Characterizing Engineering Work in a Changing World:

Synthesis of a Typology for Engineering Graduates' Occupational Outcomes

James N. Magarian and Warren P. Seering

Revision 11/28/2018[1]

---

[1] An earlier version of this paper appears as a doctoral dissertation chapter from the first author at the Massachusetts Institute of Technology (September 2018)

Abstract

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, such as in studies of underrepresented groups' persistence in engineering. 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. The review identifies "design responsibility" – responsibility for the outcomes of design implementation, inclusive of safety, ethicality, and general effectiveness of designs – as an enduring commonality among engineers. Subsequent stages of the review then uncover how this design responsibility has often manifested in engineering practice. Based on the literature 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 – showing how the types can be distinguished based on the nature of design responsibility associated with each. These definitions thus serve as the foundation for a stratified typology of occupations' engineering-relatedness. We conclude by discussing how utilization of this stratified approach for measuring engineering graduates' occupational outcomes can enhance transparency and consistency among studies that examine such outcomes. By building the typology upon a distilled notion of fundamental job responsibility, 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.

Contents

Part 1: Critical Need

1.1 The case for a unifying framework
1.2 A history of engineering identity crises
1.3 Reconciling key competing perspectives
1.4 Pragmatic challenges of categorization
1.5 Purpose and criteria for a new typology

Part 2: Systematic Exploration of Engineering Work

2.1 Overview of sequential literature review approach
2.2 Search-specific questions, methods, and literature review results
2.3 Limitations of methods and results

Part 3: Typology Synthesis and Discussion

3.1 Typology synthesis
3.2 Employing the typology
3.3 Challenging cases and typology limitations
3.4 Future work
3.5 Conclusions: Engineers, Engineer-C's, and shifting the conversation toward "design responsibility"

Part 1: Critical Need

1.1 Engineering Work – The Case for a Unifying Framework

At a time when engineering educators strive to align student aspirations with careers in engineering, 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, without 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* (U.S. BLS, 2016), to the National Science Foundation's *Characteristics of Recent Science and Engineering Graduates* (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.

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.

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.

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.

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: A Categorization Scheme that Adds Clarity and Facilitates Consistency

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.

Part 2: Systematic Exploration – Discerning the Core and Extended Network of Engineering Work in the 21st Century

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.

2.2 Search-specific Questions, Methods, and Literature Review Results

Figure 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.

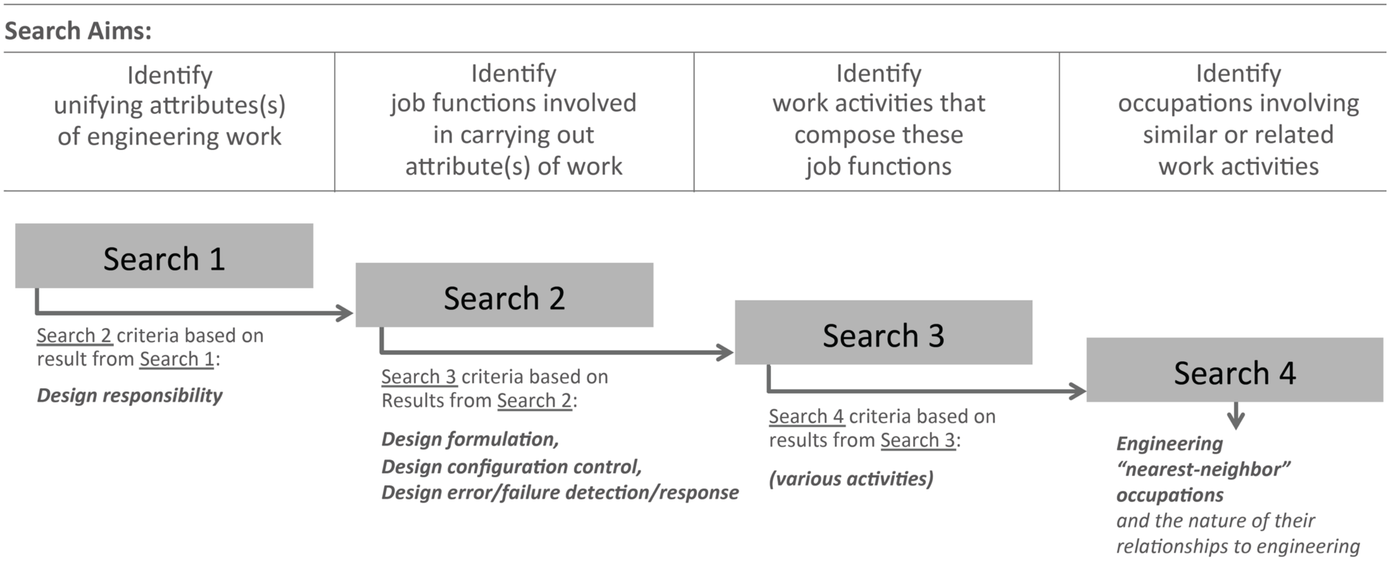


Figure 1 – Sequential nature of searches employed in systematic literature review

2.2.1 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 Table 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 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. The final set of cluster statements is a result of reconciliation of each coauthor's review and analysis of the set of sources. Table 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 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 2 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 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 and Serra, 2013, p. 181).
- "Engineers can expect to be held accountable, if not legally liable…for caused harms" (Harris, 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 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 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 2 – Results from Search 1: Attributes that unify and dis-unify engineering professionals [continued]

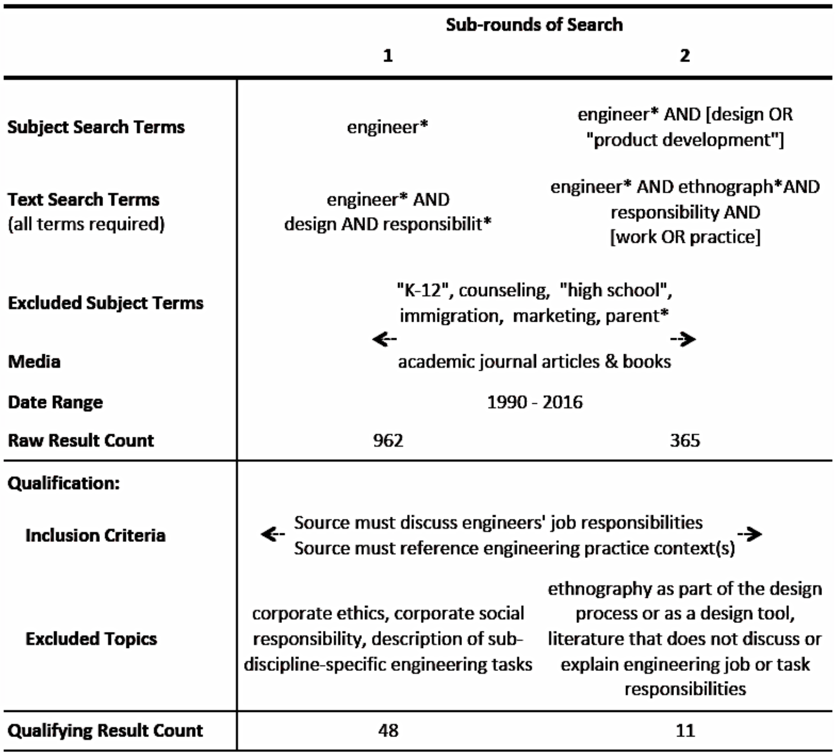
Source Topic Area	Supporting Sources	What attributes of engineering are discussed as unifying or dis-unifying it as a profession?	
		Unifying	Dis-unifying
Engineering ethics textbooks	Schlossberger (1993); Unger (1994); Beder (1998); Vesilind and Gunn (1998); Fleddermann (2004); Martin and Schinzinger (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)	

2.2.2 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. 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.

Table 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

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 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. The job function names and the sets of sources supporting each reflect a reconciliation of the two authors’ separate content analyses.

Table 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

Table 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)	
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
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 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).

2.2.3 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 Table 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 5.

Table 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

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. Again, the resultant set of cluster statements resulted from reconciling both coauthors' reviews. Table 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.

Table 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 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

The activities listed in Table 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.

2.2.4 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 7.

Table 7 – Criteria 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 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 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 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 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 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.

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.

Part 3: Typology Synthesis and Discussion

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 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.

