FACTORS THAT FACILITATE OR INHIBIT INTEREST OF DOMESTIC STUDENTS IN THE ENGINEERING PHD: A MIXED METHODS STUDY

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FACTORS THAT FACILITATE OR INHIBIT INTEREST OF DOMESTIC STUDENTS IN THE ENGINEERING PHD: A MIXED METHODS STUDY

By

Michelle C. Howell Smith

A DISSERTATION

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FACTORS THAT FACILITATE OR INHIBIT INTEREST OF DOMESTIC STUDENTS IN THE ENGINEERING PHD: A MIXED METHODS STUDY

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Given the increasing complexity of technology in our society, the United States has a growing demand for a more highly educated technical workforce. Unfortunately, the proportion of United States citizens earning a PhD in engineering has been declining and there is concern about meeting the economic, national security and quality of life needs of our country.

This mixed methods sequential exploratory instrument design study identified factors that facilitate or inhibit interest in engineering PhD programs among domestic engineering undergraduate students in the United States. This study developed a testable theory for how domestic students become interested in engineering PhD programs and a measure of that process, the Exploring Engineering Interest Inventory (EEII). The study was conducted in four phases.

The first phase of the study was a qualitative grounded theory exploration of interest in the engineering PhD. Qualitative data were collected from domestic engineering students, engineering faculty and industry professional who had earned a PhD in engineering. The second phase, instrument development, developed the Exploring Engineering Interest Inventory (EEII), a measurement instrument designed with good psychometric properties to test a series of preliminary hypotheses related to the theory
generated in the qualitative phase. In the third phase of the study, the EEII was used to collect data from a larger sample of junior and senior engineering majors. The fourth phase integrated the findings from the qualitative and quantitative phases.

Four factors were identified as being significant influences of interest in the engineering PhD: Personal characteristics, educational environment, misperceptions of the economic and personal costs, and misperceptions of engineering work. Recommendations include increasing faculty encouragement of students to pursue an engineering PhD and programming to correct the misperceptions of the costs of the engineering PhD and the nature of the work that PhD engineers do. The tested model provides engineering educators with information to help them prioritize their efforts to increase interest in the engineering PhD among domestic students.
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DEDICATION

This dissertation is dedicated to my family; to my parents, Ken and Sharon Howell for instilling in me the value of education and supporting me in all of my academic endeavors; to my husband, Matt Smith, for believing in me and not letting me quit; and to my children, Kevin and MaKenna Smith, for giving my life meaning beyond just the work I do.

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Chapter 1: Introduction

Engineering is everywhere in our daily lives and engineers create the scientific and technological innovations that attempt to solve the “grand challenges” of our time, such as population, energy, environment, food, water, terrorism, housing, health, and transportation problems (e.g., Duderstadt, 2008; Feisel & Rosa, 2005; Maddox & Smith-Maddox, 1990; Vest, 2008). While there is some debate regarding shortages in the supply of engineers, it is clear that the United States will need a workforce with increased technological skills to address problems that are increasingly more complicated in order to protect our economic system, international competitiveness, national security, and quality of life (Butz et al., 2003). The National Academy of Sciences (2007) expressed concern regarding the looming shortage of scientists and engineers, describing it as a “Gathering Storm.” The status of this storm was recently updated to a “Category 5” as a warning and a reminder that “rebuilding from such an event is far more difficult than preparing in advance to withstand it” (National Academy of Sciences, 2010, p. 66).

As the challenges facing engineers become larger and more complex, so does the need for increased sophistication and innovation to address these challenges. The PhD in engineering provides an opportunity to develop engineers to meet these new and ever-changing demands. As early as the turn of the 20th century, the importance of engineering PhDs to society has been noted:

The demands of modern civilization call for engineers who can do more than keep abreast of theory and practice of their profession. They must be able to solve new problems and to advance the state of the art in which their work lies. In applied science no less than pure science there is a need for research and for the
Interest in the Engineering PhD development of the research spirit. (Massachusetts Institute of Technology, 1902, p. 940)

Currently, the production of domestic PhDs in engineering is not sufficient to meet the growing demands for their skills in the United States (National Science Board, 2003).

The PhD has traditionally been perceived as an apprenticeship period to prepare future faculty of our nation’s colleges and universities and with the impending retirement of a substantial number of baby-boomer faculty, there will be increased opportunities for PhDs to obtain faculty positions (Austin, 2002; Campbell, 2003; Campbell, Fuller & Patrick, 2005; Golde & Dore, 2001; Lederman, 2007; Louis, Holdsworth, Anderson & Campbell, 2007). In engineering, however, only 15-30% of PhDs obtain an academic position, while the remaining 70-85% of engineering PhDs obtain positions in non-academic settings (Fox & Stephan, 2001; Mason, Goulden, & Frasch, 2009; National Science Foundation, 11-306, 2010). Therefore, engineering PhDs are needed for both academic and industrial positions.

