the specific discussion about "design responsibility" within the source, and then identified the one or more general areas of engineering practice that the source referred to – we frame these general areas of practice as "job

functions" constituting engineering. At least six job function clusters related to design responsibility were discernable within the literature; however, as we show, three of these were cited substantially more frequently than all of the others. Table 3-4 summarizes the results of Search 2's content analysis, listing the discerned job functions, along with the supporting sources for each from the literature.

Table 3-3. Criteria and results count for Search 2: Sources discussing design responsibility of engineers

	Sub-rounds of Search	
	1	2
Subject Search Terms	engineer*	engineer* AND [design OR "product development"]
Text Search Terms (all terms required)	engineer* AND design AND responsibilit*	engineer* AND ethnograph*AND responsibility AND [work OR practice]
Excluded Subject Terms	"K-12", counseling, "high school", immigration, marketing, parent*	
Media	academic journal articles & books	
Date Range	1990 - 2016	
Raw Result Count	962	365
Qualification:		
Inclusion Criteria	Source must discuss engineers' job responsibilities Source must reference engineering practice context(s)	
Excluded Topics	corporate ethics, corporate social responsibility, description of sub-discipline-specific engineering tasks	ethnography as part of the design process or as a design tool, literature that does not discuss or explain engineering job or task responsibilities
Qualifying Result Count	48	11

Table 3-4. Results from Search 2 – Job functions encompassing engineers' design responsibility

Sources discussing engineering job functions through which "design responsibility" manifests in practice	Job functions				Engineering discipline observed/discussed
	Engineering Design Formulation including design verification	**Configuration Control of Designs** (e.g., engineering change management)	**Design Error / Failure Detection and Response**	**Other** (e.g., manufacturing oversight; training/teaching; informing society)	
Avvakumovits (1996)		X			Civil
Baird et al. (2000)	X		X		Mechanical
Beder (1998)	X		X		General
Bibby et al. (2006)		X			Civil
Brown (2007)			X		General
Bucciarelli (1994)	X	X			General
Bucciarelli (2002)	X				Mechanical / Electrical
Burk (2011)	X	X	X		Systems
Coeckelbergh (2006)	X				General
Collin (2004)	X				General
Cunningham et al. (2013)	X				General
Filho and Kaminski (2009)	X	X			Mechanical
Fleischer and Liker (1992)	X				Mechanical
Gainsburg et al. (2010)	X				Civil
Galpin et al. (2007)				X	General
Gillum (2000)		X	X		Civil
Gotternbarn (1999)	X		X		Software
Hailpern and Santhanam (2002)	X				Software
Hall (2009)	X				Software
Hayes (2015)	X				Civil
Hwang et al. (2009)		X			General
Jack (2013)	X		X		General
Jackson and Hundley (2004)			X		Civil
Jemielniak (2007)	X				Software
Karlsson et al. (2008)	X	X			Civil
Kemper and Sanders (2001)	X		X		General
Kunda (2006)	X				General
Le May and Le May (2016)			X		Civil
Lindsay (2002)	X				General
Loui (1998)	X				General
Loulakis and McLaughlin (2016)	X		X		Civil
Main (2002)	X				General
Millet (1999)				X	Civil
Nethercot (2008)	X				Civil
Onarheim (2012)	X				Mechanical
Pahl et al. (2007)	X	X	X		General
Pesch (2014)	X				General
Pfatteicher (2000)		X	X		Civil
Robinson (2000)				X	Civil
Roeser (2012)	X				General
Rowland and Rowland (1995)	X				Software
Shankar et al. (2012)		X			Mechanical
Suchman (2000)	X				Civil
Swierstra and Jelsma (2006)	X				General
Trevelyan (2007)	X	X	X	X	General
Trevelyan (2010)	X	X	X	X	General

Table 3-4. Results from Search 2 – Job functions encompassing engineers' design responsibility [continued]

Sources discussing engineering job functions through which "design responsibility" manifests in practice	Job functions				Engineering discipline observed/discussed
	Engineering Design Formulation including design verification	**Configuration Control of Designs** (e.g., engineering change management)	**Design Error / Failure Detection and Response**	**Other** (e.g., manufacturing oversight; training/teaching; informing society)	
Van de Poel and Royakkers (2011)	X		X		General
Van de Poel and Van Gorp (2006)	X				General
Vinck et al. (2003)	X	X	X	X	General
Waelbers (2011)				X	General
Walesh (2012)	X	X	X		Civil
Whitbeck (2011)	X		X		General
Wirfs-Brock (2009)	X	X			Software
Workman (1995)				X	Computer
Wright (1997)		X			General
Yogeswaran and Kumaraswamy (1999)				X	Civil

Though the literature uses the word "responsibility" frequently regarding engineers' actions in practice, our analysis suggests that much of design responsibility's manifestation is encompassed within the engineers' job functions of: (1) design formulation, (2) configuration control of designs (e.g., control and management of design releases and design changes), and, (3) design error or failure discovery and response. Search 2 also produced a disjointed variety of other results that fall beyond these three job function clusters – clearly engineers have responsibilities in a wide variety of other aspects of the product realization process. Yet, given that this search aimed to establish high-confidence areas of "where to look" for visible markers of design responsibility embodied in practice, we chose to focus the subsequent search (Search 3) on identifying activities falling within these three primary job functions. Example statements from among sources listed in Table 3-4 illustrate design responsibility's manifestation within the three areas:

Design formulation:

- "Engineers have the primary responsibility for making a product, machine, or system work in accord with established design criteria" (Main, 2002, p. 28).
- "Detailed design is primarily the responsibility of discipline-specific engineers" (Burk, 2011, p. 202).

Configuration Control of Designs:

- "...problems...can arise from implementing an engineering change order (ECO)...The responsibility for these problems is usually placed squarely on the shoulders of the design engineer" (Wright, 1997, p. 37).
- "Engineers coordinate, monitor, and evaluate work while it is being performed, adapting plans and organization to circumstances" (Trevelyan, 2010, p. 189).

Error or Failure Detection and Response:

- "[Engineers] diagnose perceived performance deficiencies (or failures), conceive and design remediation works, and predict how well the modified system will perform" (Trevelyan, 2010, p. 189).
- "[Software engineers] take responsibility for detecting, correcting, and reporting errors in software and associated documents on which they work" (Gotterbarn, 1999, p. 88).

Search 3 – Identifying work activities that compose the job functions of engineers

Search question: *Among literature that discusses the engineering job functions of design formulation, configuration control of designs, and design error or failure detection and response, what specific work activities does this literature identify as composing these job functions?*

In Search 3 we employed a date range from 1990 to 2016 and constructed the search in order to discern specific work activities that compose the three job functions established in Search 2. Here we ran three sub-rounds of search utilizing the specific subject terms, text terms, and Boolean combinatory logic as summarized in Table 3-5. Qualification review of the Search 3 raw results aimed to retain sources that discussed particular engineering work processes or practices in real-world contexts. A total of 129 sources were retained in the qualified results set. Search 3's qualification criteria and the resultant topic areas of excluded sources are summarized in Table 3-5.

Content analysis for Search 3 involved a two-level source sorting approach similar to that employed for Search 1. Here, however, the high-level topic bins were pre-established by the job functions identified in Search 2 (e.g., engineering design formulation, configuration control of designs, and design error or failure detection and response). For all sources within each topic bin, we searched body texts to identify discussions of engineers' specific activities in the context of carrying out the subject job functions. As with the Search 1 content analysis, here we also carried out clustering to establish broad themes encompassing groups of related sources – in this case the clustered themes are of the form of specific job activities. Table 3-6 summarizes the content analysis of the Search 3 results. This table thus takes the form of a list of 10 job activities tied to overarching "design responsibility" that the literature commonly associates with the practice of engineering.

The activities listed in Table 3-6 highlight engineers' myriad roles in carrying out processes, conducting analyses, processing changes, collaborating and coordinating, and making corrective actions as they fulfill their design responsibility during various aspects of the product realization process. Since thematic clustering processes such as the one employed in this study do an injustice to certain sparse or more nuanced discussions within the literature, we do not purport that these 10 activities in fulfillment of design responsibility are the only ones. We instead assert that these activities reflect the more prominently documented examples of how design responsibility is enacted in engineering practice.

Table 3-5. Criteria and results count for Search 3: Sources discussing job functions of engineering

	Sub-rounds of Search		
	1	**2**	**3**
Subject Search Terms	engineer* AND [design OR "product development"]	engineer*	engineer*
Text Search Terms (all terms required)	engineer* AND "design process" AND responsibilit* AND role	engineer* AND ["change management" OR "change control" OR "configuration management" OR "design change"]	engineer* AND [failure OR error] AND [prevention OR process]
Excluded Subject Terms	"K-12", counseling, "high school", immigration, marketing, parent*		
Media	academic journal articles & books		
Date Range	1990 - 2016		
Raw Result Count	437	879	636
Qualification:			
Inclusion Criteria	Source must discuss engineering work process or practice details Source must reference engineering practice contexts		
Excluded Topics	architecture, curricula, design process not generalizable beyond specific sub-disciplines (e.g., genetics), manufacturing processes, pedagogy, product portfolio management, specific environmental issues	automation, communication networks, cost control, curricula, government, legal and contractual issues, mathematical algorithms, policy, predictive modeling, specific commercial software packages	contingency planning, financial impacts of design failure, injuries/accidents in industrial plants, materials failure analysis (e.g., microscopy, specimen testing), predictive modeling, robustness algorithms, system diagnostics and prognostics
Qualifying Result Count	50	43	24

Table 3-6. Results from Search 3: Work activities composing engineers' design responsibility

Topic Area	Supporting Sources	Emergent Themes: Work activities through which design responsibility manifests in practice
Engineering Design Formulation	Ichida and Voigt (1996); Magrab (1997); Adams (1999); Samuel and Weir (1999); Murdoch and McDermid (2000); Armstrong (2001); Main (2002); Annacchino (2003); Anderson (2004); Ciambrone (2007); Hart (2007); Pahl et al. (2007); Cross (2008); Dym and Little (2009); Eder and Hosnedl (2010); Jones (2010); Benavides (2012); Dieter and Schmidt (2012); Catic and Malmqvist (2013); Weiss (2013); Williams and Johnson (2013); Britton and Torvinen (2014); Mital et al. (2014); Horenstein (2015); Ulrich and Eppinger (2016)	- Engineers follow protocols that impose checks upon their designs (e.g., design reviews, peer reviews, stakeholder reviews, drawing and/or code reviews, verification testing, qualification testing) to verify safety and effectiveness
	Pugh (1991); Magrab (1997); Skalak et al. (1997); Hazelrigg (1998); Cather, et, al, (2001); Annacchino (2003); Anderson (2004); Dick (2006); Hatamura (2006); Morgan and Liker (2006); Pahl et al. (2007); Park (2007); Cross (2008); Dym and Little (2009); Eder and Hosnedl (2010); Cussler and Moggridge (2011); Haik and Shahin (2011); Benavides (2012); Dieter and Schmidt (2012); Cadden and Downes (2013); Weiss (2013); Britton and Torvinen (2014); Mital et al. (2014); Cobb et al. (2016); Ullman (2016); Ulrich and Eppinger (2016)	- Engineers commit to a thorough consideration of possible solution concepts before deciding upon the best concept suited to meet identified users'/customers' needs, and thus to be carried forward into design realization
	Ichida and Voigt (1996); Moss (1996); Twigg (1998); Armstrong (2001); Annacchino (2003); Allard et al. (2009); Lloyd and Busby (2003); Anderson (2004); Ciambrone (2007); Pahl et al. (2007); Dym and Little (2009); Eder and Hosnedl (2010); Jones (2010); Dieter and Schmidt (2012); Pavkovic et al. (2013); Weiss (2013); Britton and Torvinen (2014); Mital, et. al. (2014); Monticolo et al. (2014); Horenstein (2015); Ullman (2016); Ulrich and Eppinger (2016)	- Engineers accept responsibility for documentation and communication of designs, including the key underlying assumptions, constraints, and trade-offs that drove the designs
	Moss (1996); Magrab (1997); Jeng and Eastman (1999); Armstrong (2001); Monplaisir and Singh (2002); Annacchino (2003); Anderson (2004); Morgan and Liker (2006); Ciambrone (2007); Pahl et al. (2007); Dym and Little (2009); Maier et al. (2009); Holt and Barnes (2010); Whyte and Lobo (2010); Zirpoli and Becker (2010); Cussler and Moggridge (2011); Benavides (2012); Dieter and Schmidt (2012); Cataldo and Herbsleb (2013); David (2013); Weiss (2013); Britton and Torvinen (2014); Horenstein (2015); Ullman (2016); Ulrich and Eppinger (2016)	- Engineers engage in collaboration and coordination routines in order to enact designs that accommodate the aggregate needs of the other participatory stakeholders in the product value creation process (e.g., other engineering teams, manufacturing, supply chain, marketing)