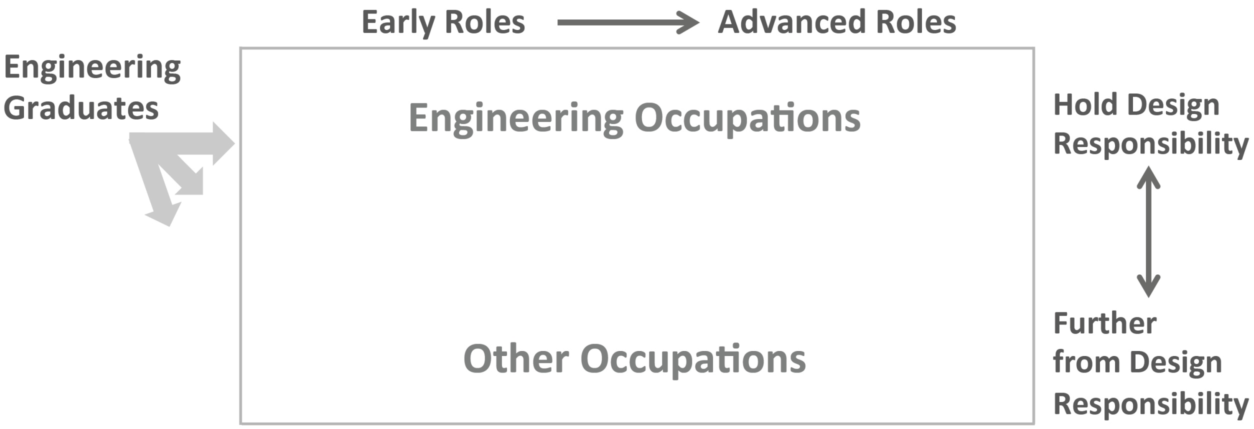


Figure 2 – Partial construction of engineering graduates' occupational outcomes typology

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 8). Time spent reviewing modern job descriptions in technology development labor markets make it clear, as one author states, that: "engineer[s] will become more and more engaged in broad, trans-disciplinary collaboration" (Sorensen, 2009, p. 103).

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

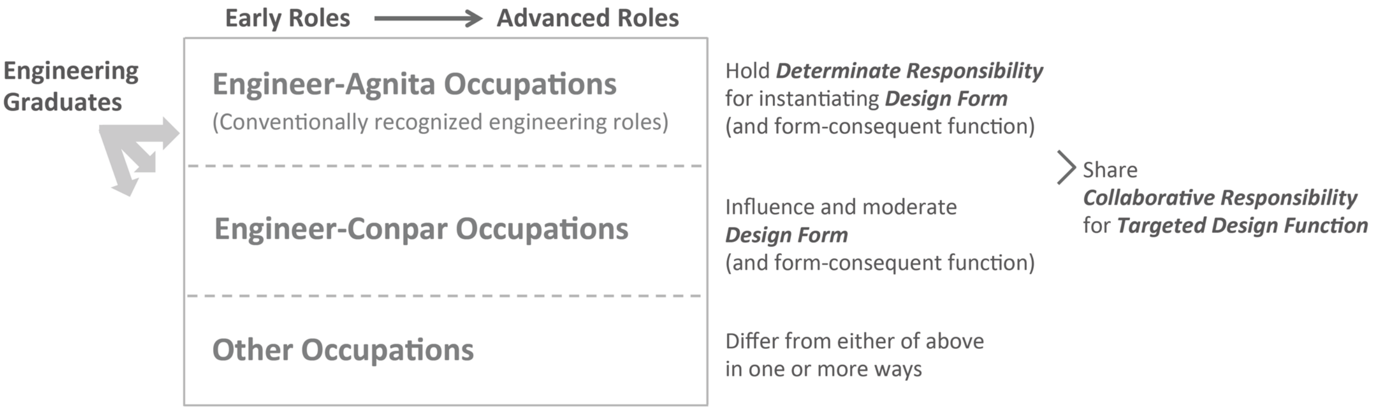


Figure 3 – Expansion of engineering graduates' occupational outcomes typology

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 describes system analysts' role to "confirm that the designed system will meet requirements," inclusive of conducting modeling to ascertain design performance (1996).
- Kemper and Sanders describe an interplay between engineers and industrial designers, whereby stylistic and usability attributes of designs are influenced by the latter (2001).
- Van de Weerd, et. al., illustrate product managers' role in establishing product requirements based on customer needs and parsing these requirements into specific planned product releases (2006).
- Rauniar, et. al., 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 (2008).
- Onarheim describes project managers' responsibility for translating "target product profiles" into design constraints through a process described as "establishing corner flags" (2012).
- *O*Net* 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" (2017).

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); and 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 9, alongside distilled markers of *determinate responsibility over design form* based upon our review (e.g., Search 3 results). The characteristics summarized in Table 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 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 9 indicates an individual holds responsibility at the associated categorical level (e.g., collaborative-over-function or determinate-over-form). Table 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.

Table 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*

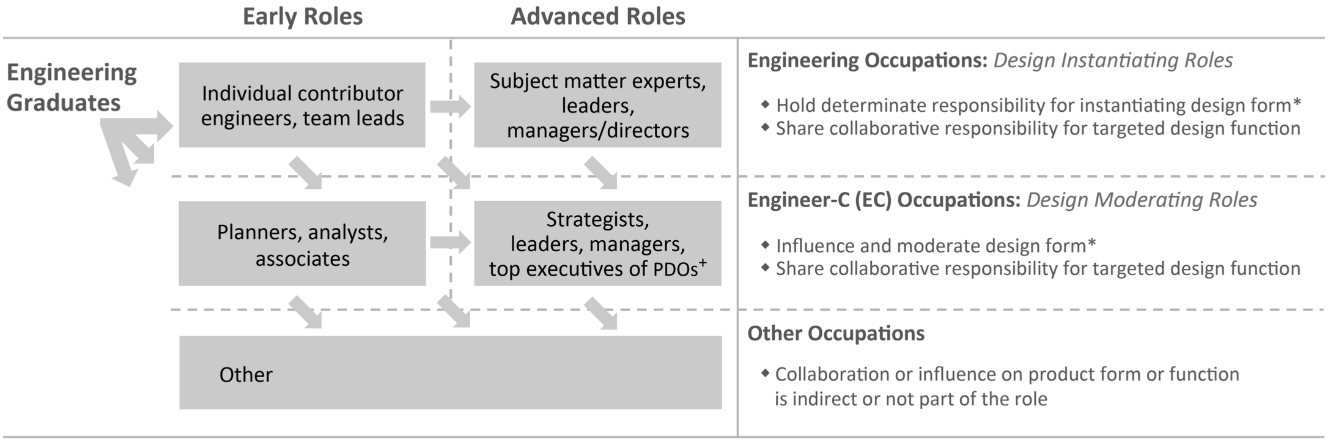
Individual belongs to an occupation that:

- 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

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.

Full instantiation of the engineering graduates' occupational outcomes typology based upon Propositions 1-5 is shown in Figure 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 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.



* Here we refer to both design form and form-consequent function
⁺ PDO = Product (or, process/service/system) Development Organization

Figure 4 – Engineering graduates' occupational outcomes typology with notional career progressions and dispersion patterns overlaid

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 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 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 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 merely one 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 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 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 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 and 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 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 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 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.

3.4 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 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 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.

3.5 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-Cs

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.

References

ABET Engineering Accreditation Commission. (2015). *Criteria for Accrediting Engineering Programs.* ABET.

Adams, P. S. (1999). Establishing a safe design process. *Professional Safety*, *44*(11), 29-32.

Ahmad, N., Wynn, D. C., & Clarkson, P. J. (2013). Change impact on a product and its redesign process: a tool for knowledge capture and reuse. *Research in Engineering Design*, *24*(3), 219-244.

Aiello, B., & Sachs, L. (2016). *Agile application lifecycle management: Using DevOps to drive process improvement*. Boston, MA: Addison-Wesley.

Allard, S., Levine, K. J., & Tenopir, C. (2009). Design engineers and technical professionals at work: Observing information usage in the workplace. *Journal of the Association for Information Science and Technology*, *60*(3), 443-454.

Allen, T. J., & Katz, R. (1995). The project-oriented engineer: a dilemma for human resource management. *R&D Management*, *25*(2), 129-140.

American Institute of Chemical Engineers (AIChE). (2016). About AIChE. Retrieved from: http://www.aiche.org/about

American Society of Civil Engineers (ASCE). (2016). About ASCE. Retrieved from: http://www.asce.org/about_asce/

American Society for Engineering Education (ASEE). (2016). Transforming undergraduate education in engineering: about TUEE. Retrieved from: http://tuee.asee.org/about/

American Society of Mechanical Engineers (ASME). (2016a). Engineering history. Retrieved from: https://www.asme.org/about-asme/engineering-history

American Society of Mechanical Engineers (ASME). (2016b). About ASME. Retrieved from: https://www.asme.org/about-asme

Anderson, D. M. (2004). *Design for manufacturability and concurrent engineering*. Lafayette, CA: CIM Press.

Annacchino, M. (2003). *New Product Development: From Initial Idea to Product Management*. Oxford, UK: Butterworth-Heinemann.