Engineering education literature predominantly focuses on the undergraduate engineering experience. Current research efforts are revealing information about undergraduate education: academic pathways, retention, motivation, engineering identity development, and career decision-making (Amelink & Creamer, 2010; Clark et al., 2008; Chen, Lattuca, & Hamilton, 2008; Eris et al., 2010; Jones, Paretti, Hein, & Knott, 2010; Lichtenstein, McCormick, Sheppard, & Puma, 2010; Lichtenstein et al., 2009; Matusovich, Streveler, & Miller, 2010; Ohland et al., 2008; Sheppard et al., 2004; Stevens, O’Connor, Garrison, Jocuns, & Amos, 2008). Our knowledge about the doctoral education experience, however, is deficient. The existing literature has not focused on the
process of how engineers come to cultivate their interest in doctoral-level engineering education, and how they turn this interest into action and pursue such a degree. While existing research has identified a shortage of domestic engineers with advanced education, it has not addressed the process to understand why this occurs. Research is needed to identify the factors that contribute to the declining proportion of domestic PhD students in engineering and to identify strategies that will increase interest in the PhD. Researchers have not explored this area thoroughly and have not used rigorous qualitative methods, such as grounded theory, to develop a model detailing this process, and by extension, there has been no quantitative testing of a theoretical model. As noted by Seymour and Hewitt (1997), “without systemic investigation, we could not know whether all of the pertinent issues had been raised, or which elements matter more than the others” (p. 6). A validated theoretical model will provide engineering educators and administrators with accurate information to more effectively guide their efforts in increasing the interest of domestic students in the engineering PhD, and ultimately, increasing enrollments.

Within the educational setting, engineering educators and administrators are aware that domestic students are not choosing to obtain PhD degrees in engineering. While those in the engineering field may have many of their own anecdotal explanations of the reasons domestic engineering students do not persist through the doctoral level, no set of definitive answers has been documented. The question remains: Why do so few domestic undergraduate engineering students choose not to seek a doctorate?
Purpose Statement

The purpose of this mixed methods sequential exploratory instrument design study was to identify the factors that facilitate and inhibit interest in engineering PhD programs among domestic engineering undergraduate students. This study aimed to develop a testable theory for how domestic students became interested in engineering PhD programs and a measure of that process. The study was conducted in three phases. The first phase of the study was a qualitative grounded theory exploration of interest in the engineering PhD. Focus groups were conducted with domestic undergraduate engineering students at seven different institutions across the country. Doctoral students and faculty in engineering at each site participated in in-depth individual interviews. Industry professional who had earned a PhD in engineering also participated in in-depth individual interviews via the phone. The second, instrument development phase, developed the Exploring Engineering Interest Inventory (EEII), a measurement instrument designed with good psychometric properties to test a series of preliminary hypotheses related to the theory generated in the qualitative phase. In the third phase of the study, the EEII was used to collect data from a larger sample of junior and senior engineering majors at the same institutions that participated in the first phase of the study. The reason for collecting qualitative data initially was that there were no existing instruments, nor even a theoretic framework, for understanding the interest in engineering PhD programs of this population. By basing the instrument's development on the theory generated from a grounded theory study, the intent was to develop an instrument that more accurately measured the phenomenon than if it had been based on the scant amount of information currently available in the literature.
Audiences That Will Benefit

This dissertation will be of interest to a wide variety of audiences. From a content perspective, this study will be pragmatically useful because it is specifically designed to provide a fuller understanding of the ways universities can increase domestic student interest in engineering PhD programs. Maximizing the practical application of the results is at the forefront of the methodological design. The intent is to develop and test a theory for how domestic students become interested in the engineering PhD. From this theory, specific strategies for increasing the number of domestic engineering PhDs awarded will be developed for use by engineering colleges and graduate deans. Other STEM fields may also benefit from the findings, to the extent that they share common challenges with engineering.

Research methodologists in general, and the mixed methods community in particular, will be interested in the expanded discussion of translating qualitative themes into quantitative items. Also of interest will be the use of a rigorous grounded theory approach to data analysis in the qualitative phase of the study since most mixed methods instrument development designs give less priority to the qualitative phase. Social science researchers will also find value in the synthesis and recommendations for scale development.