Table 3-6. Results from Search 3: Work activities composing engineers' design responsibility [continued]

Topic Area	Supporting Sources	Emergent Themes: Work activities through which design responsibility manifests in practice
Configuration Control of Designs	Buckley (1996); Wright (1997); Terwiesch and Loch (1999); Dart (2000); Lyon (2000); Haug et al. (2001); Keyes (2004); Moreira (2004); Jarratt et al. (2005); Jarratt et al. (2006); Watts (2008); Watts (2010); Jarratt et al. (2011); Shankar et al. 2012); Veldman and Alblas (2012); Reddi and Moon (2013); Son et al. (2014); Leon (2015); Quigley and Robertson (2015); Watts (2015); Aiello and Sachs (2016)	- Engineers follow organized and controlled processes to release new product designs and to subsequently make changes to these designs. Engineers' hold design (and design change) review and approval responsibilities as part of these processes
	Wright (1997); Lyon (2000); Haug et al. (2001); Eckert et al. (2004), Keyes (2004); Jarratt et al. (2005); Jarratt et al. (2006); Scholz-Reiter et al. (2007); Watts (2008); Hansen and Gammel (2008); Mohan et al. (2008); Rovegard (2008); Fei et al. (2011); Jarratt et al. (2011); Koh et al. (2012); Manuele (2012); Ahmad et al. (2013); Hamraz et. al. (2013a); Hamraz et. al. (2013b); Leon (2015); Quigley and Robertson (2015); Watts (2015); Aiello and Sachs (2016)	- Before changing or correcting a design, engineers analyze the proposed change for any potential adverse impacts to baseline product performance
	Lyon (2000); Haug et al. (2001); Berczuk and Appleton (2003); Keyes (2004); Mohan et al. (2008); Shiau and Wee (2008); Watts (2008); Kocar and Akgunduz (2010); Watts (2010); Son et al. (2014); Papinniemi et al. (2014); Monticolo et al. (2015); Subrahmanian et al. (2015); Leon (2015); Quigley and Robertson (2015); Watts (2015); Aiello and Sachs (2016); Morris et al. (2016)	- Engineers utilize design baseline management information systems to control design data, authorize design data access, and to provide design change traceability in collaborative design environments
	Wright (1997); Lyon (2000); Haug et al. (2001); Keyes (2004); Scholz-Reiter et al. (2007); Quintana et al. (2012); Reddi and Moon (2013); Han et al. (2015); Quigley and Robertson (2015); Watts (2015); Morris et al. (2016); Aiello and Sachs (2016)	- Throughout a product's lifecycle, engineers ensure continued design information accuracy, prevent information conflicts, and oversee dissemination of design baseline and change information to stakeholders (e.g., via a design baseline management information system)
Design Error/Failure Detection and Response	Petroski (1994); Millet (1999); Busby and Strutt (2001); Keil and Robey (2001); Evan and Manion (2002); Busby and Coeckelbergh (2003); Davidson and Labib (2003); Kardon (2005); Kappelman et al. (2006); Lee et al. (2006); Boin and Schulman (2008); Savoie and Frey (2012); Cataldo and Herbsleb (2013); Williams and Johnson (2013); Horenstein (2015); Williams and Johnson (2015)	- Engineers continually monitor designs and design processes for possible errors and issues throughout the product lifecycle, advocating for changes when necessary
	Petroski (1994); Gillum (2000); Moncarz and Taylor (2000); Pfatteicher (2000); Evan and Manion (2002); Pahl et al. (2007); Wearne (2008); Willis (2009); Lopez et al. (2010); Love et al. (2011); Fehr (2012); Le May and Le May (2016)	- Engineers commit to determining root causes of failures that have occurred, and to following up with design, implementation, standards and/or process corrective actions

Search 4 – Identifying occupations involving similar or related work activities as engineers

> **Search question:** *Among the documented set of present-day occupations, which of them show evidence of similar work activities to those of engineering practice identified in Search 3, beyond those occupations with the word "engineer" in their titles?*

Search 4 was conducted within the *O*Net* database (O*Net, 2017) with the aim of identifying occupational titles and descriptions, rather than journal articles or books. The search occurred in September 2017 and considered the entirety of U.S. occupations set listed within the database. By striving to identify occupations consisting of activities similar to those of engineering roles, yet not titled as such, we aimed to identify the set of roles in next-closest proximity to conventional engineering roles – engineering's "nearest neighbors." A keyword search was employed utilizing the following combinatory search logic: *engineer** + *(design** + *process)* + *(analyze* + *configuration* OR *change)* + *(collaborate* + *communicate* OR *coordinate)*. This search logic was derived from the results of Search 3 in order to construct a query for roles with similar work components to engineering; however, we opted not to use the words "error" or "failure" in the search criteria because of their widely varied usage contexts across job description data. As expected, job titles with the word "engineer" in the title dominated the top of the list. Thus, we began processing the results set by filtering the set to remove any entries with "engineer" in the title. We next removed jobs requiring less than a bachelor's degree, given our focus on occupations mostly likely to be pursued by engineering school graduates. We also removed all jobs in teaching and architecture fields due to their clear association with other specific occupation groups. Finally, we retained the 100 remaining results in order of relatedness to the search terms, and added each of their top-ten listed "alternate occupational titles" from the database. O*Net's search algorithm lists occupation results in descending order of relation to search terms based on several factors: job titles, job descriptions, job tasks, and detailed work activities (see: Morris, 2017, for a description of the algorithm). The alternate titles we

added are those that O*Net reports as the closest title variants to each of its database's primary entries if the primary entry is searched for independently. Search 4 thus resulted in a list of 1,000 present-day non-engineering-titled occupations bearing a relatively strong relationship to engineering roles as compared to other occupations. The search criteria and results counts are summarized in Table 3-7.

Table 3-7. Criteria and results count for Search 4: Occupations in close proximity to engineering roles

	Occupations Search Query
Search Terms	engineer* AND [design* AND process] AND [analyze AND change OR configuration] AND [collaborate AND communicate OR coordinate]
Database	Occupation*NET Database (https://www.onetonline.org/find)
Date of Search	September, 2017
Raw Results Count	1022 (primary job titles)
Exclusion Filters	Occupations with "engineer" in job title Occupations requiring less than a bachelor's degree Architect occupations Teaching occupations
Final Results Count (based on cutoff threshold)	100 (primary job titles) 1000 (primary job titles + top-10 alternate titles for each)

The method of qualification for Search 4's results was distinct from the other searches, given that Search 4 encompassed a jobs database review rather than a literature review. Though the jobs in the results set were arrived at systematically, discretion was needed to establish the cutoff threshold for the quantity of nearest-matching results included in the results set. We opted to evaluate setting this threshold at 100 primary job titles. A cutoff threshold was necessary because the *O*Net* algorithm would otherwise proceed to report all results in its database in decreasing order of relatedness to the search terms. We tested the robustness of our threshold choice by conducting a preliminary results clustering analysis based on job title. We sought to ensure that we were not curtailing any prominent

job clusters through our imposition of the threshold. We noticed that job titles became increasingly unrelated to each other with increased distance down the results list. We thus reviewed the next 50 job titles beyond the initial threshold of 100 results, and were not able to discern any clusters of 5 or more similarly titled jobs among the 50. Our assessment is that jobs in the region beyond the threshold are sparsely related, and that our threshold choice of 100 produces a results set that is appropriately aligned with our goal of being able to identify the occupational groups in closest proximity to traditional engineering jobs.

We next carried out formal content analysis on the Search 4 results, with the goal of discerning clusters of engineering-similar jobs from among the qualified results list. We based this clustering analysis on both job titles and job description summary statements (e.g., the 1-2 sentence heading statements atop each O*Net database entry) to arrive at four pronounced clusters of related occupations: *developers* (as pertaining to software or computer-related contexts); *designers*; *coordinative and managerial roles*; and *analyst and technical communicator* roles. Table 3-8 presents a summary of Search 4's content analysis, wherein each column delineates a specific occupational cluster and contains several example constituent job titles, one of which is expanded as a detailed example. While the results in Table 3-8 do not tell us anything definitive about which of these jobs should be considered "engineering" jobs, we do make the assumption that this roles set encompasses engineering's "nearest neighbor" occupations within product, process, service, or system development ecosystems. We proceed, in Part 3 of this paper, to develop a parsing scheme for these engineering nearest neighbors.

Table 3-8. Results from Search 4: Non-engineering-titled occupations sharing attributes with engineering roles

Job Title Clusters:	Developers - Software or Computer Context	Designers	Coordinative and Managerial Roles	Analysts and Technical Communicators
Example Job Titles	- Software Application Developers - System Software Developers - Web Developers - Computer Network Architects - Software Architects - Network Developers	- Industrial Designers - Designers (a) - Design Directors - Systems Designers (b) - Environmental Designers - Interface Designers	- Project Managers (c) - Product/Systems Development Managers (d) - Managers (e) - Leads (f) - Directors (g) - Chief Technical Officers	- Computer Systems Analysts - Operations Research Analysts - Decision Analysts - Sustainability Analysts - Technical Writers - Technical Editors
Example Job Details:	***Software Application Developers***	***Industrial Designers***	***Project Managers***	***Computer Systems Analysts***
Description	Develop, create, and modify general computer applications software or specialized utility programs. Analyze user needs and develop software solutions. Design software or customize software for client use with the aim of optimizing operational efficiency. May analyze and design databases within an application area, working individually or coordinating database development as part of a team. May supervise computer programmers.	Develop and design manufactured products, such as cars, home appliances, and children's toys. Combine artistic talent with research on product use, marketing, and materials to create the most functional and appealing product design.	Plan, initiate, and manage projects. Lead and guide the work of technical staff. Serve as liaison between business and technical aspects of projects. Plan project stages and assess business implications for each stage. Monitor progress to assure deadlines, standards, and cost targets are met.	Analyze science, engineering, business, and other data processing problems to implement and improve computer systems. Analyze user requirements, procedures, and problems to automate or improve existing systems and review computer system capabilities, workflow, and scheduling limitations. May analyze or recommend commercially available software.
Primary Tasks	- Modify existing software to correct errors or to improve its performance - Analyze user needs and requirements to determine feasibility of designs - Confer with systems analysts, engineers, programmers and others to design systems - Store, retrieve, and manipulate data for analysis of system capabilities and requirements - Design, develop, and modify software systems using scientific analysis and mathematical models to predict and measure outcome and consequences of design.	- Prepare sketches of ideas, detailed drawings, illustrations, artwork, and blueprints - Confer with engineering, marketing, production, or sales departments, or with customers - Modify and refine designs using working models - Direct and coordinate the fabrication of models or samples - Evaluate feasibility of design ideas	- Manage project execution to ensure adherence to budget, schedule, and scope - Develop or update project plans, including information such as objectives, technologies, systems, specifications, schedules, funding, and staffing - Monitor or track project milestones and deliverables - Confer with project personnel to identify and resolve problems - Develop and manage work breakdown structures of projects	- Test, maintain, and monitor computer programs and systems, including coordinating the installation of computer programs and systems - Troubleshoot program and system malfunctions to restore normal functioning - Expand or modify system to serve new purposes or improve work flow - Use computers in the analysis and solution of business problems, such as development of integrated production and inventory control and cost analysis systems - Consult with management to ensure agreement on system principles
Primary Work Styles	- Analytical Thinking - Attention to Detail - Innovation - Integrity - Achievement/Effort	- Innovation - Attention to Detail - Analytical Thinking - Persistence - Dependability	- Leadership - Initiative - Persistence - Attention to Detail - Dependability	- Analytical Thinking - Attention to Detail - Adaptability/Flexibility - Dependability - Integrity

Notes:

1. Column headings represent the 4 primary occupation clusters discerned in Search 4
2. Example Job Titles are drawn from both primary and alternate job title results from the specified *Occupation Information Network* (*O*Net*) search
3. Example Job Details are excerpted from *O*Net* database entries for the first example given in each category; in the case of project managers where there are multiple entries, verbiage is taken from the IT Project Manager profile
4. Primary Tasks and Primary Work Styles: excerpted from the O*Net detailed occupational profile of the subject job; the top 5 attributes in the database are shown for both Tasks and Work Styles
5. Curtailed job titles are presented for those with multiple similar entries in the database; the notes below explain how the curtailed titles are often used as the root of longer titles:
   (a) "Designer" is a recurrent job title root in the results set, referencing various product development contexts. Examples titles include: "Automotive Designers," "Bicycle Designers," "Boat Designers," "Athletic Shoe Designers," etc.
   (b) Examples of "Systems Designer" roles in the results set include: "Computer Systems Designers" and "Industrial Green Systems Designers"
   (c) "Project Manager" roles are usually preceded by discipline modifiers in the results set. Examples include: "Information Technology Project Managers," "Energy Project Managers," "Construction Project Managers, "Transportation Project Managers," etc.
   (d) "Product Manager," "Product Development Manager," and "System Development Manager" are listed in the results set in reference to computing and alternative energy contexts
   (e) "Manager" is a recurrent job title root in the results set. Examples titles include: "Software Development Manager," "Compliance Manager," "Information Security Manager," "Technical Manager," "Sustainability Manager," and others
   (f) "Lead" is a recurrent job title root in the results set. Examples include: "Systems Applications Programming Lead," "Lead Simulation Modeler," "Energy Projects Lead," "Software Development Team Lead," "Computer Network Specialist Lead," and others
   (g) "Director" is a recurrent job title root in the results set. Example titles incude: "Web Development Director," "Planning Director," "Construction Director," "Water Resources Program Director," "Technology Director," and others

In sum, this sequential literature review provided us with key substantiation for constructing a set of propositions to underpin an engineering graduates' occupational outcomes typology. The review allowed us to discern a core attribute of engineering work and to identify visible markers (e.g., work activities) representative of how this attribute is likely to manifest in practice (Table 3-6). We then examined a sampling of occupation roles in near proximity to engineering roles, and established a set of non-engineering-titled role types that clearly exhibit some degree of overlap with engineering roles (Table 3-8). We hereafter proceed in Part 3 of this paper to develop and present a typological system relating these engineering "nearest neighbor" roles, engineering roles, and roles of more distant proximity to engineering.

3.2.3 Limitations of methods and results

Methods employed in this study have known deficiencies. We chose to employ systematic literature review to enable a broad inquiry into the fundamental characteristics of what it means to work as an engineer. Such an inquiry required consideration of wide time ranges and sought to draw highly generalized inferences from large quantities of search results. To handle this scope, we employed thematic clustering analysis. Cluster statements are paraphrases, and thus are not directly extracted from any specific source (Krippendorf, 2004). Detail is inevitably lost in this process; therefore, content analysis results are inherently incomplete and should be viewed as such. While we worked to ensure an absence of conflicts among clustered sources, we are unable to precisely quantify the degree of nuanced detail that is lost during processing.

The nature of our sources also limits the completeness of our analysis. For example, we rely on journal articles and books for a meta-analysis of engineering practice. As Trevelyan and Tilli (2007) note, engineering practice may be inadequately covered in these types of sources; therefore, use of field research methods or consultation of literature sources from additional realms may have improved the fidelity of our analysis. But such alternate methods are not without their own risks or

limitations. For example, drawing from non-peer reviewed sources may have provided views more specifically focused on engineering practice but at the expense of accuracy and unbiasedness. Meanwhile, field research methods such as ethnography provide an excellent means of building rich descriptions of specific context, but at the expense of the efficiency necessary to cover our broad desired scope. Again, these considerations imply an incompleteness of the coverage of our inferences about engineering work, prompting us to frame our results as a series of propositions (culminating in a proposed framework) rather than as a set of verified and conclusive statements.

Finally, our use of *O*Net* as a primary source for detailed current job description data in Search 4, coupled with the content analysis applied to such, carry limitations. Though our content analysis identified four prominent occupational clusters among the results, we acknowledge that other, less definitive groupings of the occupations likely also exist, as do lone occupations that do not fit neatly among the four clusters (e.g., niche specialist roles). A challenge to the comprehensiveness of clustering centers on the fact that the search algorithm is keyword-based, yet the ways in which certain words are used in job descriptions vary considerably, resulting in some less relevant occupations permeating the results set. Additionally, certain less-common job descriptions are likely missing from the *O*Net* database, as suggested by the comparatively larger volume of job titles in the Bureau of Labor Statistics' Direct Match File (US BLS, 2013). While *O*Net* covers approximately 1,100 jobs, plus their alternate titles, and includes rich descriptions across an array of attribute categories within each (Peterson et al., 2001), we nonetheless limit our interpretation of *O*Net* results: we assume that results represent common examples of jobs encompassing the job attribute search terms, but we do not assume that results represent a comprehensive list of possible job titles. We do assume that *O*Net* search results we acquired represent typical and reasonable examples of jobs in close proximity to engineering roles in our present time.

3.3 Typology synthesis and discussion

3.3.1 Typology synthesis: Characterizing occupational outcomes of engineering graduates

We proceed to develop a series of propositions to support construction of a typology that delineates engineering work, identifies and situates engineering-related work in proximity to engineering work, and distinguishes other work from either of the preceding. Collier et al. (2012) define a typology as "an organized system of types", which, in this case, we establish as the system of occupational outcome types that present-day engineering graduates achieve and then propagate through. The typology strives to account for two dimensions of variance that differentiate the types: *divergence* in the nature of job responsibilities and *progression* of role types with age and experience. Both such dimensions are conceptualized with reference to an occupation type datum: the roles set that most embodies the discerned core of engineering work and that is temporally placed at the junior-most phase of engineering graduates' careers. The typology then categorizes other occupational role types in relation to the datum across both dimensions. At a most basic level, our synthesis builds upon the notion of *design responsibility* as a unifying criterion of engineering's core; therefore, we begin with the following proposition:

> **Proposition 1:** *possession of design responsibility is a consensus (or near-consensus) unifier of those in engineering occupational roles.*

The enduring nature of design responsibility as a definitive attribute of engineering practice gives us confidence in this proposition – historic literature preceding our review calls similar attention to it. Baddour et al. (1961), for example, describe engineers' "willingness to assume final responsibility for a useful result" (p. 650). Mann (1962) discusses "the engineer's responsibility for the physical realizability of his creation," and "acceptance of responsibility for solutions" (p. 2). And

Hall (1965) explains: "After a design has been formulated, the engineer has the responsibility of following it through to its realization…[to ensure] the product of the design can be achieved" (p. 294). We see design responsibility signifying an engineering occupational obligation over the many decades leading to our sources' similar conclusions in the 21st century.

Yet, despite this seemingly straightforward assertion – that design responsibility characterizes engineering practice – a more detailed review of the literature and of sample job descriptions make it clear that such a criterion is not without complications. The following additional propositions address these complications.

First we must acknowledge that the precise nature of design responsibility and the way it is enacted by engineering practitioners is likely to change over the course of individuals' careers. A rich history of scholarship on the organization of engineering work describes a common (and long-established) tendency for engineering practitioners to gravitate toward increasingly managerial roles as they progress through their careers (see: Goldner & Ritti, 1967; Bailyn & Lynch, 1983; Rynes et al., 1988; Biddle & Roberts, 1994; Busby & Coeckelbergh, 2003). For the purposes of developing an occupational outcomes typology, we must ask: do we or do we not wish to count engineering practitioners who have transitioned to managerial roles as having relinquished their engineering status? We assert that many of such managers should certainly continue to be counted among those practicing engineering – but that the distinction, similar to the case of early-career roles, can also be explained by the individual's proximity to design responsibility. Robinson (2012) presents evidence that many individuals in the role of "engineering manager" continue to be responsible for "technical" elements of work, while Trevelyan and Tilli (2007) conclude: "management is an intrinsic part of many engineering roles" (p. 302). If we view engineering as a particular occupational function in the context of

organizations or projects – one with its own internal seniority hierarchy – we may consider the occupational function itself as holding design responsibility, with its members as enactors of this responsibility at various levels of accountability. For instance, if an individual contributor engineer makes a flawed design decision, is this individual's direct-line manager not ultimately responsible for ensuring the flaw is resolved, just as the individual contributor also holds responsibility? In a most direct exemplification of this responsibility hierarchy, certain safety-critical engineering contexts employ an "engineer of record" to sign off on designs (Gillum, 2000; Kardon, 2005). On large projects, such individuals may oversee teams of contributing engineers yet preside as authority over the design. While the visible formality of this authority undoubtedly varies by situation, we argue that an engineering managerial chain of command ultimately presides over – and bears the consequence of – design responsibility. However, one cannot presume that *all* managerial roles that an individual engineer may be promoted into necessarily fall along this chain of command: if an individual is promoted from an engineering role into a managerial role in other occupational functions, such as in business development, strategy, or operations, they may effectively move to a position one or more degrees removed from design responsibility, and thus no longer be most appropriately categorized as "engineer" in the conventional sense. We summarize our conclusions about engineers' career advancement progression in relation to design responsibility through the following proposition.

> **Proposition 2**: *the nature of engineers' design responsibility can evolve over the course of a career, from junior to senior stages.*
>
> > **Proposition 2a**: *junior members of the engineering occupation hold design responsibility over their contributions toward engineering projects, though they may or may not (depending on experience levels and context) require a more senior engineering or engineering manager to validate their contributions.*
> >
> > **Proposition 2b**: *senior and managerial members of the engineering occupation hold design responsibility over their own contributions, as well as over their*

team's / department's / directorate's contributions. Individuals who have delegated engineering design responsibility but are ultimately responsible for outcomes may still be considered engineers.

Figure 3-2 illustrates the partial typology we've constructed thus far. Here we have simply instantiated the two primary axes of the framework: one of progression in engineers' careers, and one of proximity to design responsibility. The following additional propositions serve to incorporate further differentiating detail into the framework.

Figure 3-2. Partial construction of engineering graduates' occupational outcomes typology

We next turn to the elaborative question of: *design responsibility over what?* In other words, what is the scope that this responsibility encompasses? Clearly there are others involved in designs beyond engineers, even if we limit our consideration of "design" to specific contexts that involve design parameters rooted in applied sciences or mathematics. Other occupations' involvement is highlighted by the prevalence of documented hybrid roles entailing collaboration with engineers – such as examples revealed by our Search 4: industrial designers who "prepare sketches of ideas" and "refine designs using working models," or project managers who "lead and guide the work of technical staffs" and "identify and resolve problems [with the

project]," among others (see: Table 3-8). Time spent reviewing modern job descriptions in technology development labor markets make it clear, as one author states, that: "engineers will become more and more engaged in broad, trans-disciplinary collaboration" (Sorensen, 2009).

Defining engineering work in the 21st century involves acknowledging that design is collaborative across varied occupational roles in product/technology development ecosystems while also acknowledging that engineers' responsibility over design is unique in its nature. The engineering ethicists' (and others') arguments that to be an engineer is to be responsible for the outcomes of designs (see: Table 3-2), combined with a more granular definition of design help to elucidate this uniqueness. Scholars of engineering design have long defined design in terms of both *form* and *function*, and have identified processes by which a design is evolved from functional requirements (e.g., target functions) into a specific implemented form (e.g., realized form with its consequent functions). Cross (2006), for example, describes a product development process through which the initial gap between a product's envisioned functional design requirements and its formalized design structure achieves closure. And, Pahl et al. (2007) describe stages of conceptualization, embodiment, and detailing that, in succession, involve giving increasingly specific form to functional requirements. When it comes to the functional specification of products – what a product should accomplish, the utility it should provide to its users, even the appearance it should exude – our literature review makes it clear such decisions are collaborative endeavors in today's product development ecosystem between engineers and complimentary roles, such as user experience designers, product managers, analysts, strategists, and others. But our review also makes a strong case that the final implemented *form* of products – and, in particular, how the specified product functionality maps to a final product implementation – is generally viewed as the unique responsibility of

engineers. The following examples help illustrate these complimentary but differing natures of responsibility.

In engineered products (or processes, systems, or services), particularly complex ones, we see evidence that design *forms* are generally codified via revision-controlled sets of governing information artifacts – software source code, drawings, schematics, chemical formulae, etc. – and that engineers are tasked with being responsible for the integrity of this formal design definition (see: Table 3-6). In short, engineers instantiate (or oversee the instantiation of) the specific final form of the design that ultimately gets delivered. Eckert et al. (2004), for example, describe an environment at an aerospace firm where numerous product design changes were being processed in rapid succession as the firm worked to incorporate issue resolutions and responses to customer concerns. They describe a collaborative environment, with many participants from different disciplines involved in proposing and reviewing the design changes – but ultimately a senior engineer was responsible for vetting and approving changes to the design baseline. Kardon (2005) describes scenarios in civil and structural engineering where engineers-of-record are formally liable for the performance of designs instantiated under their watch, and can be charged with negligence if designs fail to perform (e.g., perform as functionally specified). And Twigg (1998) describes a complex supply chain in the automotive industry, replete with design interdependencies across suppliers and sub-systems – yet one for which control over design integrity is maintained through clear assignment of engineering design authority and sign-off responsibility. Our review (see: Table 3-2 and Table 3-6) suggests that ownership of the form representation of designs is a hallmark of what it means to be an engineer – the taking of responsibility for what actually gets built, shipped, compiled, uploaded, etc., often as marked by technical sign-off duties in design information management systems.