Antoniou, Y., Assimakopoulos, M., & Chatzis, K. (2007). The national identity of inter-war greek engineers: elitism, rationalization, technocracy, and reactionary modernism. *History and technology*, *23*(3), 241-261.

Armstrong, J. H., Dixon, J. R., & Robinson, S. (1999). *The decision makers: Ethics for engineers*. London, UK: Thomas Telford.

Armstrong, S. (2001). *Engineering and product development management: the holistic approach*. Cambridge University Press.

Atman, C. J., Sheppard, S. D., Turns, J., Adams, R. S., Fleming, L. N., Stevens, R., ... & Yasuhara, K. (2010). *Enabling engineering student success: The final report for the center for the advancement of engineering education*. Center for the Advancement of Engineering Education (CAEE).

Auyang, S. Y. (2009). *Engineering— an endless frontier*. Harvard University Press.

Avvakumovits, O. (1996). Supervise, inspect, or observe? The structural engineer's role in construction. *Practice Periodical on Structural Design and Construction*, *1*(3), 79-80.

Ayre, M., Mills, J., & Gill, J. (2013). 'Yes, I do belong': The women who stay in engineering. *Engineering Studies*, *5*(3), 216-232.

Bacharach, S. B., Bamberger, P., & Conley, S. C. (1990). Work processes, role conflict, and role overload: The case of nurses and engineers in the public sector. *Work and Occupations*, *17*(2), 199-228.

Baddour, R. F., Holley Jr, M. J., Koppen, O. C., Mann, R. W., Powell, S. C., Reintjes, J. F., Shaw, M. C., Stenning, A. H., Wadleigh, K. R., Whitaker, H. P., & Taylor, E. S. (1961). Report on engineering design. *Journal of Engineering Education*, 51(8), 645–660.

Bailyn, L., & Lynch, J. T. (1983). Engineering as a life-long career: Its meaning, its satisfactions, its difficulties. *Journal of Occupational Behaviour*, *4*(4), 263-283.

Baird, F., Moore, C. J., & Jagodzinski, A. P. (2000). An ethnographic study of engineering design teams at Rolls-Royce Aerospace. *Design Studies*, *21*(4), 333-355.

Baranowski, M. (2011). Rebranding engineering: Challenges and opportunities. *The Bridge*, 41(2), 12-16.

Basart, J. M., & Serra, M. (2013). Engineering ethics beyond engineers' ethics. *Science and Engineering Ethics*, *19*(1), 179-187.

Baura, G. (2006). *Engineering ethics: An industrial perspective*. Cambridge, MA: Academic Press.

Beder, S. (1998). *The new engineer: Management and professional responsibility in a changing world*. Melbourne, Australia: Macmillan Education.

Benavides, E. M. (2012). *Advanced engineering design: An integrated approach*. Cambridge, UK: Woodhead Publishing.

Berczuk, S. P., & Appleton, B. (2002). *Software Configuration Management Patterns: Effective Teamwork, Practical Integration*. Boston, MA: Addison-Wesley.

Bibby, L., Austin, S., & Bouchlaghem, D. (2006). The impact of a design management training initiative on project performance. *Engineering, Construction, and Architectural Management*, *13*(1), 7-26.

Biddle, J., & Roberts, K. (1994). Private sector scientists and engineers and the transition to management. *Journal of Human Resources*, 29(1), 82-107.

Boin, A., & Schulman, P. (2008). Assessing NASA's safety culture: the limits and possibilities of high-reliability theory. *Public Administration Review*, *68*(6), 1050-1062.

Borrego, M., Foster, M. J., & Froyd, J. E. (2014). Systematic literature reviews in engineering education and other developing interdisciplinary fields. *Journal of Engineering Education*, *103*(1), 45-76.

Borrego, M., Foster, M. J., & Froyd, J. E. (2015). What Is the State of the Art of Systematic Review in Engineering Education?. *Journal of Engineering Education*, *104*(2), 212-242.

Bowen, W. R. (2014). *Engineering ethics: challenges and opportunities*. Berlin, Germany: Springer Science+Business.

Brauer, C. S. (2013). Just sustainability? Sustainability and social justice in professional codes of ethics for engineers. *Science and Engineering Ethics*, *19*(3), 875-891.

Britton, G. A., & Torvinen, S. (2013). *Design synthesis: Integrated product and manufacturing system design*. Boca Raton, FL: CRC Press.

Brown, S. (2007). Forensic engineering: Reduction of risk and improving technology (for all things great and small). *Engineering Failure Analysis*, *14*(6), 1019-1037.

Bucciarelli, L. L. (1994). *Designing engineers*. MIT press.

Bucciarelli, L. L. (2002). Between thought and object in engineering design. *Design Studies*, *23*(3), 219-231.

Buckley, F. J. (1996). Implementing configuration management: Hardware, software, and firmware. Los Alamitos, CA: IEEE Press.

Burk, R. C. (2011). Systems engineering in professional practice. In Parnell, G. S., Driscoll, P. J., & Henderson, D. L. (Eds.), *Decision Making in Systems Engineering and Management*. Hoboken, NJ: John Wiley & Sons.

Burke, R. J. (1969). Effects of aging on engineer's satisfactions and metal health: Skill obsolescence. *Academy of Management Journal*, *12*(4), 479-486.

Busby, J. S., & Coeckelbergh, M. (2003). The social ascription of obligations to engineers. *Science and Engineering Ethics*, *9*(3), 363-376.

Busby, J. S., & Strutt, J. E. (2001). What limits the ability of design organizations to predict failure?. *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, *215*(10), 1471-1474.

Bush, V. (1965). The engineer. In Love, A., & Childers, J. S. (Eds.), *Listen to leaders in engineering*. Atlanta, GA: Tupper and Love.

Cadden, T., & Downes, S. J. (2013). Developing a business process for product development. *Business Process Management Journal*, *19*(4), 715-736.

Catalano, G. D. (2014). Engineering ethics: Peace, justice, and the earth. *Synthesis Lectures on Engineering, Technology and Society*, *8*(2), 1-85.

Cataldo, M., & Herbsleb, J. D. (2013). Coordination breakdowns and their impact on development productivity and software failures. *IEEE Transactions on Software Engineering*, *39*(3), 343-360.

Cather, H., Morris, R. D., Philip, M., & Rose, C. (2001). *Design Engineering*. Oxford, UK: Butterworth-Heinemann.

Ćatić, A., & Malmqvist, J. (2013). Effective method for creating engineering checklists. *Journal of Engineering Design*, *24*(6), 453-475.

Cech, E., Rubineau, B., Silbey, S., & Seron, C. (2011). Professional role confidence and gendered persistence in engineering. *American Sociological Review*, *76*(5), 641-666.

Cech, E. (2015). Engineers and engineeresses? Self-conceptions and the development of gendered professional identities. *Sociological Perspectives*, *58*(1), 56-77.

Child, J., & Fulk, J. (1982). Maintenance of occupational control: The case of professions. *Work and Occupations*, *9*(2), 155-192.

Chubin, D. E., May, G. S., & Babco, E. L. (2005). Diversifying the engineering workforce. *Journal of Engineering Education*, *94*(1), 73-86.

Ciambrone, D. F. (2007). *Effective Transition from Design to Production*. Boca Raton, FL: CRC Press.

Cobb, C. L., Hey, J., Agogino, A. M., Beckman, S. L., & Kim, S. (2016). What Alumni Value from New Product Development Education: A Longitudinal Study. *Advances in Engineering Education*, *5*(1), 1-37.

Coeckelbergh, M. (2006). Regulation or responsibility? Autonomy, moral imagination, and engineering. *Science, Technology, & Human Values*, *31*(3), 237-260.

Collier, D., LaPorte, J., & Seawright, J. (2012). Putting typologies to work concept formation, measurement, and analytic rigor. *Political Research Quarterly*, *65*(1), 217-232.

Collin, K. (2004). The role of experience in work and learning among design engineers. *International Journal of Training and Development*, *8*(2), 111-127.

Correll, S. J. (2004). Constraints into preferences: Gender, status, and emerging career aspirations. *American Sociological Review*, *69*(1), 93-113.

Crawley, E., Malmqvist, J., Ostlund, S., & Brodeur, D. (2014). *Rethinking engineering education – The CDIO approach*. Berlin, Germany: Springer Science+Business.

Cross, N. (2006). *Designerly ways of knowing*. Berlin, Germany: Springer Science+Business.

Cross, N. (2008). *Engineering design methods: Strategies for product design*. Hoboken, NJ: John Wiley & Sons.

Cunningham, S. W., Hillerbrand, R., & Thissen, W. A. (2013). Humility and new modes of engineering design. *IEEE Engineering Management Review*, *41*(1), 7-8.

Cussler, E. L., & Moggridge, G. D. (2011). *Chemical product design*. Cambridge University Press.

Dart, S. (2000). *Configuration management: The missing link in web engineering*. Norwood, MA: Artech House.