Research Questions

The qualitative and quantitative phases of the study were designed to answer particular research questions that reflect the different nature of qualitative and quantitative inquiry. On a broader level, the study was also guided by mixed methods research questions regarding the relationships of the qualitative and quantitative phases.
These questions are presented as a sub-set of the primary phase (qualitative or quantitative) most relevant to the question.

**Phase I: Qualitative research questions.**

1. What perceptions do domestic engineering students, engineering faculty members and other engineering PhDs hold about PhD education in engineering?

2. What factors facilitate or inhibit interest in the engineering PhD among domestic engineering students?
   a. What are the initial conditions of domestic engineering students that influence their interest in the engineering PhD?
   b. What is the context that supports the continuation of (or changes to) the level of interest of domestic engineering students in the engineering PhD?
   c. What are the intervening conditions that influence the level of interest of domestic engineering students in the engineering PhD?

3. What strategies were reported that could be used to increase interest in the engineering PhD among domestic engineering students?

**Phase III: Quantitative research questions.**

1. What is the factor structure of the instrument, as determined from a sub-set of the available cases (n=300)?

2. What are the reliability measures for the factors retained by the EFA? Which items detract from the reliability of the scores from each factor?

3. Is the factor structure of the instrument validated and retained by the remaining cases (n=604)?
4. Which factors retained by the EFA and confirmed by the CFA are significantly related to interest in pursuing a PhD in engineering?
   a. $H_0 = \text{There is no relationship between the factor scale scores and interest in the engineering PhD.}$

5. What additional characteristics and experiences are significantly related to interest in pursuing a PhD in engineering? (e.g. engineering experiences, institution type, minority status, gender, socio-economic status, and whether someone important to the student had earned a PhD)
   a. $H_0 = \text{There is no relationship between the engineering experiences, institution type, minority status, gender, socio-economic status, and whether or not someone important to the student had earned a PhD and interest in the engineering PhD.}$

6. Does the instrument discriminate between undergraduates (novice) and PhD students/recent PhD alumni (experts)?

**Phase IV: Synthesis mixed methods research questions.**

1. Does the factor structure of the instrument confirm the qualitative themes?
2. Based on the results from the quantitative phase, how would the recommendations from the qualitative phase be prioritized?
3. How does the instrument that has been designed based on the qualitative data provide a better measure of the phenomenon than other measurement alternatives or development approaches?
Significance of the Study

This study includes several innovative components that have the potential to significantly impact the fields of both engineering education and research methodology. The first and primary contribution of this study is the development of a theory for explaining how domestic students become interested in the engineering PhD. This theory will then inform specific recommendations for engineering programs to increase interest in the engineering PhD among domestic students. Additionally, the development of the Exploring Engineering Interest Inventory (EEII) will provide engineering programs with a measurement tool to assist them in prioritizing those recommendations for their specific program. Mixed methods instrument development designs traditionally give priority to the quantitative phase so the use of rigorous grounded theory methods in the qualitative phase gives equal significance to both qualitative and quantitative phases. This study also aims to extend mixed methods research methodology by providing a pragmatic model for mixed methods instrument development designs. Specific attention is being paid to the translation of the qualitative themes and theory into a quantitative instrument. Recommendations for operationalizing qualitative data will be articulated.

Definition of Terms

*Interest in Engineering PhD:* The dependent variable for this study is interest in the engineering PhD. There are increasingly more committed levels of interest, ranging from passive awareness to active consideration, to actively planning to pursue a PhD, to actively pursuing a PhD.

*Domestic:* A U.S. citizen or Permanent Resident.
Interest in the Engineering PhD

**Industry PhD:** A person who has earned a PhD in engineering and works in an industrial setting rather than an academic setting.

**Nature of Work:** The content of one’s work; what one does on a day to day basis. The nature of work for a bachelor’s-level engineer is different from the nature of work for a PhD engineer.

**STEM, SME, S&E:** Science, technology, engineering and mathematics (STEM); science, mathematics and engineering (SME); and science and engineering (S&E) are different acronyms used in the literature to refer to different combinations of these fields as a collective group.

**URM:** The acronym URM or term “underrepresented minority” represents the following underrepresented minorities in engineering as a collective group: Hispanic/Latino, American Indian or Alaska Native, Black or African American, and Native Hawaiian or other Pacific Islander. Although women of all races and ethnicities are also underrepresented in engineering, they will be referred to specifically in order to clearly distinguish discussions of race from gender.