To offer a summative example: consider a scenario where members of many complimentary occupations are deeply involved in collaborating to specify how a laptop computer should look and feel, and how well it should perform across a variety of technical parameters. Inputs from a range of occupational roles may inform the conclusion that the aesthetic characteristics of an aluminum case are most appropriate for the laptop – but when it comes to formalizing what exact alloy of aluminum will be used, taking into account such considerations as heat transfer, structural integrity, and manufacturability, among other things, such formalization becomes the engineer's responsibility. We posit that responsibility for an as-delivered design *inclusive of the most infinitesimal levels of design definition* is what uniquely characterizes engineers' design responsibility. Yet, the way engineers are often embedded in broader product and technology development ecosystems suggests engineers' work is often *moderated* by others in complimentary roles. Though engineers are responsible for instantiation of design form, the well-documented presence of complimentary roles suggest engineers may rarely have free-reign. Industrial designers, for example, may establish the net shape of a product while "conferring with engineering," or, project managers may "establish objectives" while "conferring with project personnel" (Table 3-8). The broad set of pertinent 21st century role descriptions thus suggests a give-and-take surrounding products' target functionalities, which we conceptualize as a *collaborative responsibility* shared between engineers and others. We offer Proposition 3 to distinguish conventional engineers' roles among the nested and complimentary responsibilities at play.

> **Proposition 3:** *the nature of engineers' design responsibility differs as it pertains to the form of designs versus the function of designs.*

Proposition 3a: *those occupying engineering roles hold determinate responsibility for instantiating the form of designs, and for form-consequent function emerging from this instantiated form.*

Proposition 3b: *those occupying engineering roles share collaborative responsibility with other related occupations over the target function of designs.*

Proposition 3 prompts an expansion of the occupations typology from its basic skeleton (Figure 3-2) to account for this more granular distinction of the nature of design responsibilities among occupation types. An intermediate occupation type is introduced, as shown in Figure 3-3. This expansion presents a need to establish categorical names – a delicate task, given our imperative for neutral, non-judgmental type-labeling.

We opt to employ English-Latin hybrid categorical names in pursuit of such neutrality. As with labeling choices in other scientific fields, use of Latin-based categorization takes advantage of the diminished emotional anchoring associated with a legacy language. It allows us to uniquely conceptualize the new hybrid terms without their being laden with prejudicial meaning. We introduce the following terms for the typology's upper two strata:

- ***Engineer-Agnita Occupations*** (***Engineer-A's***, or ***EA's***, or per convention, ***Engineers***) – historically recognized, or conventionally acknowledged engineers.
  (The hybrid name utilizes the Latin "agnita," meaning recognized or acknowledged)
- ***Engineer-Conpar Occupations*** (***Engineer-C's***, or ***EC's***) – engineering partners and colleagues; fellow participants in product or technology development.
  (The hybrid name utilizes the Latin "conpar," meaning companion, mate, or partner)

The scheme in Figure 3-3 illustrates the complimentary, interdependent nature of the roles that engineers and engineer-C's hold in product or technology development realms.

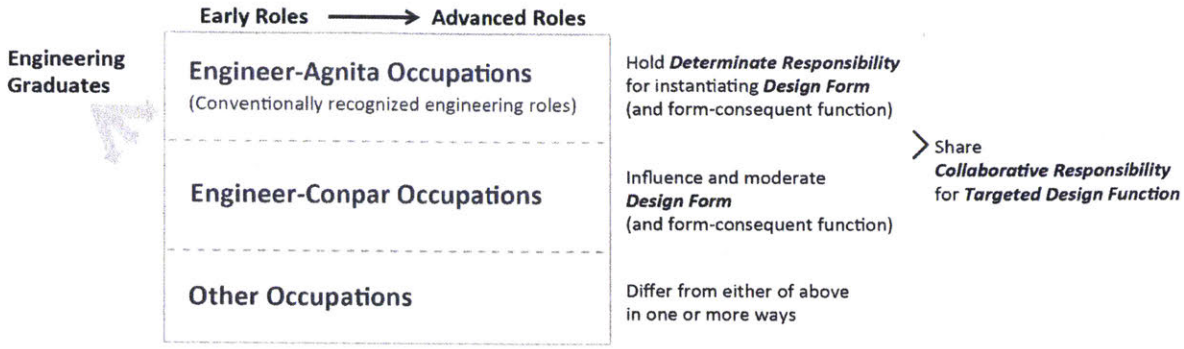


Figure 3-3. Expansion of engineering graduates' occupational outcomes typology

We proceed now to more specifically explore *collaborative responsibility for targeted design function* and to elaborate upon the defining criteria for engineer-C's. Our review suggests a proximal relationship between engineers and engineer-C's that is distinctly close compared to that between the conventionally acknowledged engineers and *other* occupations. Sources provide several examples of this proximity:

- Sheard (1996) describes system analysts' role to "confirm that the designed system will meet requirements" (p. 2), inclusive of conducting modeling to ascertain design performance.
- Kemper and Sanders (2001) describe an interplay between engineers and industrial designers, whereby stylistic and usability attributes of designs are specified by the latter.
- Van de Weerd et al. (2006) illustrate product managers' role in establishing product requirements based on customer needs and parsing these requirements into specific planned product releases.
- Rauniar et al. (2008) discuss product managers' role in setting project-level goals and targets for product development teams that are in "strategic alignment" with business and company goals.
- Onarheim (2012) describes project managers' responsibility for translating "target product profiles" into design constraints through a process described as "establishing corner flags."
- *O*Net* (2017) describes information technology project managers' role as "a liaison between business and technical aspects of a project," and lists project scoping, planning, objective setting, and conferring with project personal to resolve problems among "primary tasks."

The above analyst, designer, product manager, and project manager portrayals illustrate design form-*moderating* roles that are characteristic of engineer-C's in our framework. In each of these cases, we see how the work of such individuals is carried out complimentarily with that of engineers, who presumably act upon and are guided by the outputs of each of the above.

Further, the typology distinguishes other occupations from both engineer-A's and -C's in that others do not directly share collaborative design responsibility for target product function, nor do they directly influence, moderate, or instantiate product form. For example, consider the possible difference between an engineer-C (for example, a project manager with cost control and product specification responsibilities on an engineering project) and a financial analyst housed within the same product development firm. The financial analyst is certainly also a participant in the broader product development economy, but is likely further removed from engineering. The financial analyst may determine how costs need to be controlled within a particular product line or division; this determination may be translated into project-specific cost targets, which in turn may translate into design constraints. But, while the project manager is likely to directly interface with engineering to control these costs and translate them into design-influencing parameters, the financial analyst is more likely to influence design only through intermediaries (e.g., such as the project manager), rather than directly. In some cases, the project manager may be considered an engineer himself or herself, depending on how design responsibility is allocated in particular contexts.

The nature of the jobs within the four engineering "nearest neighbor" occupational clusters from Search 4, combined with supporting role descriptions (see: Sheard (1996); Van de Weerd et al. (2006); Rauniar et al. (2008); Onarheim (2012)), suggest possible modes of collaborative responsibility shared between engineers and engineer-C occupations. We posit a

series of expected markers of *collaborative responsibility over target design function* in Table 3-9, alongside distilled markers of *determinate responsibility over design form* based upon our review (e.g., Search 3 results). The characteristics summarized in Table 3-9 may inform the construction of research survey questions targeted at engineering graduates whose occupational outcomes are of interest. Such questions could be used to help identify the nature of survey respondents' design responsibilities, and, in turn, could assist in placing respondents into *engineer*, *engineer-C*, or *other occupation* categories. It is important to note that the statements in Table 3-9 assume that design responsibility is held at the occupation function-level (e.g., at a given instant, an individual need not be doing design work to be considered an engineer if she or he belongs to a occupational function holding design responsibility), and that the "product" could be of the form of a product, process, service, or system. Affirmation of any one of the given responsibility statements in Table 3-9 indicates an individual holds responsibility at the associated categorical level (e.g., collaborative-over-function or determinate-over-form). Table 3-9 does not constitute an exhaustive list, but serves to illustrate the characteristics of these two primary responsibility categories as we have conceptualized them based upon the literature review.

Proposition 4 formalizes the conceptualization of engineer-C occupations. Proposition 5 elaborates on what distinguishes other occupations from both engineers and engineer-Cs.

> **Proposition 4:** *Engineer-Conpar* (Engineer-C, or EC) occupations share *collaborative responsibility* over the *target function* of designs with engineering occupations, and influence and moderate the *form* of designs (and the form-consequent function of designs).
>
> **Proposition 5:** Other Occupations (e.g., neither engineers nor engineer-C's) do not share collaborative responsibility over the function of designs, and do not directly influence or moderate the form of designs.

Table 3-9. Characteristics of the categories of design responsibility

In each case, affirmation of ***any one or more*** of the markers indicates posession of the responsibility type *The term "products" refers to products, processes, services, or systems*
*Markers of **Collaborative Responsibility** over target design function*
Individual belongs to an ocupation that: - Plays a direct role in establishing the target functional specifications of products - Provides information directly to (or shares information directly with) those who are designing a product (or part of a product) in order to influence its design - Participates in reviewing proposals for product designs and design changes - Monitors, simulates, or analyzes product performance to establish feedback on how well it is performing, and relays this feedback to those working on the design of the product - Conveys information about product issues or failures directly to those tasked with correcting the design of the product - Creates communication artifacts or documents that explain, discuss, or clarify technical information about a product by working directly with those who are designing the product
*Markers of **Determinate Responsibility** for instantiating design form*
Individual belongs to an occupation that: - Holds responsibility for establishing the specific defining details of a product or part of a product, and is ultimately accountable for the correctness and integrity of these details - Should there be a product flaw discovered, is responsible for establishing conclusions about the cause of the flaw, and for establishing and implementing the specific design change that will resolve the flaw - "Signs off" as the technical authority certifying the effectiveness and safety of a design, part of a design, or on behalf of a particular technical sub-domain involved in the design

Full instantiation of the engineering graduates' occupational outcomes typology based upon Propositions 1-5 is shown in Figure 3-4. Notional career progression and dispersion patterns are overlaid to exemplify how the typology accommodates these dynamics. The descriptive text within the cells of Figure 3-4 serve to illustrate how job scope, expertise level, and/or leadership or managerial purview may vary within the established bounds of each occupational category. However, this text is not intended to represent specific job titles. The typology avoids utilizing job titles as a means of type-categorization due to the potential for variation in their meaning across employment contexts. The typology thus best serves as a tool

for original research when the nature of subjects' job responsibilities can be assessed, through surveying, interviewing, or other means, rather than as a scheme for parsing existing job titles into categories. In the remaining sections of this paper, we discuss employing the typology in original research, the typology's strengths and limitations, and opportunities for further development.

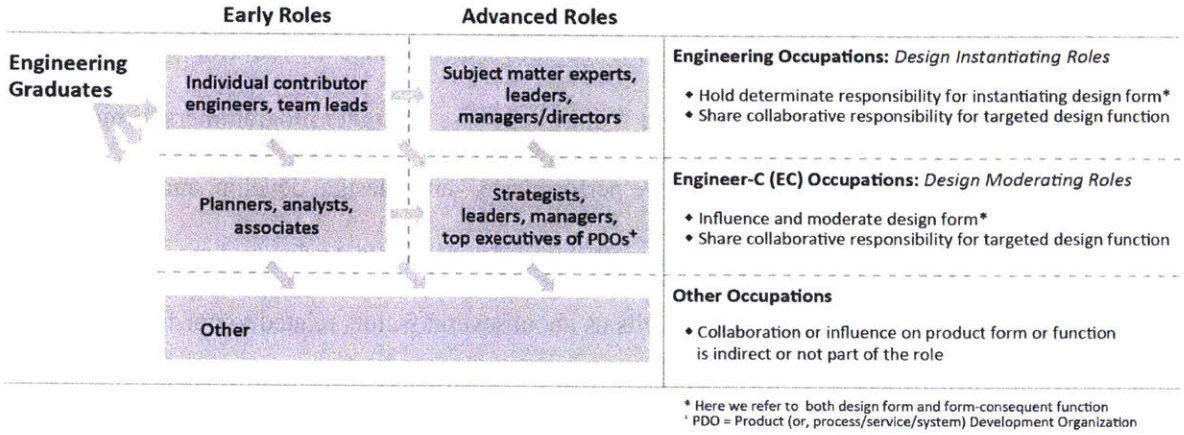


Figure 3-4. Engineering graduates' occupational outcomes typology with notional career progression and dispersion patterns overlaid

3.3.2 Employing the typology

The example job profiles uncovered in Search 4 of this review provide good cases for exploring this new typological approach (see: Table 3-8) – such are the jobs in today's market that are identified as nearest neighbors to engineering roles, yet are not titled as "engineer." We identified four groups of common jobs in this area: developers, designers, coordinative and managerial roles, and analysts and technical communicators. A foundational assumption of our approach is that there is unlikely to be an effective way of automatically parsing these boundary-blurring jobs into *engineer*, *engineer-C*, or *other* categories without knowing about the specific nature of job responsibilities.