Dasgupta, N., Scircle, M. M., & Hunsinger, M. (2015). Female peers in small work groups enhance women's motivation, verbal participation, and career aspirations in engineering. *Proceedings of the National Academy of Sciences*, *112*(16), 4988-4993.

David, M. (2013). Organising, valuing and improving the engineering design process. *Journal of Engineering Design*, *24*(7), 524-545.

Davidson, G. G., & Labib, A. W. (2003). Learning from failures: Design improvements using a multiple criteria decision-making process. *Proceedings of the Institution of Mechanical Engineers, Part G: Journal of Aerospace Engineering*, *217*(4), 207-216.

Davis, M. (1996). Defining "engineer:" How to do it and why it matters. *Journal of Engineering Education*, *85*(2), 97-101.

Davis, M. (1997). Is there a profession of engineering? *Science and Engineering Ethics*, *3*(4), 407-428.

Davis, M. (2001). The professional approach to engineering ethics: Five research questions. *Science and Engineering Ethics*, *7*(3), 379-390.

Delahousse, B. (2009). Engineers in organizations: loyalty and responsibility. In Christensen, S. H., Delahousse, N. & Meganck, M. (Eds.), *Engineering in Context*. Washington, DC: Academica.

Dias, P. (2014). The disciplines of engineering and history: Some common ground. *Science and Engineering Ethics*, *20*(2), 539-549.

Dick, M. J. (2006). *Creative Product Development: From Concept to Completion*. Belmont, CA: PPI.

Didier, C. (2010). Professional ethics without a profession: A French view on engineering ethics. In Van de Poel, I. and Goldberg, D. E. (Eds.), *Philosophy and engineering: An emerging agenda (Vol. 2).* Berlin, Germany: Springer Science+Business.

Didier, C., & Derouet, A. (2013). Social responsibility in French engineering education: A historical and sociological analysis. *Science and Engineering Ethics*, *19*(4), 1577-1588.

Dieter, G. E., & Schmidt, L. C. (2012). *Engineering design.* New York, NY: McGraw-Hill.

Diogo, M. P., & de Matos, A. C. (2012). Going public: The first Portuguese National Engineering Meeting and the popularization of the image of the engineer as an artisan of progress (Portugal, 1931). *Engineering Studies*, *4*(3), 185-204.

DiVincenzo, T. (2006). Project managers stay in charge and out front. *Occupational Outlook Quarterly*, *50*(2), 19-25.

Downey, G. (2005). Are engineers losing control of technology?: From 'problem solving' to 'problem definition and solution' in engineering education. *Chemical Engineering Research and Design*, *83*(6), 583-595.

Downey, G. L., & Lucena, J. C. (2004). Knowledge and professional identity in engineering: code-switching and the metrics of progress. *History and Technology*, *20*(4), 393-420.

Downey, G. L., Lucena, J. C., & Mitcham, C. (2007). Engineering ethics and identity: Emerging initiatives in comparative perspective. *Science and Engineering Ethics*, *13*(4), 463-487.

Dreicer, G. K. (1995). Influence and intercultural exchange: Engineers, engineering schools and engineering works in the nineteenth century. *History and Technology*, *12*(2), 163-177.

Dym, C. L., Little, P., Orwin, E. J., & Spjut, E. (2009). *Engineering design: A project-based introduction*. Hoboken, NJ: John Wiley & Sons.

EBSCO Host (2016). *EBSCO Discovery Service – support site: databases*. Retrieved from: http://support.ebsco.com/help/index.php?help_topic_id=DB

Eckert, C., Clarkson, P. J., & Zanker, W. (2004). Change and customisation in complex engineering domains. *Research in Engineering Design*, *15*(1), 1-21.

Eder, W. E., & Hosnedl, S. (2010). *Introduction to design engineering: Systematic creativity and management*. Boca Raton, FL: CRC Press.

Emes, M., Smith, A., & Cowper, D. (2005). Confronting an identity crisis—How to "brand" systems engineering. *Systems Engineering*, *8*(2), 164-186.

Eris, O., Chachra, D., Chen, H. L., Sheppard, S., Ludlow, L., Rosca, C., ... & Toye, G. (2010). Outcomes of a longitudinal administration of the persistence in engineering survey. *Journal of Engineering Education*, *99*(4), 371-395.

Evan, W. M., & Manion, M. (2002). *Minding the machines: Preventing technological disasters*. Upper Saddle River, NJ: Prentice Hall.

Faulkner, W. (2009). Doing gender in engineering workplace cultures II: Gender in/authenticity and the in/visibility paradox. *Engineering Studies*, *1*(3), 169-189.

Fehr, G. (2011). How to avoid future problems based on previous failure analyses. *Leadership and Management in Engineering*, *12*(1), 1-5.

Fei, G., Gao, J., Owodunni, O., & Tang, X. (2011). A method for engineering design change analysis using system modelling and knowledge management techniques. *International Journal of Computer Integrated Manufacturing*, *24*(6), 535-551.

Ferrall, C. (1995). Levels of responsibility in jobs and the distribution of earnings among US engineers, 1961–1986. *ILR Review*, *49*(1), 150-169.

Filho, D. G., & Kaminski, P. C. (2009). Co-design–from an automaker perspective. *International Journal of Product Development*, *8*(3), 333-353.

Fleddermann, C. B. (2004). *Engineering ethics*. Upper Saddle River, NJ: Prentice Hall.

Fleischer, M., & Liker, J. K. (1992). The hidden professionals: Product designers and their impact on design quality. *IEEE Transactions on Engineering Management*, *39*(3), 254-264.

Frey, W. J., & O'Neill-Carrillo, E. (2008). Engineering ethics in Puerto Rico: Issues and narratives. *Science and Engineering Ethics*, *14*(3), 417-431.

Gainsburg, J., Rodriguez-Lluesma, C., & Bailey, D. E. (2010). A "knowledge profile" of an engineering occupation: temporal patterns in the use of engineering knowledge. *Engineering Studies*, *2*(3), 197-219.

Galpin, T., Hilpirt, R., & Evans, B. (2007). The connected enterprise: Beyond division of labor. *Journal of Business Strategy*, *28*(2), 38-47.

Gerstl, J. E., & Hutton, S. P. (1966). *Engineers: The anatomy of a profession–A study of mechanical engineering in Britain.* London, UK: Tavistock Publications.

Gillum, J. D. (2000). The engineer of record and design responsibility. *Journal of Performance of Constructed Facilities*, *14*(2), 67-70.

Godwin, A., Potvin, G., Hazari, Z., & Lock, R. (2016). Identity, critical agency, and engineering: An affective model for predicting engineering as a career choice. *Journal of Engineering Education*, 105(2), 312-340.

Goldner, F. H., & Ritti, R. R. (1967). Professionalization as career immobility. *American Journal of Sociology*, 489-502.

Gotterbarn, D. (1999). Not all codes are created equal: The software engineering code of ethics, a success story. *Journal of Business Ethics*, *22*(1), 81-89.

Govindarajan, M., Natarajan, S., & Senthilkumar, V. S. (2004). *Engineering Ethics*. Upper Saddle River, NJ: Prentice-Hall.

Grasso, D. & Burkins, M. B. (2010). Beyond technology: the holistic advantage. In Grasso, D. & Burkins, M. B. (Eds.). *Holistic Engineering Education*. Berlin, Germany: Springer Science+Business.

Grayson, L. P. (1980). A Brief History of Engineering Education in the United States. *Engineering Education*, *68*(3), 246-64.

Haik, Y. & Shahin, T. M. M. (2011). *Engineering design process*. Boston, MA: Cengage Learning.

Hailpern, B., & Santhanam, P. (2002). Software debugging, testing, and verification. *IBM Systems Journal*, *41*(1), 4-12.

Hall, N. A. (1965). The profession of engineering. In Love, A., & Childers, J. S. (Eds.), *Listen to leaders in engineering*. Atlanta, GA: Tupper and Love.

Hall, D. (2009). The ethical software engineer. *IEEE Software*, *26*(4), 9-10.

Hamraz, B., Caldwell, N. H., & Clarkson, P. J. (2013a). A holistic categorization framework for literature on engineering change management. *Systems Engineering*, *16*(4), 473-505.

Hamraz, B., Caldwell, N. H., Wynn, D. C., & Clarkson, P. J. (2013b). Requirements-based development of an improved engineering change management method. *Journal of Engineering Design*, *24*(11), 765-793.

Han, J., Lee, S. H., & Nyamsuren, P. (2015). An integrated engineering change management process model for a project-based manufacturing. *International Journal of Computer Integrated Manufacturing*, *28*(7), 745-752.

Hansen, M. D., & Gammel, G. W. (2008). Management of Change. *Professional Safety*, *53*(10), 41-50.