**Philosophical Foundations**

Postpositivism is the research paradigm most closely associated with both quantitative inquiry and grounded theory qualitative approaches (Hatch, 2002, Creswell & Plano Clark, 2007). However, postpositivism’s assumption of a singular reality and the reliance on only deductive approaches for determining that reality does not fully serve the purpose of this study. Pragmatism, on the other hand, acknowledges the role of both the singular reality and the individual experience in understanding that reality (Johnson & Onwuegbuzie, 2004). Knowledge, then, is provisional and open to expansion by
experimenting and additional experience. Pragmatism allows for mixing methods within a single study so that the inherent strengths of each approach can be maximized while minimizing the inherent weaknesses (Onwuegbuzie & Leech, 2005), providing that the methodology is relevant to answering the research question (Johnson & Onwuegbuzie, 2004).

While pragmatism has been suggested as a helpful frame for conducting mixed methods research (Johnson & Onwuegbuzie, 2004), Johnson’s (2011) “metaparadigm” of dialectical pragmatism operationalizes pragmatism within a dialectical approach of interacting with the research process. Both pragmatism and dialectical pragmatism are especially well suited for research teams as they encourage the open conversation of ideas (Johnson, 2011; Onwuegbuzie & Leech, 2005). The tenants of dialectical pragmatism suggested by Johnson include:

(a) dialectically-listen carefully to different paradigms, disciplines, theories, and stakeholder/citizen perspectives,

(b) combine important ideas from competing paradigms and values into a new workable whole for each research study/program evaluation,

(c) explicitly state and “pack” the approach with stakeholders’ and researchers’ epistemological and socio/political values to guide the research (including the *valued ends* one hopes for and the *valued means* for getting there),

(d) conduct the research ethically,
(e) facilitate utilization of research finding (locally and more broadly), and

(f) continually evaluate outcomes of the research/utilization process.

(p. 8)

The tenants of dialectical pragmatism can be observed in this study in the following ways:

(a) Stakeholders (engineers) were central to developing the theory and refining the instrument.

(b) A research team consisting of a lead researcher, two research assistants, and additional consultants and advisors collaborated in conducting this study, providing a variety of perspectives and opportunities for synthesis of approaches.

(c) The funding agency provided the general parameters for this study in the request for proposal (RFP), which provided a focus on the utility of the results. The methodology for the study aims to be a model for conducting instrument development studies, which provides a focus on the rigor of the process.

(d) Ethical standards were at the forefront of this study and are discussed within each phase of the project.

(e) The utility of both the theory developed and the results of the instrument was a primary goal of the project; the results should be useful to stakeholders.
(f) This study was conducted in phases, which provided multiple opportunities to evaluate progress and adjust plans to maximize the rigor and utility of the study.

**Delimitations and Limitations**

This study is delimited by its focus on *domestic* engineering students in the United States. This study is not designed as a comparative study with other countries where there is a larger interest in engineering PhD programs. This study is also delimited by focusing on the *interest* in engineering PhD programs. While there would certainly be value in a longitudinal study exploring actual enrollments in PhD programs, the time and budget for this study did not allow for that approach. The focus on *doctoral* programs is also a delimitation of the study. Master’s programs are not of specific interest in this study beyond their relationship to doctoral programs.

Methodologically, this study is delimited by a focus on expanding mixed-methods instrument development designs, with particular attention on translating qualitative data into quantitative items. Given that there were no existing instruments and limited information in the literature for this particular content area, this delimitation was appropriate. This study is further delimited by the time frame of the funding agency. Ideally, separate quantitative data collections would have occurred for the EFA and CFA phases of the instrument analysis. The time constraints only allowed for one quantitative data collection, so a portion of the overall quantitative data will be used for the EFA and the remaining data will be used for the CFA.

This study is limited by the access to specific institutional sites for data collection. While every effort was made to recruit sites that reflected the diversity of engineering
programs, many of the sites were located in the Midwest. Specific data collection targets of institutions in the southeast and mid-Atlantic regions were not met. The limited geographic diversity of the data collection sites will influence the generalizability of the findings. Additionally, failure to recruit a Historically Black College and University (HBCU) included as a data collection site is a limitation of the study, as the unique perspectives from students at that type of institutions are not included in the data. Reputational factors of the engineering programs are another limitation of this study. While there was one top-10 engineering program included in the study, this institution did not offer a PhD program in engineering. The study would have benefited by including a top-tier doctoral-granting engineering program.
Chapter 2: Literature Review

This literature review is organized around exploring questions relevant to increasing interest in the engineering PhD. Why do we need engineering PhDs? What is the role of the PhD? Is there really a shortage of engineering PhDs? What about the leaky pipeline? What are the pathways to the engineering PhD? What is the need for this study?