However, data from *O*Net* gives us at least enough information to discuss possible categorization rationales for the sake of methodological illustration.

Let us first consider "Software Application Developers," as listed in Table 3-8 – setting aside, for a moment, an ongoing discussion about whether software developers should be entitled to formal engineering professional licensure (see Davis, 1996, for issues challenging such licensing, and NCEES, 2012, for a recent developments paving the way for licensing). From Table 3-8, we observe that the "Software Application Developer" profile includes such language as: "develop, create, and modify general computer applications software," "may supervise computer programmers," "modify existing software to correct errors or to improve performance," and "design, develop, and modify software systems using scientific analysis and mathematical models…to predict and measure outcome and consequences of design." This language tells us about several factors related to our framework: that the role is not limited to that of a computer programmer – the role appears to involve accountability over software product design, its associated validation, with conscious purview over design outcome and consequence. The description also implies duties to correct errors and to improve baseline product performance. This role thus appears consistent with the markers of *determinate responsibility over design form* as listed in Table 3-9. Additionally, the job profile states that the individual will "analyze user needs and requirements" and "confer with systems analysts, engineers, programmers, and others to design systems" – job features considered to be markers of *collaborative responsibility over target design function* from Table 3-9. Ideally, survey response or interview data from this role's occupant would bolster our conclusions about the role's inherent design responsibilities, but from the evidence we have, the role appears consistent with that of an *engineer* based upon the typology. We cannot, however, generalize that *all* "developers" are engineers, nor can

we draw such a conclusion about the many other software development-related job titles utilized in today's job market based on this one simple example.

Next we consider the "Project Manager" profile from Table 3-8. This profile includes such language as "plan, initiate, and manage projects," "lead and guide the work of technical staffs, "serve as liaison between business and technical aspects of projects," "ensure adherence to budget, schedule, and scope," and "confer with project personnel to identify and resolve problems." Throughout this profile, we see language associated with collaborative responsibility over design function (e.g., "lead and guide," "serve as liaison," "confer"), but no such language that suggests design responsibility over the final configuration or of specific design details. This information suggests a role consistent with an *engineer-C* occupation. Yet, we cannot conclude that *all* project managers are *engineer-C*'s; it is entirely conceivable that "player/coach" roles exist whereby a project manager also possesses responsibility over determinate design details (see: Allen & Katz, 1995), and thus could be considered an *engineer*. Again, original research data about individual subjects' job responsibilities are needed to lead researchers to the most robust conclusions about occupational categorization using the typology.

Analyses similar to these can be carried out for any of the types of jobs listed in Table 3-8 and beyond: from "industrial designers" and "interface designers," to "product development managers" and "project leads," to "systems analysts" and "sustainability analysts." Some cases are more nuanced than others; for example, designers clearly have responsibility over "design" – yet here we return to our discussion on the breadth of what "design" encompasses for purposes of this typology: it is not simply what a product looks like nor its list of performance requirements. Engineers, we contend, are "on the hook" for the finalized and specific instantiation of the lowest level of design details (whether they delegate tasks related to these design details, or whether they instantiate these details themselves): such is the essence of *determinate responsibility over design form*.

3.3.3 Challenging cases and typology limitations

As we set out to develop this typology, we were cognizant that long lists of categorization rules would make the framework unwieldy, or in some cases even fragile. We sought to balance parsimony of the typology with maximal coverage of engineering graduates' occupational outcomes. As a result, we expect there to be some number of occupational roles that may require a particularly nuanced analysis or simply may not be categorize-able using the typology.

Engineering faculty members create one such categorization dilemma: are professors of engineering themselves engineers? Should engineering graduates in pursuit of faculty roles be counted among those exiting the engineering pipeline? On the one hand engineering faculty members are the educators of future engineers and are experts in their engineering domains. But, in many (though not all) cases, they do not hold determinate responsibility over design forms because their engagement in teaching and basic research limits their participation in engineering practice. At the same time, they are not categorized effectively by the typology's other designations. Engineering faculty members represent one case where we simply recommend counting participants separately as their own occupational category. This approach lends transparency and allows the user of occupational outcomes results to further interpret or process the results as they wish.

Technical and/or engineering consultants compose another challenging case; however, here we assert that such individuals can likely be parsed into one of two type-categories depending on detailed information about their design responsibilities. For example, engineering consultants who provide design services in such realms as civil, structural, geotechnical, or environmental engineering disciplines, among others, may carry determinate design responsibility over the form of designs in cases where they supply finalized designs to construction contractors (or other external entities) while remaining affixed to the associated projects as "engineers of record" or "design authority." In these

types of cases, contractors cannot change designs at will and consulting engineers are liable for design outcomes, solidifying their position as engineers in the typology. In other cases, however, individuals may employ the title of "consultant" in seemingly engineering-related contexts, but not possess determinate design responsibility over form. Such may be the case when consultants are retained to provide design recommendations, carry out supporting studies, and/or provide various non-binding inputs to engineering teams. These latter roles are presumably better characterized as engineer-C's.

The field of systems engineering and its sub-domains also provide challenges to this categorization framework. The International Council on Systems Engineering (INCOSE) defines systems engineering quite broadly:

> *Systems Engineering is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, then proceeding with design synthesis and system validation while considering the complete problem* (INCOSE, 2017).

At first glance this definition appears primarily aligned with the *collaborative responsibilities over target design function* roles set, suggesting categorization of systems engineers as engineer-C's. However, the systems engineering discipline continues to grapple with its identity and occupational definition (see commentary within INCOSE, 2017; also: Emes et al., 2005; Kasser & Hitchens, 2012). Closer consideration of possible manifestations of the "design synthesis" and "system validation" aspects of the role suggests that responsibility for the final realized *form* and *consequent function* of systems can sometimes be part of the role as well. While systems engineers may be involved in design at a higher level of abstraction than other engineers (e.g., at the "architectural" level), these individuals may have sign-off authority on detailed design manifestations at lower levels, and may test designs and play a direct role in design refinements as a result of those tests (e.g., as opposed to simply reporting test results to another group) – such arrangements, should they be in place, point

toward possession of design responsibility over both form and function. Meanwhile, Sheard's (1996) "Twelve systems engineering roles", describes a pronounced diversity of what may be considered systems engineering; here we see analysts, designers, managers, engineers, and coordinators, among others, all listed under a systems engineering umbrella. It thus seems plausible that some systems engineering roles are better described as engineering roles while other are better described as engineer-C roles.

Finally, we call attention to roles within very small companies and start-ups. In these contexts, where individuals may wear many hats, we expect a blurring of some of the category boundaries. For example, certain roles in small organizations may involve interfacing and collaborating directly with engineers in ways that would be uncharacteristic of that same role in many other types of organizations. Consider a start-up company employing one individual whose job it is to both run the company's finances as well as to serve in a project manager capacity, directing and conferring with engineers. For such cases, we recommend simply employing the typology as described in this paper, whereby for any given individual, it is explored whether they may possess any of the forms of design responsibility listed in Table 3-9. This "start-up effect" may introduce increased breadth to the variety of roles categorized as engineers or engineer-C's, but provided that the roles legitimately include the form of design responsibility as recorded, measurement error is avoided.

3.3.4 Future work

Various next steps can serve to further validate the typology and to enhance its usability for researchers. First, the tangible markers of design responsibility (e.g., Table 3-9) can be further substantiated through field validation. This field research would assess the degree of corroboration between these markers and workers' and their managers' acknowledgement of the underlying

responsibilities, resulting in potential refinement to Table 3-9. Sampling for such studies would be of chief concern, as all elements of this typology are derived from commonalities across an intentionally broad range of engineering practice literature. We must avoid adding new markers to the list that are drawn from niche contexts; however, we should scour practice contexts for substantive examples that disprove the list in order to refine the wording to make it more robust.

Next, evaluating the typology's degree of coverage is prudent: for a given sample of engineering graduates, what percentage of their occupational outcomes over time are categorize-able by this typology? For the typology to be useful to the research community, high coverage is a necessity. Initial attempts at employing the typology for engineering schools' alumni surveys, for example, could serve as excellent opportunities to gauge coverage and to understand reasons for any coverage issues. Discerned reasons for coverage problems could prompt refinement to the typology to increase coverage – but as discussed, the benefits of any added categorization rules must be weighed against the usability benefits of a parsimonious framework.

In the typology's present form, the definition of *design domain* is largely left unresolved – and accommodation of varying design domains is not yet provided by the typology. For example, herein we state an assumption that engineers operate in specific contexts involving "design parameters rooted in applied sciences or mathematics" but we provide no such rubric for establishing the precise bounds of such contexts. A follow-on systematic review that helps to more clearly delineate those bounds may be prudent. Additionally, we envision that this typology could possibly be expanded into a third dimension – one where the idea of design responsibility as a roles delineator could be applied across other domains (e.g., apparel, culinary, multimedia, theatrical, etc.). Were such an expansion to be made, the typology could help clarify roles sets beyond engineering product development.

Finally, and importantly, the research community's inputs from studying engineering graduates' occupational outcomes should be used to evolve the typology and to inform the design of follow-on typology validation studies. This paper is intended to start a conversation about a new way of talking about engineering graduates' occupational outcomes. Enhancing the consistency and clarity by which we measure this important variable benefits the entire community, and this typology and its subsequent iterations can be a platform to facilitate this clarity.

3.3.5 Conclusions: Engineers, Engineer-C's, and shifting the conversation toward "design responsibility"

Adoption of an engineering graduates' occupational outcomes typology that acknowledges a range of engineering-relatedness among occupations has the potential to provide pronounced benefits to the engineering education research community. According to the U.S. Census Bureau, nearly 20% of engineering graduates (across all ages) are counted as leaving engineering specifically due to their obtaining of managerial roles outside of STEM (U.S. Census Bureau, 2014). Yet, legacy occupational measurement systems make it quite difficult to know the true nature of the work that these particular graduates have taken on – some likely remain closer to engineering than others. We ponder how many of these graduates would best be characterized as engineer-C's, rather than remain uncategorized, based upon this new typology. Relatedly, measurement of graduates' attrition from engineering roles can suffer from inconsistency or opacity if different researchers measure it in different ways. This typology offers a way for the research community to unify its occupational outcomes measurement method while enhancing one another's understanding of empirical results.

The rise of the Engineer-C's

The 21st century brings evidence that the number of individuals engaged in engineer-C work may be growing rapidly – for instance, the leading project management professional

society's membership quadrupled between 1999 and 2005 (DiVincenzo, 2006). Engineering educators are faced with a choice of whether to acknowledge that a significant number of engineering graduates will likely land at these types of roles, and if so, to decide whether engineering education should address student preparedness for such roles. The answer to the latter question is beyond the scope of this paper, but we contend that measurement of graduates' participation among engineer-C roles should be carried out nonetheless in order to best prepare educators to answer it in the near future.

An additional benefit of measuring engineering graduates' occupational outcomes with the increased granularity afforded by this three-tiered typology relates to efforts aimed at enhancing diversity and equality in the engineering workforce. If engineering attrition is measured in a binary fashion (e.g., persistence vs. departure), then we learn less about the nature of departures. Information about the alternate occupational paths pursued by underrepresented groups may support efforts aimed at increasing these groups' representation in core engineering roles. Seron et al. (2016), for example, describe an apparent tendency for female engineering students to gravitate toward project management roles on engineering teams, while males seem to associate more with hands-on design roles. This typology may help reveal inequality among its occupation sub-types if the research community employs it consistently across engineering career outcomes research.