Harris, C. E. (2008). The good engineer: Giving virtue its due in engineering ethics. *Science and Engineering Ethics*, *14*(2), 153-164.

Harris Jr, C. E., Pritchard, M. S., Rabins, M. J., James, R., & Englehardt, E. (2013). *Engineering ethics: Concepts and cases*. Boston, MA: Cengage Learning.

Hart, G. C. (2007). Design review of buildings. *The Structural Design of Tall and Special Buildings*, *16*(5), 569-581.

Hatamura, Y. (2006). *Decision-making in engineering design: Theory and practice*. Berlin, Germany: Springer Science+Business.

Haug, M., Olsen, E. W., Cuevas, G., & Rementeria, S. (2001). *Managing the change: Software configuration and change management*. Berlin, Germany: Springer-Verlag.

Hayes, J. (2015). Taking responsibility for public safety: How engineers seek to minimise disaster incubation in design of hazardous facilities. *Safety Science*, *77*, 48-56.

Hazelrigg, G. A. (1998). A framework for decision-based engineering design. *Transactions-American Society of Mechanical Engineers: Journal of Mechanical Design*, *120(4)*, 653-658.

Herkert, J. R. (2001). Future directions in engineering ethics research: Microethics, macroethics and the role of professional societies. *Science and Engineering Ethics*, *7*(3), 403-414.

Herman, C. (2015). Rebooting and rerouting: Women's articulations of frayed careers in science, engineering and technology professions. *Gender, Work & Organization*, *22*(4), 324-338.

Heywood, J. (2009). Introduction – engineering education in context. In Christensen, S. H., Delahousse, N. & Meganck, M. (Eds.), *Engineering in Context*. Washington, DC: Academica.

Holt, J. E. (2001). The status of engineering in the age of technology: Part I. Politics of practice. *International Journal of Engineering Education*, *17*(6), 496-501.

Holt, R., & Barnes, C. (2010). Towards an integrated approach to "Design for X": an agenda for decision-based DFX research. *Research in Engineering Design*, *21*(2), 123-136.

Hong, P., Vonderembse, M. A., Doll, W. J., & Nahm, A. Y. (2005). Role change of design engineers in product development. *Journal of Operations Management*, *24*(1), 63-79.

Horenstein, M. N. (2015). *Design concepts for engineers*. Hoboken, NJ: Pearson.

Humphreys, K. K. (1999). *What every engineer should know about ethics*. Boca Raton, FL: CRC Press.

Hunt, J. (2016). Why do women leave science and engineering?. *ILR Review*, *69*(1), 199-226.

Hwang, J., Mun, D., & Han, S. (2009). Representation and propagation of engineering change information in collaborative product development using a neutral reference model. *Concurrent Engineering*, *17*(2), 147-157.

Ichida, T., & Voigt, E.C. (1996). *Product design review: A methodology for error-free product development*. Boca Raton, FL: CRC Press.

Igbaria, M., Kassicieh, S. K., & Silver, M. (1999). Career orientations and career success among research, and development and engineering professionals. *Journal of Engineering and Technology Management*, *16*(1), 29-54.

Institute of Electrical and Electronics Engineers (IEEE). (2016). *About IEEE*. Retrieved from: http://www.ieee.org/about/index.html

International Council on Systems Engineering (INCOSE). (2017). *What is Systems Engineering?* Retrieved from: http://www.incose.org/AboutSE/WhatIsSE

Jack, H. (2013). *Engineering design, planning, and management*. Cambridge, MA: Academic Press.

Jackson, D. C., & Hundley Jr, N. (2004). Privilege and responsibility: William Mulholland and the St. Francis dam disaster. *California History*. 82(3), 8-47.

Jamison, A. (2013). The making of green engineers: Sustainable development and the hybrid imagination. *Synthesis Lectures on Engineering*, 8(1). San Rafael, CA: Morgan and Claypool.

Jarratt, T., Clarkson, J., & Eckert, C. (2005). Engineering change. In Clarkson, J., & Eckert, C. (Eds.), *Design process improvement: A review of current practice*. London, UK: Springer-Verlag.

Jarratt, T., Clarkson, J., & Eckert, C. (2006). Pitfalls of engineering change – change practice during complex product design. In ElMaraghy, H. A., & ElMaraghy, W. H. (Eds.). *Advances in Design*. London, UK: Springer-Verlag.

Jarratt, T. A. W., Eckert, C. M., Caldwell, N. H., & Clarkson, P. J. (2011). Engineering change: An overview and perspective on the literature. *Research in Engineering Design*, *22*(2), 103-124.

Jemielniak, D. (2007). Managers as lazy, stupid careerists? Contestation and stereotypes among software engineers. *Journal of Organizational Change Management*, *20*(4), 491-508.

Jeng, T. S., & Eastman, C. M. (1999). Design process management. *Computer-Aided Civil and Infrastructure Engineering*, *14*(1), 55-67.

Johnson, D. G. (1991). The social and professional responsibility of engineers. In Johnson, D.G. (Ed.), *Ethical issues in engineering*. Upper Saddle River, NJ: Prentice-Hall.

Jones, C. (2010). *software engineering best practices: Lessons from successful projects in the top companies*. New York, NY: McGraw-Hill.

Jones, P. M. (2011). Becoming an engineer in industrialising Great Britain circa 1760–1820. *Engineering Studies*, *3*(3), 215-232.

Jorgenson, J. (2002). Engineering selves: Negotiating gender and identity in technical work. *Management Communication Quarterly*, *15*(3), 350-380.

Kappelman, L. A., McKeeman, R., & Zhang, L. (2006). Early warning signs of IT project failure: The dominant dozen. *Information Systems Management*, *23*(4), 31-36.

Kardon, J. B. (2005). Concept of "care" in engineering. *Journal of Performance of Constructed Facilities*, *19*(3), 256-260.

Karlsson, M., Lakka, A., Sulankivi, K., Hanna, A. S., & Thompson, B. P. (2008). Best practices for integrating the concurrent engineering environment into multipartner project management. *Journal of Construction Engineering and Management*, *134*(4), 289-299.

Kasser, J. and Hitchins, D. (2012). Yes systems engineering, you are a discipline. *INCOSE International Symposium*. 22(1). 416-431.

Kedrowicz, A. A., & Sullivan, K. R. (2012). Professional identity on the Web: Engineering blogs and public engagement. *Engineering Studies*, *4*(1), 33-53.

Keil, M., & Robey, D. (2001). Blowing the whistle on troubled software projects. *Communications of the ACM*, *44*(4), 87-93.

Keltikangas, K., & Martinsuo, M. (2009). Professional socialization of electrical engineers in university education. *European Journal of Engineering Education*, *34*(1), 87-95.

Kemper, J. D. (1967). *The Engineer and His Profession*. New York, NY: Holt, Rinehart, and Winston.

Kemper, J. D., & Sanders, B. R. (2001). *Engineers and their Profession*. Oxford University Press.

Kerr, S., Von Glinow, M. A., & Schriesheim, J. (1977). Issues in the study of "professionals" in organizations: The case of scientists and engineers. *Organizational Behavior and Human Performance*, *18*(2), 329-345.

Keyes, J. (2004). *Software configuration management*. Boca Raton, FL: CRC Press.

Kiepas, A. (1997). Ethical aspects of the profession of engineer and of education towards it. *European Journal of Engineering Education*, *22*(3), 259-266.

Kline, R. R. (2008). From progressivism to Engineering Studies: Edwin T. Layton's The Revolt of the Engineers. *Technology and Culture*, *49*(4), 1018-1024.

Kocar, V., & Akgunduz, A. (2010). ADVICE: A virtual environment for Engineering Change Management. *Computers in Industry*, *61*(1), 15-28.

Koh, E. C., Caldwell, N. H., & Clarkson, P. J. (2012). A method to assess the effects of engineering change propagation. *Research in Engineering Design*, *23*(4), 329-351.

Krippendorff, K. (2004). *Content analysis: An introduction to its methodology*. Thousand Oaks, CA: Sage.

Kunda, G. (2006). *Engineering culture: Control and commitment in a high-tech corporation*. Temple University Press.

Langdon, D., McKittrick, G., Beede, D., Khan, B., and Doms, M. (2011). STEM: Good jobs now and for the future. U.S. Department of Commerce – Economics and Statistics Administration. Retrieved from: http://www.esa.doc.gov/reports/stem-good-jobs-now-and-future

Lawson, W. D. (2002). In defense of a little theory. *Journal of Professional Issues in Engineering Education and Practice*, *128*(4), 206-211.

Layton, E. T. (1971). *The revolt of the engineers*. Cleveland, OH: Case Western Reserve University Press.

Lee, S., Peña-Mora, F., & Park, M. (2006). Reliability and stability buffering approach: Focusing on the issues of errors and changes in concurrent design and construction projects. *Journal of construction engineering and management*, *132*(5), 452-464.