Why do we Need Engineering PhDs?

Engineering is a unique academic discipline. Unlike science fields which focus on discovering the unknown, engineering “seeks to develop and integrate knowledge to create new fundamental materials, devices, and systems that have never before existed” (National Science Foundation, 2005). Feisel and Rosa (2005) describe the purpose of the engineering profession is to “manipulate materials, energy and information, thereby creating benefit for humankind” (p. 121). Engineering addresses issues as diverse as nanomaterials, biological systems, environmental sustainability, energy efficiency, network security, metabolic pathways, and manufacturing.

Men and women in the engineering workforce have a growing role in the future of our country as they will be called on to “seize opportunities and solve global problems of unprecedented scope and scale” (Vest, 2008, p. 235). As the challenges facing engineers become larger and more complex, so does the need for increased sophistication and innovation to address these challenges. As noted by Duderstadt (2008), the important intellectual problems of our time will be solved through interdisciplinary efforts of “big think” rather than through “small think” approaches of disciplinary specialization (p. 33). The PhD in engineering provides an opportunity to develop engineers to meet these new
and ever-changing and increasingly complex demands. A recruitment brochure from Intel (2006) describes the PhD to potential students this way:

With a PhD you become trained to become an innovator – to create the next generation of technologies, with the potential for worldwide impact. A PhD gives you the freedom to be a technical leader. In short, you can work on more interesting projects and can make more significant contributions….The industry is interested in hiring PhDs because the student possesses the analytical knowledge as well as the out-of-the-box creative thinking that leads to exciting breakthroughs.

The conceptualization of the PhD in engineering as a facilitator of innovation was echoed by Wendler et al. (2010). “Graduate education goes beyond just providing students with advanced knowledge and skills—it also further develops critical thinking skills and produces innovators. It is the application of knowledge and skills in creative and innovative ways that will help ensure our country’s future economic prosperity, influence social growth, and maintain our leadership in the global economy” (p. 1). An adequate supply of engineering PhDs is essential to not only maintaining our way of life, but in ensuring a prosperous future for our society.

**What is the Role of the PhD?**

At first glance, the role of the PhD degree seems fairly straightforward. The PhD focuses on contributing to disciplinary knowledge through original research (Hansen, 2009). The PhD, therefore, is a research degree; a degree designed to teach students the skills they need to conduct original research such as conceptualizing problems, identifying issues and critically reflecting on the scientific process (Bellare, ca. 1997;
Interest in the Engineering PhD

Comer, ca. 1985; Jones, 2002). But the PhD, in practice, is much more complex than simply teaching research skills. It is also an opportunity to acculturate new scholars to their chosen academic discipline (Golde & Dore, 2001). PhD programs provide students with both the formal training and mentoring necessary to establish students as leaders in their fields (Louis, Holdsworth, Anderson, & Campbell, 2007). This process is facilitated through the “establishment of complex relationships with their sponsors, new scientists, and members of the broader scientific community, [who] invest a great deal of time and other resources in maintaining the community” (Campbell, 2003, p. 923). Ambrose and Norman (2006) note the investment of time (by faculty and other researchers) and financial resources (by professional associations and foundations) into improving doctoral engineering education as evidence that the engineering profession supports the improvement of faculty preparation.

The assumption of the traditional model of doctoral education is that the primary role of the PhD is to prepare students for researched-based academic careers (Campbell, Fuller, & Patrick, 2005). Doctoral students interested in faculty careers need to learn how to work with colleagues from other disciplines and to understand expectations for public and institutional service (Austin, 2002). Several studies provide strategies for developing the teaching skills of engineering faculty (Adams & Felder, 2008; Ambrose & Norman, 2006; Fink, Ambrose, & Wheeler, 2005; Trautman & Krasny, 2006).

While the assumption of interest in a faculty position holds true for many students pursuing a PhD, it is not an appropriate assumption for the engineering field. Figure 1 shows trends from the past 20 years from the Survey of Earned Doctorates (National Science Foundation, 11-306, 2010) for doctoral recipients with definite post-graduation
U.S. employment. Across all majors, academic careers were obtained fairly consistently by slightly more than 50% of all PhD recipients. In engineering fields, however, academic careers have declined from approximately 30% to 15%.