Shifting the conversation

Williams (2002), Downey (2005), and others, contend that the nature of technological work is changing rapidly in the 21st century, and that an ever-broadening array of occupations will routinely engage with technology and play roles in its development. Indeed, lists of job titles and job profiles associated with technological development in our present era can be dizzying.

As engineering graduates participate in increasing varieties of jobs, educators will be faced with choices about how their academic institutions view and deal with this career dispersion. Keeping pace with ever-changing sets of job titles in real-time may be near impossible. Yet, decades of literature on the nature of engineering work suggest an enduring central theme about what it has consistently meant to be an engineer: design responsibility. Though we can't predict the future, a means of monitoring graduates' occupational outcomes based upon relatedness to this theme may serve an important benchmarking/comparison function that can reveal how workforce roles and graduates' participation patterns are evolving. Meanwhile, in our present time, engineering educators have the opportunity to foster renewed clarity about what it means to be an engineer by framing engineering work as centered upon design responsibility. Not only can this approach serve to further elucidate the widely-recognized core of engineering work, but the design responsibility gradient established in this typology may prove to be an enduring way of relating other work to this core as job titles continue to come and go.

Amid the recent push to clarify the meaning of engineering work, scholars of engineering education have built a compelling case that educators should include social, coordinative, and collaborative job characteristics in their conceptions of engineering practice (see: Bucciarelli, 2002; Trevelyan & Tilli, 2007; Trevelyan, 2010). These scholars emphasize that collaboration and coordination are central parts of engineering, not merely peripheral job attributes. We must underscore that this typology fully aligns with that notion. The typology highlights that engineering (and other occupations) involve collaboration in carrying out technical work – yet that engineers simultaneously possess a unique level of responsibility over design outcomes compared to other occupations. It is difficult to know if today's soon-to-be graduates understand this key distinction between types of work. These students are no doubt exposed to a complex

array of informal messages about typical engineer-C roles via social media and the popular press – such as one piece touting product managers as "the digital industry's rock stars" (Tsuchiyama, 2011).

In these changing times, and as we work to increase the engagement of underrepresented groups in engineering practice, we are compelled to investigate whether these groups' engagement is growing at the heart of engineering design responsibility, whether the growth is largely in the engineer-C roles, or in both. We aim not to negatively judge graduates' decisions to pursue engineer-C roles – in fact, enhancing engineering education's preparation of graduates for these roles may be prudent. But we contend that measurement of graduates' engagement in engineering roles is perhaps most accurately and most transparently achieved through the use of a stratified engineering-relatedness typology. Through this means, we can identify whether progress is attained at making the core of engineering work more inclusive and welcoming for all engineering graduates.

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4. Reconsidering the college-careers interface in engineering: Removing impediments to students' career development

4.1 Engineering schools confront a growing challenge

The National Academy of Engineering (NAE, 2005), the American Society for Engineering Education (ASEE, 2012) and other key stakeholder organizations regard undergraduate engineering education as a foundational component of aspiring engineers' professional development. Over the past two decades, such groups have launched campaigns to assess engineering degree programs' effectiveness at preparing students for engineering careers, and have proposed wide-ranging curricular and programmatic improvements toward this end, often informed by industry feedback (see, e.g., ASEE, 1996, 2012, 2015; NAE 2004, 2005). During these same decades, however, substantive changes have transpired in the careers landscapes faced by engineering students. The boundaries around engineering work have expanded and blurred during this timeframe, as traditionally categorized engineering roles have been joined in job markets by increasing numbers of engineering-related hybrid roles and new job formulations that attract engineering students (for a review, see: Chapter 3); further, engineering students are now commonly recruited for non-engineering roles (Carnevale et al., 2011; Langdon et al., 2011). Though the supply of engineering graduates has largely accommodated this expansion in variety of labor demand (Anft, 2013; Salzman, 2013), recent literature, reviewed herein, suggests that today's engineering students are increasingly at risk of being underprepared to make well-fitting career decisions – such as whether to pursue engineering, engineering-related, or non-engineering occupations – as they approach graduation. In this changing world, engineering educators face reckoning with the scope of their mission: to what extent should engineering schools take responsibility for undergraduate students' preparedness to make well-informed career decisions?

Implications of the variation in career plans among engineering students at the end of bachelor's degree programs require careful assessment. Upon initial inspection, such variation appears

benign: recent engineering graduates have fared notably well in job markets, whether in acquiring jobs within or outside of their fields of study. Unemployment rates among recent engineering graduates are presently low (e.g., at or below 4% across the primary engineering degree fields, as of January 2018), and under-employment rates are currently lower for recent engineering graduates than they are for recipients of all other bachelor's degree types, with the exception of nursing and education (Federal Reserve Bank of New York, 2018). Thus, while studies indicate that 20% - 30% of engineering students expect to work outside of their degree fields at their first full-time jobs (Chapter 1; see also: Atman et al., 2010), this career path variation does not appear to tend toward adverse employment outcomes for engineering students. Moreover, many of these ostensible "exits" from engineering career paths likely lead to positions in close proximity to traditionally categorized engineering roles, in areas such as project management, product management, or quantitative analysis, among others (See Chapter 1 for statistics on engineering students' post-graduation plans; see Chapter 3 for a discussion on occupations' engineering-relatedness).

Yet, despite favorable employment statistics for recent engineering graduates, other indicators suggest that opportunities exist for improvement in student-occupation matching during early career stages. Among students who successfully earn engineering degrees, attrition from traditional engineering career paths appears to be at least partly systemic, with certain student subsets exhibiting a greater likelihood of taking jobs outside of their degree field at or soon after graduation compared to their peers. These subsets include female students (Frehill, 2012; Ayre, et al., 2013; Glass et al., 2013), as well as students possessing certain self-perceptions about their skills and abilities, such as those with relatively high self-assessed interpersonal and leadership abilities (Chapter 1; see also: Atman et al., 2010), and those with relatively low confidence or perceived enjoyment in working with mathematics (Chpater 1; see also: Correll, 2001; Eris et al., 2010). Original empirical research (Chapter 2) indicates that these trends of disproportionate attrition may, in part, reflect missed

opportunities for more ideal student-job matching, as such matching may be constrained by students' under-informedness about variation in attributes across available engineering jobs. These findings, based on a random controlled job preference survey experiment conducted on over 1,000 senior year mechanical engineering students, as described in Chapter 2, suggest that becoming informed about particular attributes of a given engineering job affects job attraction differently, on average, for different types of students. The three student subsets discussed above – females, those with high self-assessed leadership potential, and those with low perceived enjoyment of working with mathematics – exhibited significant differences in their average job attraction, compared to their peers, in response to information about jobs' social characteristics, advancement opportunities into leadership roles, and mathematics intensity, respectively. Moreover, this study found that statistical models for students' job attraction that included interactions between students' characteristics and jobs' attributes explained significantly more variance in job attraction compared to similar models that omitted such interaction terms. These findings call attention to under-informedness as a potential risk factor for undue student attrition from engineering career paths: qualified students who might otherwise be drawn to working at a particular engineering role might be inclined to avoid the role if they are insufficiently aware of key job attributes.

Existing studies examining factors underlying engineering students' occupational outcomes often have not accounted for variability in what it can mean to work as an engineer, nor have they typically controlled for the extent that students are aware of this variability (Brunhaver et al., 2013). Such omissions make the implicit assumption that students possess a universal, homogenous conception of engineering work. This assumption appears to be increasingly unreasonable in today's world, as literature has reported on substantial differences in attributes across traditionally categorized engineering jobs in areas such as computational intensity, social interactivity, and career advancement prospects, among others (Perlow & Bailyn, 1997; Ranson, 2003; Goold, 2012; Brunhaver et al.,

2013), and as other studies have documented a growing presence of engineering-related hybrid jobs featuring elements of engineering work juxtaposed with work from other disciplines (Chapter 3; see also: Williams, 2002; Downey, 2005). These hybridizations have included elements of marketing, management, design, or data analysis, and such positions often exist alongside traditionally categorized engineering roles in workplaces. Hybrid roles, moreover, carry a wide range of job titles, most of which are not yet formally tracked in government labor statistics systems (see discussion within Chapter 3). Yet, the roles' titles often center on terms such as "designer," "manager," or "analyst" (e.g., "interface designer," "project manager," "product development manager," "system analyst," "decision analyst") (Chapter 3, Table 3-8). While some of these roles, such as project managers, are not new, the roles' prevalence have nonetheless undergone sharp increases since the turn of the 21st century – as suggested, in the case of project managers, by a quadrupling of membership in the primary professional society of project managers between 1999 and 2005 (DiVincenzo, 2006). Recent survey data indicates that 14% of graduating mechanical engineering seniors expected to work in these types of roles in their first full-time job after college or graduate school – moreover, students with such career expectations composed the majority, at 55%, of those in the survey's sample who expected to work outside of traditionally categorized engineering jobs after graduation (Chapter 1). While some of these roles' job titles, particularly those that include the term "manager," may appear to indicate positions more advanced than entry-level roles, contemporary students' expectations to work in such areas likely reflect companies' recent trend of developing entry-level variants of the positions. Tech giant Google, for example, has launched a popular "associate product manager" position for which it recruits candidates directly out of college (Levy, 2011), and other firms have created similarly-titled entry-level or early-career positions (Glassdoor, 2018a, 2018b, 2018c).

The presence of variety among engineering and engineering-related work underscores the importance of job attribute informedness in shaping engineering students' career intentions. This

variety likely introduces further complexity into students' process of forming an engineering professional identity during undergraduate educational years as they begin to explore job options. Development of a strong professional identity has often been examined as a key factor in relation to students' persistence from engineering school into engineering careers (Stevens et al., 2008; Matusovich et al., 2010; Cech et al., 2011; Eliot & Turns, 2011; Ayre et al., 2013; Hatmaker, 2013; Cech, 2015). In our recent survey study of senior year mechanical engineering students, we expectedly found a statistically significant association between strong professional identity (defined as a student's identification with one specific profession) and students' intention to work in engineering-titled occupations (Chapter 1). These results corroborate earlier findings, such as those from Matusovich et al. (2010), who found that students at highest risk of leaving engineering were those with "limited connection between engineering and their personal sense of self" (p. 300), and those from Ayre et al. (2013), who found that individuals who persisted in engineering careers more often reported possessing a "sense of belonging" to their specific field (p. 230). Yet, recent studies report that many engineering students struggle in formulating professional identity over the course of their undergraduate engineering school experience (Stevens et al., 2008; Lichtenstein et al., 2009). In our survey sample of over 1,000 mechanical engineering students, for example, 45% of these students did not identify with a specific profession (or were unsure about identifying with a profession) by their senior year (Chapter 1).

Recent evidence makes clear that today's undergraduate engineering students are often unconvinced about what they want to do for a living; yet, we ask: is the engineering educational experience designed for this type of an uncertain audience? Further, given that the undergraduate years encompass an influential period in the formation of professional perceptions and intentions (Stevens et al., 2008; Lichtenstein et al., 2009), what can engineering educators due to ensure that the occupational sorting that occurs at the college-careers interface is equitable, well-informed, and

conducive to satisfying student-occupation matches? We do not mean to imply that all students should be expected to attain a best-fitting occupation on the first try – literature on career development has highlighted that exploration and iteration are often necessary in achieving career fit (Ibarra, 1999, 2004; Ibarra & Barbulescu, 2010). Nor do we impose value judgment on whether an engineering, engineering-related, or non-engineering role is the best fit for a given student. Rather, we call attention to systemic nature of attrition from traditional engineering careers in the current system and inquire whether certain career development impediments exist that disproportionately hinder particular student subsets' pursuit of engineering careers.

We next review results from recent original survey experiment research (Chapter 2) indicating that specific information about engineering jobs can influence attraction to these jobs in different ways for different subsets of engineering students. We discuss implications of these findings in light of additional literature that suggests students' experiences during their undergraduate engineering education, as well as their exposure to longstanding reputations about engineering work, risks leaving them with incomplete or inaccurate impressions of the role possibilities available among traditionally categorized engineering jobs. We then conclude this chapter by reviewing possible constraints and limitations inherent in engineering education that can impede students' preparedness to make career-related decisions, while reviewing potential opportunities for educators to enhance preparedness.