Le May, E., & Le May, I. (2016). Assigning responsibility for a structural failure. *Engineering Failure Analysis*, *62*, 316-323.

Leon, A. (2015). *Software configuration management handbook*. Norwood, MA: Artech House.

Lichtenstein, G., Loshbaugh, H. G., Claar, B., Chen, H. L., Jackson, K., & Sheppard, S. D. (2009). An engineering major does not (necessarily) an engineer make: Career decision making among undergraduate engineering majors. *Journal of Engineering Education*, *98*(3), 227-234.

Lindsay, R. C. (2002). Design safety: Reasonable safety vs. foolproof design. *Cost Engineering*, *44*(8), 10-10.

Lloyd, P., & Busby, J. (2003). "Things that went well—No serious injuries or deaths": Ethical reasoning in a normal engineering design process. *Science and Engineering Ethics*, *9*(4), 503-516.

Lopez, R., Love, P. E., Edwards, D. J., & Davis, P. R. (2010). Design error classification, causation, and prevention in construction engineering. *Journal of Performance of Constructed Facilities*, *24*(4), 399-408.

Lord, S. M., Camacho, M. M., Layton, R. A., Long, R. A., Ohland, M. W., & Wasburn, M. H. (2009). Who's persisting in engineering? A comparative analysis of female and male Asian, black, Hispanic, Native American, and white students. *Journal of Women and Minorities in Science and Engineering*, *15*(2).

Loui, M. C. (1998). The engineer's responsibility for quality. *Science and Engineering Ethics*, *4*(3), 347-350.

Loulakis, M. C., & McLaughlin, L. P. (2016). Engineer found negligent for not verifying product data. *Civil Engineering*, *86*(6), 92-92.

Love, P. E., Lopez, R., & Edwards, D. J. (2013). Reviewing the past to learn in the future: making sense of design errors and failures in construction. *Structure and Infrastructure Engineering*, *9*(7), 675-688.

Lowell, B. L., Salzman, H., Bernstein, H. (2009). Steady as she goes? Three generations of students through the science and engineering pipeline. Proceedings from: *Association for Public Policy Analysis and Management Annual Meeting: November 2008, Washington, D.C.*

Lucena, J., Downey, G., Jesiek, B., & Elber, S. (2008). Competencies beyond countries: The re-organization of engineering education in the United States, Europe, and Latin America. *Journal of Engineering Education*, *97*(4), 433-447.

Lucena, J., & Schneider, J. (2008). Engineers, development, and engineering education: From national to sustainable community development. *European Journal of Engineering Education*, *33*(3), 247-257.

Lurie, Y., & Mark, S. (2016). Professional ethics of software engineers: An ethical framework. *Science and Engineering Ethics*, *22*(2), 417-434.

Lynch, W. T., & Kline, R. (2000). Engineering practice and engineering ethics. *Science, Technology, & Human Values*, *25*(2), 195-225.

Lyon, D. D. (2000). *Practical CM: Best configuration management practices*. Oxford, UK: Butterworth-Heinemann.

Magrab, E. B. (1997). *Integrated product and process design and development: The product realization process*. Boca Raton, FL: CRC Press.

Maier, A. M., Kreimeyer, M., Lindemann, U., & Clarkson, P. J. (2009). Reflecting communication: a key factor for successful collaboration between embodiment design and simulation. *Journal of Engineering Design*, *20*(3), 265-287.

Main, B. W. (2002). Design reviews: Checkpoints for design. *Professional Safety*, *47*(1), 27-33.

Mann, R. (1962). Design and experiment—scope and reality. In *Proceedings, Second Conference on Engineering Design Education, UCLA, September 1962*.

Manuele, F. A. (2012). Management of change: Examples from practice. *Professional Safety*, *57*(7), 35.

Martin, M. W. (2002). Personal meaning and ethics in engineering. *Science and Engineering Ethics*, *8*(4), 545-560.

Martin, M. W., & Schinzinger, R. (2005). *Ethics in engineering*. New York, NY: McGraw-Hill.

McCuen, R. H., & Gilroy, K. L. (2011). *Ethics and professionalism in engineering*. Peterborough, Ontario: Broadview Press.

Meiksins, P. (1988). The "Revolt of the Engineers" reconsidered. *Technology and Culture*, *29*(2), 219-246.

Meiksins, P., & Smith, C. (1993). Organizing engineering work: a comparative analysis. *Work and Occupations*, *20*(2), 123-146.

Meiksins, P. F., & Watson, J. M. (1989). Professional autonomy and organizational constraint. *The Sociological Quarterly*, *30*(4), 561-585.

Melik, R. (2007). *The rise of the project workforce: managing people and projects in a flat world*. Hoboken, NJ: John Wiley & Sons.

Michelfelder, D., & Jones, S. A. (2013). Sustaining engineering codes of ethics for the twenty-first century. *Science and Engineering Ethics*, *19*(1), 237-258.

Millet, R. A. (1999). Failures: how to avoid them. *Journal of Management in Engineering*, *15*(5), 32-36.

Mital, A., Desai, A., Subramanian, A., & Mital, A. (2014). *Product development: a structured approach to consumer product development, design, and manufacture*. Amsterdam, Netherlands: Elsevier.

Mohan, K., Xu, P., & Ramesh, B. (2008). Improving the change-management process. *Communications of the ACM*, *51*(5), 59-64.

Moncarz, P. D., & Taylor, R. K. (2000). Engineering process failure—Hyatt walkway collapse. *Journal of Performance of Constructed Facilities*, *14*(2), 46-50.

Monplaisir, L., & Singh, N. (2002). *Collaborative engineering for product design and development*. Valencia, CA: American Scientific Publishers.

Monticolo, D., Mihaita, S., Darwich, H., & Hilaire, V. (2014). An agent-based system to build project memories during engineering projects. *Knowledge-Based Systems*, *68*, 88-102.

Monticolo, D., Badin, J., Gomes, S., Bonjour, E., & Chamoret, D. (2015). A meta-model for knowledge configuration management to support collaborative engineering. *Computers in Industry*, *66*, 11-20.

Moreira, M. E. (2004). *Software configuration management implementation roadmap*. Hoboken, NJ: John Wiley & Sons.

Morgan, L. A. (2000). Is engineering hostile to women? An analysis of data from the 1993 national survey of college graduates. *American Sociological Review*, *65*(2), 316-321.

Morgan, J. M. & Liker, J. K. (2006). *The Toyota product development system: Integrating people, process, and technology*. New York, NY: Productivity Press.

Morris, J. (2017). A weighted O*Net keyword search (WWS). Retrieved from: https://www.onetcenter.org/reports/WWS.html

Morris, A., Halpern, M., Setchi, R., & Prickett, P. (2016). Assessing the challenges of managing product design change through-life. *Journal of Engineering Design*, *27*(1-3), 25-49.

Moss, M. A. (1996). *Applying TQM to product design and development.* New York, NY: Marcel Dekker.

Mote, C. D. (2015). *Annual address: NAE strategic plan, goals, and grand challenges for engineering*. Retrieved from: https://www.nae.edu/Projects/Events/AnnualMeetings/115641/146242.aspx

Murdoch, J., & McDermid, J. A. (2000). Modelling engineering design processes with role activity diagrams. *Journal of Integrated Design and Process Science*, *4*(2), 45-65.

National Academy of Engineering (NAE). (2004). *The Engineer of 2020: Visions of Engineering in the New Century*. Washington, DC: National Academies Press.

National Academy of Engineering (NAE). (2005). *Educating the engineer of 2020: Adapting engineering education to the new century*. Washington, DC: National Academies Press.

National Council of Examiners of Engineers and Surveyors (NCEES). (2012). *NCEES introduces PE exam for software engineering*. Retrieved from: https://ncees.org/ncees-introduces-pe-exam-for-software-engineering

National Research Council (NRC), U.S., Committee on the Education and Utilization of the Engineer. (1985). *Engineering education and practice in the United States: Foundations of our techno-economic future*. Washington, DC: National Academies Press.

National Science Board (NSB), U.S. (2010). *Preparing the next generation of stem innovators: Identifying and developing our nation's human capital*. Arlington, VA: National Science Board.

National Society of Professional Engineers (NSPE). (2016). *About NPSE*. Retrieved from: https://www.nspe.org/membership/about-nspe

Nethercot, D. A. (2008). Reliability, responsibility and reality in structural engineering. *Proceedings of the Institution of Civil Engineers-Structures and Buildings*, *161*(4), 215-218.

Newberry, B. (2007). Are engineers instrumentalists? *Technology in Society*, *29*(1), 107-119.

Newberry, B. (2009). *The Dialectics of Engineering*. In Christensen, H., Delahouse, B., & Meganck, B. (2009). *Engineering in Context*. Washington, DC: Academica Press.