The need for new faculty, however, will grow in the coming decade as a large segment of the faculty retires, thereby opening up academia to a new generation of the professoriate (Austin, 2002; Lederman, 2007).

The role of doctoral education, therefore, is much broader than preparing future faculty for our nation’s colleges and universities; it also prepares critical human resources such as scientists, engineers, researchers, and scholars who “create and share new knowledge and new ways of thinking that lead, directly and indirectly, to innovative products, services, and works of art” (National Science Foundation, 11-306, 2010). This innovation is necessary to ensuring not only the continued economic growth and cultural development of the United States, but also raising our standard of living.
As noted by Campbell, Fuller, and Patrick (2005), doctoral training is increasingly disconnected from the types of jobs PhDs obtain. A recent study of doctoral students across all STEM disciplines in the University of California system found that while 40% of men and 31% of women initially planned on pursuing a “fast-track” position in academia, only 28% of men and 20% of women maintained that career goal (Mason, Goulden & Frasch, 2009). Fox and Stephan (2001) found similar trends when looking at career goals of doctoral students in chemistry, computer science, electrical engineering, microbiology and physics; “Overall, students report preferences for nonacademic or for academic research careers over academic teaching….Preferences for nonacademic careers are higher in chemistry and electrical engineering” (p. 112). This trend continues when looking at the Survey of Earned Doctorates (National Science Foundation, 11-306, 2010) for definite post-graduation U.S. employment in business and industry sectors (Figure 2). While business and industry employment hovers around 25% across all majors, over 70% of engineering majors obtain a position in this sector upon completion of their doctoral degree.
Limited employment opportunities in traditional academic research positions may not be the sole reason for students to consider non-academic employment upon completion of their PhD. Mason, Goulden and Frasch (2009) note that a bad reputation has developed for the academic fast track. PhD students have the opportunity to directly observe faculty life and many do not want the unrelenting work hours that they see their advisors and mentors working. Instead, they seek opportunities for flexible careers that allow them to balance their work and family lives.

The emphasis on dissertation research at the expense of other more relevant training and skill development produces graduates who are not fully prepared for their likely future careers in industry (Campbell, Fuller, & Patrick, 2005). Although they did not include engineering doctoral students in their study, Golde and Dore (2001) comment that “students who move into non-academic positions need to understand the kinds of career options that are possible and to understand that these are respectable choices” (p. 17). Campbell et al. (2005) recommend “a shift from the current model, with its focus on dissertation research, to a broader conception of doctoral education that includes training and mentoring that will be relevant to future careers” (p. 153). Golde (2005) suggests that reforming academic practices that do not serve the educational interests of PhD students will reduce attrition. Alternatively, the Doctor of Engineering degree has been suggested as a more appropriate degree for professional practice for doctoral students interested in industry positions (Duderstadt, 2008).

**Is there really a Shortage of Engineering PhDs?**

Each year the “Survey of Earned Doctorates” (SED) is conducted on behalf of the National Science Foundation, National Institutes of Health, U.S. Department of
Education, National Endowment for the Humanities, U.S. Department of Agriculture, and National Aeronautics and Space Administration (National Science Foundation, 11-306, 2010). The SED tracks a variety of important indicators about PhD graduates and provides data to inform policy makers and educators. The most recent data from the SED reports that the number of doctoral degrees earned in engineering increased from 5,823 in 1993 to 8,066 in 2007 (Figure 3). While this overall increase is positive, growth in degrees awarded to international students (62% increase) significantly outpaced growth in domestic PhDs (12% increase). As a result, the percentage of PhDs awarded to U.S. Citizens declined from 46% of the total to only 37% (Figure 4).

![Figure 3: Number of Engineering PhDs Awarded by Year](image)

*Note: data not available for 1999*
Although figures 3 and 4 use the exact same data, they present conflicting messages about the trends in engineering PhD production. Kelly, Butz, Carroll, Adamson, and Bloom (2004) caution that “statements about shortages based in such metrics as declining percentages of U.S. citizens earning doctorates must be viewed in context” (p. 6). This has generated significant discussion in the engineering community regarding the true state of PhD production and anticipated needs for PhDs in the future. Several studies have noted that there is and/or has been a critical shortage of PhD engineers and scientists. (e.g., Anderson-Rowland, Bernstein, & Russo, 2007; Atkinson, 1990; Fouad & Singh, 2011; Golde, 2005). Other studies note that evidence based on actual market indicators does not support the generally held belief that there is a shortage in the STEM workforce (Kelly et al., 2004; Teitelbaum, 2004). Teitelbaum (2004) notes that the STEM workforce has not experienced increased salaries or low unemployment rates which are typical indicators of market shortages. According to a survey conducted by the Institute for Higher Education Research, there are about 25% more PhDs in STEM fields than the
Interest in the Engineering PhD