4.2 Students' attraction to working in engineering: The critical role of job information

Since awareness about key job attributes has been shown to interact with engineering students' personal characteristics to influence their job attraction (Chapter 2), a lack of awareness about certain engineering job variants can limit the breadth of the profession's appeal across the spectrum of students. Personal characteristics found to be salient in such job preference interactions include gender, anticipation of early-career appointment to leadership roles, and anticipated enjoyment of

working with mathematics, among others (see: Chapter 2). Yet, engineering work carries enduring, generalized reputations in key areas related to jobs' attractiveness that do not accurately characterize all engineering jobs. In the absence of a more complete awareness about types of available positions, these "default" reputations can make engineering work more attractive to certain subsets of students compared to others, and under-informedness about job attribute variation across positions can potentially lead to relatively lower propensities for certain student subsets to be attracted to the prospect of working at traditionally categorized engineering jobs.

For example, literature suggests the prevalence of at least three role configurations among individual-contributor engineering jobs that differ substantively in their social characteristics: technical specialist roles that are largely individualistic but include periodic interaction (Kent & Noss, 2002, 2003; Alpers, 2010; Anderson et al., 2010); collaborative team-based roles that feature frequent or continual interaction (Bucciarelli & Kuhn, 1997; Bucciarelli, 2002; Trevelyan, 2010; Robinson, 2012; Stevens et al., 2015); and, roles that involve substantial coordination across team and organizational boundaries (Lakemond et al, 2006; Herbsleb, 2007; Trevelyan, 2007; Stevens et al., 2015). Studies indicate, however, that despite engineering schools' efforts to include elements of teamwork and communication in the engineering curriculum, engineering work still largely carries a reputation of being centered on individualistic technical contribution (Seron et al., 2018). Individualistic problem set assignments in engineering courses (Bucciarelli & Kuhn, 1997; Stevens et al., 2015) and tendencies toward role segregation within student project teams that isolate and "valorize" the individualistic technical work from the more administrative or coordinative work among team members (Seron et al., 2016, 2018) may perpetuate this reputation among students. In the latter case, studies have found that such role segregation tends to be gendered, with females exhibiting a higher propensity to take the more socially-focused administrative and coordinative roles compared to males (Cech 2013; Seron et

al., 2016, 2018). Studies critique at least two key aspects of this gendered role segregation: first, that the role segregation appears to be enabled by an engineering culture that fosters competitive establishment of technical hierarchies within teams through means that have undermined development of females' technical self-confidence (Seron et al., 2016), and, second, that this culture seems to convey that social and coordinative components of engineering work are not central to "real" engineering, despite these components' essential contributions to engineering projects' success and their integral place in industry engineering practice (Cech, 2013; Seron et al., 2018). Researchers have characterized processes of "professional socialization" based on these observations that shape males' and females' senses of fit in engineering roles, and have found these processes to pervade certain engineering educational experiences, such as the formation of student teams in courses (Seron et al., 2016, 2018). While these recent research efforts have advanced our understanding of such processes in order to help educators mitigate them and improve equality, the literature suggests that gendered role preferences will continue to replicate in contemporary samples of students until widespread reform manifests.

An investigation within our job preferences survey experiment (Chapter 2) examined the presence of gendered role preferences toward engineering positions that featured experimentally manipulated social characteristics. Experimental participants – senior year mechanical engineering students – were each asked to assess the appeal of several randomly manipulated job profiles, all of which were affixed the same job title ("Mechanical Design Engineer"). Here we found, as expected, that engineering job profiles that included more pronounced social characteristics – such as emphasis of collaborative or coordinative aspects of jobs – were rated higher, on average, by females, while job profiles that emphasized individualistic work were rated higher, on average, by males. However, all variants of the experimental job profiles were designed to embody common, industry-realistic

configurations. Findings thus suggest that if female students are under-informed about the availability of engineering roles with prevalent social characteristics, then they might harbor a reduced sense of appeal toward working in engineering, compared to if they were more informed about the range of engineering job options.

Survey experiment results also suggest that engineering students' informedness about opportunities for advancement from entry-level roles into leadership positions influences the appeal of jobs differently for different subsets of students (Chapter 2). Literature has long documented the engineering profession's struggle to establish clarity about the sets of advancement trajectories that compose engineering careers (see, e.g., Bailyn & Lynch, 1983; Shapira & Griffith, 1990; Watson & Meiksins, 1991; Biddle & Roberts, 1994; Allen & Katz, 1995; Perlow & Bailyn, 1997; Igbarria et al., 1999; Hodgson et al., 2011; Joseph et al., 2012; Paton & Hodgson, 2016). For instance, the profession has grappled with whether engineers' advancement from individual-contributor roles into management roles – a common occurrence (Biddle & Roberts, 1994; Badawy, 1995; Mael et al., 2001; Hodgson et al., 2011; Joseph et al., 2012) – constitutes a continuation of an engineering career, or marks a career change (Biddle & Roberts, 1994; Perlow & Bailyn, 1997; Trevelyan, 2007; Joseph et al., 2012). Citing the likely types of professional paths followed by engineering students, key engineering education advisors called for adding leadership development components to the engineering curriculum (NAE, 2004, 2005), yet, more than a decade since such calls, educators continue to struggle to integrate such elements into degree programs (Knight & Novoselich, 2017).

Suspecting, based on the literature, that engineering students may generally lack awareness about engineering careers' leadership growth opportunities, we tested for how such awareness might affect the appeal of engineering jobs among students. Again, through the use of a survey experiment involving engineering students assessing the appeal of manipulated job profiles (Chapter 2), we

examined the effect of including a statement in the profiles disclosing advancement opportunities associated with the job. The statement explained that in 1-2 years, job candidates would be eligible, if desired, to advance into project or product management roles. We found that mentioning these opportunities increased the appeal of jobs, on average, across the participant sample – but, more notably, we found that mentioning the opportunities increased the appeal of jobs to a significantly greater extent, on average, for students with higher self-appraisal of their leadership ability, compared to those with lower self-appraisals. This latter finding is relevant because studies have shown that those engineering students with higher self-appraisal of interpersonal or leadership abilities are more likely to expect to work outside of traditional engineering occupations after college compared to their peers (Chapter 1; see also: Atman et al., 2010). Engineering employers, meanwhile, currently express comparative difficulty in recruiting engineering graduates possessing such interpersonal and leadership abilities (Salzman & Lynn, 2010; Cappelli, 2015). Findings thus suggest that engineering students who possess leadership abilities might find the prospect of working in engineering to be more appealing, overall, if they are more aware of entry-level engineering positions' growth paths into leadership roles.

While the current engineering curriculum may insufficiently develop students' awareness of how leadership can be involved in typical engineering careers (Knight & Novoselech, 2017), the curriculum may encourage students' over-estimation of the extent that mathematical work is embedded in most engineering jobs (Winkelman, 2009). Engineering carries a general reputation as being a mathematically intensive profession (NAE, 2008); yet, specific occupational roles in engineering practice have been shown to vary considerably in the intensiveness of their inherent mathematics activity (Kent & Noss, 2002, Alpers, 2010; Goold, 2012). Studies have shown that some engineering positions are indeed best characterized as computational or analytical specialist roles,

requiring mastery of certain mathematical abilities; in many cases, such positions reside in dedicated expertise groups within firms or in special consultancies (Kent & Noss, 2002; Alpers, 2010). Other engineering roles, such as design engineering positions, however, are often better categorized as generalist roles – practitioners in these types of positions use math more conceptually, or through the aid of pre-existing analysis software programs or in collaboration with experts who run detailed analyses in support of their projects (Alpers, 2010; Anderson et al., 2010; Goold, 2012). Scholars of engineering education have expressed concern that the way mathematics coursework and math-based problem solving are enacted in the engineering curriculum may thwart students' awareness of how engineering design and problem-solving are frequently carried out in industry: by teams of individuals embodying different roles in collaborative pursuit of solutions to open-ended problems (Bucciarelli & Kuhn, 1997; Winkelman, 2009; Trevelyan, 2010). Literature, meanwhile, discusses that engineering practitioners often report that their math usage in practice is substantially less intensive compared to their math usage during engineering degree programs (Alpers, 2010; van der Wal et al., 2017).

Based on the literature, we suspected that engineering students might generally be under-informed about the variety of use patterns of mathematics across different engineering-titled roles in industry. By means of our survey experiment (Chapter 2), we examined how engineering students' sense of job appeal was influenced by their informedness about different levels math intensity among identically titled engineering positions. We found that two subsets of students – those who anticipated enjoying work involving advanced mathematics, and those who did not – responded significantly differently in their ratings of job profiles that described realistic engineering positions of differing mathematics intensity. Those students who anticipated enjoying work involving advanced math (56% of the survey's sample) expressed statistically similar appeal ratings across the job profiles, regardless of whether the profiles' described jobs involving intensive or non-intensive mathematics usage;

meanwhile, those students who did not anticipate enjoying working with advanced math (43% of the sample) expressed significantly lower job appeal when informed that engineering positions involved intensive math. All students who participated in this survey experiment were senior year students on track to complete accredited engineering degrees, so, while their mathematics aptitude likely varied, it is unlikely that many (or any) possessed a low aptitude for mathematics. These findings thus suggest that a substantive subset of engineering students – those who do not anticipate enjoying working with advanced math – are likely to find engineering work less appealing than their peers if students are generally under-informed about the variety of mathematics usage inherent in different types of engineering positions.

Finally, we found that two key beliefs of engineering students – students' satisfaction with opportunities to exercise creativity at engineering jobs, and students' strength of professional identity – were significantly associated with students' expectations to work at traditionally categorized engineering positions after graduation (Chapter 1), and that these beliefs were also components of significant interaction effects in our survey experiment on job attraction (Chapter 2). In the latter case, we observed that conditional subsets of students based on the beliefs – those satisfied with opportunities for creativity at engineering jobs, and those identifying with one specific profession – both reported significantly higher job appeal ratings compared to their peers, on average, when rating engineering job profiles that expressed an expected commitment duration to remain with the jobs' employer for three years. We examined the effect of expected job commitment duration upon students' attraction to jobs because various forms of career mobility-restrictive policies – such as non-compete covenants (Lester, 2001; Marx, 2011; Cappelli & Keller, 2014) and training repayment agreements tied to commitment durations (Lester, 2001; Long, 2005; Cappelli & Keller, 2014) – have gained attention for their enactment by engineering employers in recent years (for overviews, see:

Lobel, 2013; Hyde, 2015). These policies, designed to protect firms' intellectual property and investment in employee development, have received scrutiny due to concerns that they tend to push technical talent away from regions that allow such policies, and toward those that prohibit them (Marx et al., 2015), and that they demotivate employees (Amir & Lobel, 2013). An experimental study, however, found that those job candidates who perceived a position's work as creative, rather than rote, were comparatively less demotivated by mobility-restrictive policies (Amir & Lobel, 2013). Research also found employers' investment in specialized training in areas aligned with individuals' professional interests to be associated with employees' increased retention at jobs (Benson et al., 2004). Legal precedent shows that commitment duration policies tied to employer-funded specialized training, rather than general skills training, are more likely to be upheld by courts (Lester, 2001).

In the job appeal survey experiment (Chapter 2), we tested for the effect of randomly introducing a commitment duration expectation, coupled with special skills training, to experimental job profiles. We observed that those engineering students who perceived engineering work to be creative, as well as those students with strong professional identities, reacted more positively to the presence of this job attribute than their peers. These result suggest that development of engineering students' sense that engineering work is creative, and students' sense of professional identity, both may make students more resilient to potentially adverse information about an engineering job (e.g., knowledge of a mobility-restrictive policy).

4.3 Reconsidering the college-careers interface in engineering

As cohorts of contemporary engineering students consider job markets or the prospects of graduate study as they complete engineering school, they must contemplate a larger array of job options and career path possibilities than their recent predecessors did. Further, they must do so despite undergoing the same number of preparatory years, composed of roughly the same core

curriculum, that their predecessors underwent (Seely, 2005; Sheppard et al., 2009). While the survey experiment described in Chapter 2 identifies job attributes that attract key subsets of students to traditionally categorized engineering jobs, it is clear that students' decisions on whether to pursue engineering work are far from binary. These decisions will increasingly involve navigating job options that fall along a spectrum of engineering-relatedness (see: Chapter 3). We presume that the role of job information becomes even more critical in such a multi-faceted careers landscape. Labor economists, for instance, have called attention to limitations of information flows in complex labor markets, suggesting that ideal candidate-job matching is often hindered by individuals' lack of awareness about job possibilities (Autor, 2001; Manning, 2011). In the case of soon-to-be engineering graduates, engineering schools face consideration of whether better developing students' awareness of career options should fall within their scope of developing "professional preparedness" in these graduates.