Noble, D. F. (1977). *America by Design: Science, Technology, and the Rise of Corporate Capitalism.* New York, NY: Knopf.

Occupation Net Online (O*Net). (2017). *O*Net Occupations Database - Find occupations.* Retrieved from: http://www.onetonline.org/find/

Onarheim, B. (2012). Creativity from constraints in engineering design: lessons learned at Coloplast. *Journal of Engineering Design*, *23*(4), 323-336.

Pahl, G., Beitz, W., Feldhusen, J., & Grote, K. H. (2007). *Engineering design: A systematic approach*. Berlin, Germany: Springer Science+Business.

Papinniemi, J., Hannola, L., & Maletz, M. (2014). Challenges in integrating requirements management with PLM. *International Journal of Production Research*, *52*(15), 4412-4423.

Park, G. J. (2007). *Analytic methods for design practice*. Berlin, Germany: Springer Science+Business.

Pavković, N., Štorga, M., Bojčetić, N., & Marjanović, D. (2013). Facilitating design communication through engineering information traceability. *Artificial Intelligence for Engineering, Design, Analysis, and Manufacturing (AI EDAM)*, *27*(2), 105-119.

Perlow, L., & Bailyn, L. (1997). The senseless submergence of difference. In Barley, S. R., & Orr, J. E. (Eds.). *Between craft and science: Technical work in US settings*. Cornell University Press.

Perrucci, R., & Gerstl, J. E. (1969). *Profession without Community: Engineers in American Society*. New York, NY: Random House.

Pesch, U. (2015). Engineers and active responsibility. *Science and Engineering Ethics*, *21*(4), 925-939.

Peterson, N. G., Mumford, M. D., Borman, W. C., Jeanneret, P. R., Fleishman, E. A., Levin, K. Y., ... & Gowing, M. K. (2001). Understanding work using the Occupational Information Network (O* NET): Implications for practice and research. *Personnel Psychology*, *54*(2), 451-492.

Petroski, H. (1994). *Design paradigms: Case histories of error and judgment in engineering*. Cambridge University Press.

Petroski, H. (2010). *The essential engineer: why science alone will not solve our global problems*. New York, NY: Knopf.

Project Management Institute (PMI). (2013). *Project management talent gap report*. Retrieved from: http://www.pmi.org/-/media/pmi/documents/public/pdf/business-solutions/project-management-skills-gap-report.pdf

Petticrew, M., & Roberts, H. (2006). *Systematic reviews in the social sciences: A practical guide*. Malden, MA: Blackwell.

Pfatteicher, S. K. (2000). "The Hyatt Horror": Failure and responsibility in American engineering. *Journal of Performance of Constructed Facilities*, *14*(2), 62-66.

Pfatteicher, S. K. (2010). *Lessons amid the rubble: An introduction to post-disaster engineering and ethics*. Johns Hopkins University Press.

Pinkus, R. L. B. (1997). *Engineering ethics: Balancing cost, schedule, and risk-lessons learned from the space shuttle*. Cambridge University Press.

Pugh, S. (1991). *Total Design*. Workingham, UK: Addison-Wesley.

Pursell, C. (2006). Engineering organization and the scientist in world war I: The search for national service and recognition. *Prometheus*, *24*(3), 257-268.

Quigley, J. M., & Robertson, K. L. (2015). *Configuration management: Theory, practice, and application*. Boca Raton, FL: CRC Press.

Quintana, V., Rivest, L., Pellerin, R., & Kheddouci, F. (2012). Re-engineering the engineering change management process for a drawing-less environment. *Computers in Industry*, *63*(1), 79-90.

Rauniar, R., Doll, W., Rawski, G., & Hong, P. (2008). The role of heavyweight product manager in new product development. *International Journal of Operations & Production Management*, *28*(2), 130-154.

Reddi, K. R., & Moon, Y. B. (2013). Modeling engineering change management in a new product development supply chain. *International Journal of Production Research*, *51*(17), 5271-5291.

Reynolds, T. S. (1991). Introduction and Parts I & II overviews. In Reynolds, T.S. (Ed.) *The engineer in America: A historical anthology from* Technology and Culture. The University of Chicago Press.

Ritti, R. (1968). Work goals of scientists and engineers. *Industrial Relations: A Journal of Economy and Society*, *7*(2), 118-131.

Robinson, C. (2000). Ethics: A design responsibility. *Civil Engineering*, *70*(1), 66.

Robinson, M. A. (2012). How design engineers spend their time: Job content and task satisfaction. *Design Studies*, *33*(4), 391-425.

Robinson, S., Dixon, R., Preece, C., & Moodley, K. (2007). *Engineering, business, and professional ethics*. Oxford, UK: Butterworth-Heinemann.

Roeser, S. (2012). Emotional engineers: Toward morally responsible design. *Science and Engineering Ethics*, *18*(1), 103-115.

Rovegård, P., Angelis, L., & Wohlin, C. (2008). An empirical study on views of importance of change impact analysis issues. *IEEE Transactions on Software Engineering*, *34*(4), 516-530.

Rowland, J. J., & Rowland, D. (1995). Professional competence in safety-related software engineering. *Software Engineering Journal*, *10*(2), 43-48.

Rynes, S. L., Tolbert, P. S., & Strausser, P. G. (1988). Aspirations to manage: A comparison of engineering students and working engineers. *Journal of Vocational Behavior*, *32*(2), 239-253.

Salzman, H., & Lynn, L. H. (2010). Engineering and engineering skills: What's really needed for global competitiveness? Proceedings from: *Association for Public Policy Analysis and Management Annual Meeting: November 4, 2010, Boston, MA*.

Samuel, A. E., & Weir, J. (1999). *Introduction to engineering design: Modeling, synthesis, and problem solving strategies*. Oxford, UK: Butterworth-Heinemann.

Savoie, T. B., & Frey, D. D. (2012). Detecting mistakes in engineering models: the effects of experimental design. *Research in Engineering Design*, *23*(2), 155-175.

Schlossberger, E. (1993). *The ethical engineer*. Temple University Press.

Schlossberger, E. (2016). Engineering codes of ethics and the duty to set a moral precedent. *Science and Engineering Ethics*, *22*(5), 1333-1344.

Schmidt, J. A. (2014). Changing the paradigm for engineering ethics. *Science and Engineering Ethics*, *20*(4), 985-1010.

Scholz-Reiter, B., Krohne, F., Leng, B., & Höhns, H. (2007). Technical product change teams: an organizational concept for increasing the efficiency and effectiveness of technical product changes during ramp-up phases. *International Journal of Production Research*, *45*(7), 1631-1642.

Seely, B. E. (1995). SHOT, the history of technology, and engineering education. *Technology and Culture*, *36*(4), 739-772.

Seely, B. E. (1999). The other re-engineering of engineering education, 1900-1965. *Journal of Engineering Education*, *88*(3), 285.

Seely, B. E. (2005). “Patterns in the History of Engineering Education Reform.” In National Academy of Engineering, *Educating the Engineer of 2020*. Washington, DC: National Academies Press.

Seron, C., Silbey, S. S., Cech, E., & Rubineau, B. (2016). Persistence is cultural: Professional socialization and the reproduction of sex segregation. *Work and Organizations*. 43(2), 178-214.

Shankar, P., Morkos, B., & Summers, J. D. (2012). Reasons for change propagation: a case study in an automotive OEM. *Research in Engineering Design*, *23*(4), 291-303.

Sheard, S. A. (1996). Twelve systems engineering roles. *Proceedings of the INCOSE Sixth Annual International Symposium,* 6(1), 478-485.

Sheppard, S. D., Macatangay, K., & Colby, A. (2009). Educating engineers: Designing for the future of the field. San Francisco, CA: Jossey-Bass.

Shiau, J. Y., & Wee, H. M. (2008). A distributed change control workflow for collaborative design network. *Computers in Industry*, *59*(2), 119-127.

Skalak, S. C., Kemser, H. P., & Ter-Minassian, N. (1997). Defining a product development methodology with concurrent engineering for small manufacturing companies. *Journal of Engineering Design*, *8*(4), 305-328.

Sobek, M. (2001). New statistics on the US labor force, 1850–1990. *Historical Methods: A Journal of Quantitative and Interdisciplinary History*, *34*(2), 71-87.

Son, W. C. (2008). Philosophy of technology and macro-ethics in engineering. *Science and Engineering Ethics*, *14*(3), 405.

Son, S., Na, S., Kim, K., & Lee, S. (2014). Collaborative design environment between ECAD and MCAD engineers in high-tech products development. *International Journal of Production Research*, *52*(20), 6161-6174.

Sørensen, K. H. (2009). The role of social science in engineering. In Meijers, A., Gabbay, D. M, Thagard, P., & Woods, J. (Eds.). *Handbook of the Philosophy of Science, Vol. 9: Philosophy of Technology and Engineering Sciences.* Amsterdam, Netherlands: Elsevier.