economy can afford (Browne, 1995). Some experts in the scientific labor market believe that large increases in funding for research and graduate training will actually discourage Americans from pursuing scientific careers by over-saturating the marketplace with highly trained scientists and engineers. The irony of the perceived shortage is that “scores of thousands of young PhDs labor in the nation’s university labs as low-paid, temporary workers, ostensibly training for permanent faculty positions that will never exists” (Benderly, 2010, ¶6). Postdoctoral positions are, in Benderly’s opinion, disguised unemployment.

Even amidst the debate regarding past and current shortages of engineering PhDs there does seem to be a consensus that the nation cannot be complacent in anticipating future needs. “The implications of a shortage of skills to U.S. growth, competitiveness, and security justify continued examination of the nature and sources of the production of scientists, technical workers, engineers, and mathematicians in the United States” (Kelly et al., 2004 p. 6). Based on the time required to earn a PhD, it is difficult for the labor market to respond quickly to shortages or surpluses in the employment market (Jones, 2002). Therefore, prudence suggests that we prepare sufficient PhDs to meet our nation’s future scientific and technological needs (Atkinson, 1990; National Science Board, 03-69, 2003). And even though the National Science Board concedes that there is uncertainty about the number of engineers required to meet those needs, “the United States needs a more technologically literate workforce” (07-122, 2007, p. 14).

What about the Leaky Pipeline?

In order to meet the growing demand for a more scientifically and technologically literate workforce, doctoral programs will need to develop a talent pool “that looks very
different from decades past” (Chubin, May, & Babco, 2005, p. 73). The pool of students interested in studying science and mathematics is relatively small, (Herzig, 2004) therefore, significant efforts need to be maintained to retain as many of them as possible through all levels of advanced education, especially the PhD. This is especially true for those who have been underrepresented in scientific and engineering careers (National Science Board, 03-69, 2003). Chubin, Donaldson, Olds and Fleming (2008) note that “pedagogy and faculty attitudes must evolve as to who can do engineering, what represents excellence, and how classroom experiences reflect real-world problems and workplaces” (p. 254). Failure to attract and prepare students from all demographic backgrounds to participate in a technologically-driven economy puts our economic and intellectual preeminence at risk (Chubin, May, & Babco, 2005, p. 84). Therefore, “improving education and significantly increasing the participation of minority students in higher education (with special emphasis on the study of mathematics, science, and engineering) must become our most important challenge” (Maddox & Smith-Maddox, 1990, p. 470).

Not only is this lack of diversity critical from an objective perspective (if minority groups are not represented proportionately then there are fewer people in general pursing graduate degrees in these critical areas) but also creates a subjective crisis in terms of a lack of the most talented minds to solve the most challenging problems facing our country (Cohen-Corwin, Herzig & Manderscheid, 2006). A diverse scientific community is needed to insure that issues that may disproportionately affect minority communities receive adequate attention and to influence the nature and content of the nation’s research agenda and to shape public policy and federal priorities in science and medicine (Bass,
interest in the engineering PhD 24

2007). “Society needs engineers who bring a wealth of knowledge and creative
approaches, from numerous, diverse perspectives of society, to effectively address
increase in the diversity of the scientific workforce influences the nature and content of
the nation’s research agenda and shapes public policy and federal priorities in science and
engineering (National Academy of Sciences, 2010, p. 19). Additionally, faculty ought to
reflect the student population they will be teaching in order to provide appropriate role
models for future generations of scientists and engineers (Bass, 2007; Tierney, Campbell
& Sanchez, 2004).

Doctoral students have a compelling self-interest in pursuing advanced degrees.
According to the United States Census Bureau (2006), individuals who have earned a
PhD earn almost 60% more on average than bachelor’s degree recipients. The 2007
report by the U.S. Department of Education shows that “earnings for young adults
increased when education level increased” (p. 47). Tierney, Campbell and Sanchez
(2004) make an even more direct assertion stating that “graduate education remains one
of the primary indicators of access to jobs of higher prestige and income, as well as a
prerequisite for better quality of life for persons of color” (p. 3). The College Board
conducted a study to understand the effects of higher education on not only the individual
student, but society as well. In addition to higher salaries, advanced education has a
positive impact on access to traditional employer benefits such as health insurance and
retirement. These benefits correlate with healthier lifestyles which in turn have a positive
impact on insurance rates and a decreased demand for social services (Baum & Ma,
2007). Additional benefits include greater opportunities for the next generation in terms
of higher levels of school readiness for children of parents who graduated from college. Since educational attainment has a significant impact on annual earnings, one way to minimize the impact of race on socioeconomic status is through increasing the diversity of students obtaining advanced degrees.