Though we lack information about the causal phenomena underlying graduates' sorting into the various alternative career paths that fall outside of traditional engineering routes, a multinomial analysis of engineering students' occupational expectations (Chapter 1) provides associational data on such sorting. This analysis identifies key student characteristics and perceptions that are uniquely associated with various occupational outcomes types, highlighting that the students who expect to work outside of traditional engineering roles are a notably heterogeneous group who likely depart traditional engineering paths for different reasons (See: Chapter 1, Table 1-6). For instance, the multinomial model indicates that the students who pursue alternative roles that are engineering-related (e.g., in project or product management, in technical consulting, or as analysts) expect to earn similar salaries, on average, as engineers, yet, are less satisfied with the creative opportunities they perceive to exist at engineering jobs, are more anticipatory of being promoted to an early-career leadership roles,

and find less enjoyment in working with advanced mathematics, among other differences. In contrast, those pursuing alternative roles in management consulting or finance, expect to earn higher salaries, on average, than engineers, yet, are similarly satisfied with creative opportunities at engineering jobs, are more anticipatory of promotion into an early-career leadership role, and find less enjoyment in working with advanced mathematics. Unique sets of factors are shown to be associated with each of the four alternative career pathways analyzed in the multinomial analysis (Chapter 1, Table 1-6). With presently available data, we are unsure about how comprehensively students are informed about key job attribute differences across roles within these alternative pathways, but, similar to the case of the job attraction survey experiment outlined in Chapter 2, we suspect job attraction to depend, in part, on students' degree of informedness about roles. If informedness is imperfect, as it most likely is (Autor, 2001; Manning, 2011), then the engineering profession's enduring, generalized reputations in certain key areas, as discussed in Section 4.2, might hinder ideal student-career matching by masking key differences across available engineering roles.

4.3.1 Constraints on preparedness: The strained boundaries of traditional degree programs

The literature and empirical findings reviewed in this chapter highlight the potential risk that students' under-informedness about engineering jobs poses toward sub-optimal student-career matching. We are far from the first, however, to warn about the limits of the engineering curriculum in preparing students for the diversity of work inherent in the fast-changing ecosystems of product and technology development. Williams (2002), for instance, describes an "expansive disintegration" of engineering work (p. 30), suggesting that engineering's progression toward "an open-ended Profession of Everything" (p. 70) strains engineering schools' ability to address the breadth of work varieties a graduate might face. Downey (2005) critiques the curriculum's core, which, at most engineering schools, remains primarily filled by coursework in the engineering sciences: "at present,

engineering curricula everywhere tend to include a technical core and a non-technical periphery" (p. 592), instead, he recommends, schools should "locate and champion both technical and non-technical bodies of knowledge at the core" (p. 592). The National Academy of Engineering (2004), acknowledges that "the population of individuals who are involved with or affected by technology …will be increasingly diverse and multidisciplinary" (p. 53), and prescribes, in its influential "Educating the Engineer of 2020" report (2005), that engineering educators do more to "introduce interdisciplinary learning in the undergraduate [engineering] environment" (p. 55). Meanwhile, Sheppard et al. (2009), Trevelyan (2010), Knight & Novoselich (2017), and others, critique students' lack of greater exposure to the social, interactive, and leadership elements of engineering work in the core engineering curriculum, citing these elements' centrality to many roles in engineering practice. While such educational components do exist at many of today's engineering schools, they are often placed at the outskirts of the learning experience, in optional or co-curricular experiences (see: Knight and Novoselich, 2017).

Yet, the case for diversifying the learning at engineering's curricular core centers not solely upon skills development – it is also about cultivating students' balanced, accurate, and well-informed images of engineering's breadth of job configurations. Denying social and coordinative skills (Seron et al., 2018), problem-framing skills (Downey, 2005), and leadership skills (Knight & Novoselich, 2017) their central place among learning experiences could limit not only students' development in these key areas, but also their conceptions of the types of work that can compose a successful engineering career.

Literature widely acknowledges that the present undergraduate engineering curriculum cannot, in four years, take on the additional scope of comprehensively exposing students to the myriad types of work they could face in today's product and technology development ecosystems. The

engineering curriculum has been referred to as "overstuffed" (King, 2010; Graham, 2018), "overloaded" (Seely, 2005), and "overcrowded" (Trevelyan, 2010; ASEE, 2012), due in part to the curriculum's longstanding retention of a theory-based core that limits the time available for exploration of non-technical elements of engineering practice (Sheppard et al, 2009). In light of this curricular strain, influential advisors on engineering education have advocated for expanding the standard engineering credentialing process to six years, consisting of a four-year period of general education, followed by a period of Master's-level specialization (see, e.g., NAE, 2005; Duderstadt, 2010).

The concept of an extension alone, however, does not address how educators will prepare students for choosing a well-fitting area of specialization or occupational pursuit. As researchers have observed, it is not uncommon for engineering students to be uncertain about their professional identities and career aspirations at the end of four years of undergraduate study (Stevens et al., 2008; Lichtenstein et al., 2009). We conclude this chapter with a brief review of possible means by which engineering educators can enhance their students' preparedness for career choices based on prior studies and recent engineering education reform proposals.

4.3.2 Opportunities to enhance preparedness for key choices

Students' opportunities to contemplate and explore varied engineering roles are substantially limited in the traditional four-year engineering undergraduate period (Seron & Silbey, 2009; Sheppard et al., 2009). Yet, literature on career development highlights the importance of roles awareness, exploration, and self-reflection in developing individuals' sense of career fit (Ibarra, 1999; Eliot & Turns, 2011). A recent and growing literature identifies mechanisms for building such awareness and facilitating exploration and reflection among engineering students. These mechanisms center on themes of: faculty-student engagement (Chubin et al., 2005; Lichtenstein et al., 2009; Amelink &

Creamer, 2010; ASEE, 2012), pre-professional work experiences (Atman et al., 2010; Zhao & Linden, 2011; Malcom & Feder, 2016), deferred declaration of specialty (NAE, 2005; Duderstadt, 2010), and a softening of the boundary around institutional education (e.g., extending education into just-in-time and lifelong learning realms) (NAE, 2005; Duderstadt, 2010; NAE, 2017). Foundational to all such themes, however, is a call for adapting engineering education to "legitimize and encourage becoming more than one thing, i.e., more than one type of technical professional" (Downey, 2005, p. 592).

Studies have shown that faculty-student interactions can strengthen engineering students' confidence in career directions and help them build professional identity (Chubin et al., 2005; Lichtenstein et al., 2009; Amelink & Creamer, 2010). Yet, assessment reports on engineering education have found that faculty members' often limited industry experiences can potentially hinder their ability to connect with students about careers and professional development (ASEE, 2012, 2017). Recommendations in recent ASEE reports (2012, 2017) call for engineering schools to instantiate programs allowing faculty members to acquire more industry exposure, such as by encouraging gap years prior to entering the tenure track, promoting industry sabbaticals, and recruiting a greater proportion of "professors of the practice" with industry backgrounds. When coupled with sufficient faculty-student ratios and institutional cultures that encourage faculty to take a role in students' career development, such efforts could bolster a valuable career-related information channel for students.

Engineering students' participation in internships, co-ops, and other pre-professional work experiences have also been identified as a key source of awareness about real-world work roles (Atman et al., 2010; Zhao & Linden, 2011; Malcom & Feder, 2016). Internships can help engineering students discover connections between their interests and compatible roles in engineering workplaces (Malcom & Feder, 2016), and have been identified as a means for students to experience exercising

creativity in engineering contexts (Zhao & Linden, 2011). Though findings are associational, a large-scale study indicates that students who participate in internships are significantly more likely to plan to work in their field of study after graduation (Atman et al., 2010). Yet, students face differing opportunities to engage in internships, co-ops, and other forms of pre-professional work depending on their university. The summer season provides such an opportunity for many students, but summers are limited in number and are time-restricted. Some engineering schools, such as those at Northeastern University (2018), Purdue University (2018), and Drexel University (2018), among others, offer a means for students to undertake one or more longer-term co-op employment assignments (e.g., typically six months in duration) integral to their undergraduate degree program, often for degree credit. Such programs correspond with extended duration bachelor's degrees – usually 5-years in length – and could be considered in tandem with other curricular reforms designed to enhance students' preparedness for career choices, such as deferred specialization schemes and bachelor's-to-master's programs.

Deferred specialization stands out as a recommendation in key recent reports on engineering curricular reform (NAE, 2005; Duderstadt, 2010). This approach centers on adapting the undergraduate engineering degree to be a general liberal-arts educational foundation, while establishing a distinct period for intensive study in an engineering specialty area during the Master's degree years. The National Academy of Engineering (2005), further, notes that such a two-stage credentialing structure provides an off-ramp at the end of the undergraduate years for students who wish shift toward various other (e.g., less engineering-related) career pursuits. Duderstadt (2010), similarly, proposes that the engineering bachelor's degree could be broadened to serve as a general liberal arts degree for any students with engineering-related interests. This type of proposal would allow students to sample engineering topics while attaining a bachelor's-level foundation suitable for various career pursuits. Yet, deferring the timeline for specialization does not, in itself, help students

become more informed about engineering career options. Toward this end, the Massachusetts Institute of Technology (2018a) recently began testing a different approach for adapting the undergraduate educational experience that facilitates a deferral of students' choice of degree major. In its New Engineering Education Transformation (NEET) program, MIT offers engineering students the option of enrolling in a project-based engineering bachelor's curriculum, where project-centric coursework is introduced earlier in the undergraduate years (e.g., at the beginning of their sophomore year) and where students can delay choosing their major until the end of sophomore year, after they have had a chance to experience project work in a disciplinary area of their choosing (MIT, 2018a). Undergraduate engineering students at Stanford University, meanwhile, can declare their degree major as late as the start of their junior year (Stanford, 2018). While the concept of deferred specialization may increase students' opportunities to accrue valuable experiences prior to deciding on a specialty, this approach, alone, lacks an explicit means for students to gain information about the details of industry job variants.

A hybrid strategy, discussed increasingly in recent years, begins with a degree-based engineering education (either at Bachelor's or graduate levels), but extends education into individuals' careers through follow-on coursework taken in a distributed and as-needed manner (NAE, 2005; Duderstadt, 2010; NAE, 2017). Such an approach can be facilitated through various forms of online, distance, or flexible learning. While these learning concepts are not new, a more recent development in engineering education has been the conceptualization of how these types of learning could be part of the engineering credentialing process, and how institutions can help scaffold individuals' programs of study. For instance, Georgia Institute of Technology (2018) has recently launched an initiative that will grant students "microcredentials" for coursework taken in a distributed manner; further, Georgia Tech will allow students to construct a "decentralized transcript" that "combines evidence of learning

and achievements into credentials that are relevant to potential employers" (p. 6). The National Academy of Engineering (2005) has envisioned engineering schools' development of "'executive' technical degrees similar to executive MBAs" that are designed for mid-career technical professions to tune their knowledge base to align with changing work demands or interests (p. 55). MIT (2018b), meanwhile, has established "MicroMasters" credentials designed to be earned in an online manner by working professionals and those seeking to adjust their career trajectories; these microcredentials can also build credit toward a formal Master's degree. Allowing individuals to build customized programs of study that are informed by their exploratory real-world work experiences aligns with key theoretic propositions on how individuals achieve career fit through processes of trial, adjustment, and convergence toward a career identity over time (Lent et al., 1994; Ibarra, 1999; Ibarra & Barbalescu, 2010). This approach also addresses concern of an "overstuffed" engineering curriculum and the challenge of facilitating individuals' specialization within the constraints of a traditional engineering degree. But, aside from enabling tailored skills development over a more flexible timeline, the approach also allows individuals to develop informedness about specific jobs before "completing" their education.

Whether through increased faculty engagement and mentorship, through facilitation of varied pre-professional experiences, or through flexible credentialing processes that allow for students' exploration and customization, educators have options to help students increase their informedness about jobs in engineering and engineering-related fields. The empirical findings summarized in this chapter suggest that students' awareness of jobs' unique social characteristics, leadership advancement opportunities, and mathematics intensity are particularly salient in shaping interest in jobs. There are almost certainly additional important job dimensions as well. Given that engineering work carries longstanding reputations in certain areas – reputations that do not accurately reflect all job

configurations – enhancing students' awareness about jobs could boost the overall appeal of engineering work and mitigate some students' propensities to withdraw from engineering careers. In light of the growing variety of job opportunities available to engineering students – some more closely related to engineering than others – engineering educators should revisit the scope of their mission to provide "professional preparedness." To help foster a diverse, satisfied, and confident engineering workforce, educators should consider embracing career decision preparedness as an integral part of professional preparedness.

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