Spier, R. (2001). *Ethics, tools, and the engineer*. Boca Raton, FL: CRC Press.

Stovall, P. (2011). Professional virtue and professional self-awareness: a case study in engineering ethics. *Science and Engineering Ethics*, *17*(1), 109-132.

Subrahmanian, E., Lee, C., & Granger, H. (2015). Managing and supporting product life cycle through engineering change management for a complex product. *Research in Engineering Design*, *26*(3), 189-217.

Suchman, L. (2000). Embodied practices of engineering work. *Mind, Culture, and Activity*, *7*(1-2), 4-18.

Swierstra, T., & Jelsma, J. (2006). Responsibility without moralism in technoscientific design practice. *Science, Technology, & Human Values*, *31*(3), 309-332.

Tau Beta Pi (TBP). (2016). *About Tau Beta Pi*. Retrieved from: https://www.tbp.org/about.cfm

Terwiesch, C., & Loch, C. H. (1999). Managing the process of engineering change orders: the case of the climate control system in automobile development. *Journal of product innovation management*, *16*(2), 160-172.

Thom, D. (1998). Engineering education and the new industrial revolution. *International Journal of Engineering Education*, *14*(2), 89-94.

Trevelyan, J. (2007). Technical coordination in engineering practice. *Journal of Engineering Education*, *96*(3), 191-204.

Trevelyan, J., & Tilli, S. (2007). Published research on engineering work. *Journal of Professional Issues in Engineering Education and Practice*, *133*(4), 300-307.

Trevelyan, J. (2010). Reconstructing engineering from practice. *Engineering Studies*, *2*(3), 175-195.

Tsuchiyama, R. (2011, February). The product manager as the digital industry's rock star. *Forbes*. Retrieved from: https://www.forbes.com/sites/raytsuchiyama/2011/02/14/the-product-manager-as-the-digital-industries-rock-star/

Twigg, D. (1998). Managing product development within a design chain. *International Journal of Operations & Production Management*, *18*(5), 508-524.

Ullman, D. G. (2016). *The mechanical design process*. New York, NY: McGraw-Hill.

Ulrich, K. T., & Eppinger, S. D. (2016). *Product design and development*. New York, NY: McGraw-Hill.

Unger, S. H. (1994). *Controlling technology: Ethics and the responsible engineer*. Hoboken, NJ: John Wiley & Sons.

U.S. Bureau of Labor Statistics (U.S. BLS). (2010). *Standard Occupation Code user's guide*. Retrieved from: http://www.bls.gov/soc/soc_2010_user_guide.pdf

U.S. Bureau of Labor Statistics (U.S. BLS). (2013). *Direct Match File for Standard Occupation Codes.* Retrieved from: http://www.bls.gov/soc/materials.htm

U.S. Bureau of Labor Statistics (U.S. BLS). (2016). *Occupational Employment Statistics.* Retrieved from: http://www.bls.gov/oes/current/oes_nat.htm

U.S. Census Bureau. (2014). *Where do college graduates work? A special focus on science, technology, engineering, and math*. Retrieved from: https://www.census.gov/dataviz/visualizations/stem/stem-html/

U.S. National Science Foundation (U.S. NSF). (2012). *National Medal of Science 50th Anniversary: Theodore von Karman*. Retrieved from: https://www.nsf.gov/news/special_reports/medalofscience50/vonkarman.jsp

U.S. National Science Foundation (U.S. NSF), National Center for Science and Engineering Statistics. (2016). *Characteristics of recent science and engineering graduates: 2010*. Retrieved from: https://ncsesdata.nsf.gov/recentgrads

Van de Poel, I. (2010). Philosophy and engineering: Setting the stage. In Van de Poel, I. and Goldberg, D. E. (Eds.), *Philosophy and engineering: An emerging agenda (Vol. 2).* Berlin, Germany: Springer Science+Business.

Van de Poel, I., & Royakkers, L. (2011). *Ethics, technology, and engineering: An introduction*. Hoboken, NJ: John Wiley & Sons.

Van de Poel, I., & van Gorp, A. V. D. (2006). The need for ethical reflection in engineering design: The relevance of type of design and design hierarchy. *Science, Technology, & Human Values*, *31*(3), 333-360.

Van De Weerd, I., Brinkkemper, S., Nieuwenhuis, R., Versendaal, J., & Bijlsma, L. (2006). Towards a reference framework for software product management. In *14th IEEE International Requirements Engineering Conference (RE'06)*, 319-322.

Van der Linden, F., Schmid, K., & Rommes, E. (2007). *Software Product Lines in Action: The best industrial practice in product line engineering*. Berlin, Germany: Springer Science+Business.

Veldman, J., & Alblas, A. (2012). Managing design variety, process variety and engineering change: A case study of two capital good firms. *Research in Engineering Design*, *23*(4), 269-290.

Verin, H., & Gouzevitch, I. (2011). The rise of the engineering profession in eighteenth century Europe: an introductory overview. *Engineering Studies*, *3*(3), 153-169.

Vesilind, P. A. (2002). Vestal virgins and engineering ethics. *Ethics & the Environment*, *7*(1), 92-101.

Vesilind, P.A., & Gunn, A.S. (1998). *Engineering, ethics, and the environment.* New York: Cambridge Univ. Press.

Vest, C. M. (1995). U.S. engineering education in transition. *The Bridge,* 25(4).

Vest, C. M. (2011). The image problem for engineering: an overview. *The Bridge*, 41(2).

Vinck, D., Blanco, E., Bovy, M., Laureillard, P., Lavoisy, O., Mer, S., Ravailee, N., & Reverdy, T. (2003). *Everyday engineering: An ethnography of design and innovation*. MIT Press.

Waelbers, K. (2011). *Doing good with technologies: Taking responsibility for the social role of emerging technologies*. Berlin, Germany: Springer Science+Business.

Walesh, S. G. (2012). *Engineering your future: The professional practice of engineering*. Hoboken, NJ: John Wiley & Sons.

Watson, J. M., & Meiksins, P. F. (1991). What do engineers want? Work values, job rewards, and job satisfaction. *Science, Technology, & Human Values*, *16*(2), 140-172.

Watts, F. B. (2008). *Engineering documentation control handbook*. Norwich, NY: William Andrew.

Watts, F. B. (2010). *Configuration management metrics*. Norwich, NY: William Andrew.

Watts, F. B. (2015). *Configuration management for senior managers: Essential product configuration and lifecycle management for manufacturing*. Oxford, UK: Butterworth-Heinemann.

Wearne, S. (2008). Organisational lessons from failures. *Proceedings of the Institution of Civil Engineers – Civil Engineering*, 161(CE6), 4 – 7.

Weiss, S. I. (2013). *Product and systems development: A value approach*. Hoboken, NJ: John Wiley & Sons.

Whitbeck, C. (2011). *Ethics in engineering practice and research* (2nd ed.). Cambridge University Press.

Whyte, J., & Lobo, S. (2010). Coordination and control in project-based work: digital objects and infrastructures for delivery. *Construction Management and Economics*, *28*(6), 557-567.

Williams, R. (2002). *Retooling: A Historian Confronts Technological Change*. MIT Press.

Williams Jr, C. E., & Johnson, P. W. (2013). Standards of professional practice for design management. *Journal of Professional Issues in Engineering Education and Practice*, *140*(2), 04013011.

Williams Jr, C. E., & Johnson, P. W. (2015). Inadequate design management compared with unprecedented technical issues as causes for engineering failure. *Journal of Performance of Constructed Facilities*, *29*(1), 04014031.

Willis, T. (2009). Evidence that sticks. *Industrial Engineer*, *41*(11), 44-49.

Wirfs-Brock, R. J. (2009). The responsible designer. *IEEE software*, *26*(6).

Workman, J. P. (1995). Engineering's interactions with marketing groups in an engineering-driven organization. *IEEE Transactions on Engineering Management*, *42*(2), 129-139.

WorldCat (2016). *What is WorldCat?* Retrieved from: http://www.worldcat.org/whatis/default.jsp

Wright, I. C. (1997). A review of research into engineering change management: implications for product design. *Design Studies*, *18*(1), 33-42.

Wueste, Daniel, E. (1994). *Professional ethics and social responsibility*. Lanham, MD: Rowman and Littlefield.

Yip, B., & Rowlinson, S. (2009). Job burnout among construction engineers working within consulting and contracting organizations. *Journal of Management in Engineering*, *25*(3), 122-130.

Yogeswaran, K., & Kumaraswamy, M. M. (1999). To instruct or not? The engineer's dilemma. *Construction Management & Economics*, *17*(6), 731-743.

Zirpoli, F., & Becker, M. C. (2011). The limits of design and engineering outsourcing: performance integration and the unfulfilled promises of modularity. *R&D Management*, *41*(1), 21-43.