In spite of the tangible benefits of a graduate degree, women, Hispanic/Latinos, American Indians or Alaska Natives, Blacks or African Americans and Native Hawaiians or other Pacific Islanders continue to be underrepresented in STEM fields in general and engineering in particular. As shown in Figure 5, of the engineering degrees awarded to U.S. citizens, women only represent approximately 20% of engineering degrees at both the bachelor and doctoral levels. Underrepresented minority groups, combined, account for less than 15% of the engineering bachelor’s degrees and less than 10% of the engineering doctoral degrees, even though these groups comprise almost 40% of the U.S. population (U.S. Census Bureau, 2010).

A common myth as to why there are not more underrepresented minority students earning PhDs in STEM fields is that “there aren’t many [minority] students interested in
math and science [and] those that are decide to go to medical school” (Bass, 2007, slide 7). This myth does not bear out, according to a study by Elliott, Strenta, Adair, Matier, and Scott (1996) that looked at science and engineering majors at four highly selective institutions (Brown University, Cornell University, Dartmouth University, and Yale University). The study found that minorities are “at least as interested in pursuing science as whites (Astin and Astin, 1993; National Science Board, 1993; White, 1992) and the attitude toward science, at least for African Americans, is very positive – more positive, other things being equal, than that of whites (Dunteman, Wisenbaker, and Taylor, 1979; see also citations in Oakes, 1990)” (Elliott et al., 1996, p. 682). Despite this initial interest, over half of African Americans will leave science, an attrition rate higher than any other ethnic group. However, when the academic preparation is taken into account, the study found no difference in the attrition rate based on ethnicity. Elliott et al. concludes that the outflow from the science pipeline by African Americans is not due to a lack of interest in science or scientific abilities, but to deficiencies in academic preparation. These results were consistent with more recent findings by Green (2008) who noted that “percentage-wise, African American students entering college are just as likely to choose a scientific major as white students (Smyth & McArdle, 2002; Leslie, McClure & Oaxaca, 1998; Oakes, 1990). Unfortunately, many of these students do not complete their intended scientific major” (p. 340).

The National Science Foundation, the primary funding agency for research in all areas of fundamental science and engineering, has among its legislatively authorized activities to “support activities designed to increase the participation of women and minorities and others underrepresented in science and technology” (National Science
Interest in the Engineering PhD

Foundation, n.d., ¶ K). Watson and Froyd (2007) note that in spite of significant investments, efforts to increase participation in STEM fields from underrepresented groups “continue to fall significantly short of the goals of reflecting the demographics of the overall population” (p. 19). Attrition from engineering programs has received particular attention. In addition to the personal costs to students who leave engineering programs after having invested personal and financial resources, there is also a cost to society in losing the potential contributions of that student (Fouad & Singh, 2011).

In their book, Seymour and Hewitt (1997) described their three-year ethnographic study at seven institutions in an effort to discover and establish the relative importance of the factors for leaving SME majors. They found no differences between students who left SME majors and those completed their SME degrees based on individual characteristics or institutional type. Students in both groups reported many of the same concerns about SME education: a loss of interest in science, a belief that non-SME majors are more interesting, poor teaching by SME faculty, feeling overwhelmed by SME workload and concerns about limited participation in family and social life. These factors are compounded for women and minorities who also struggle with developing a sense of belonging in the SME environment. These findings led Seymour and Hewitt to conclude that “the most effective way to improve retention among women and students of color, and to build their numbers over the longer-term, is to improve the quality of the learning experience for all students” (p. 394).

A more recent study by Marra, Bogue, Shen, and Rodgers (2007) focused specifically on the factors that influence students to leave engineering majors in an effort to address low retention rates, with particular attention to women and minority students.
By reviewing existing instruments and interview protocols from qualitative studies (particularly Seymour and Hewitt), they developed a survey with both quantitative items and three open-ended qualitative items to measure the reasons why students leave engineering majors. The survey was administered to 120 students who left engineering majors at five separate institutions. Their findings identified three primary reasons why students leave engineering majors: boredom or disappointment with the curriculum, describing it as too narrow or not creative or people oriented enough; a loss of academic self-confidence resulting from the intense workload of engineering programs and the often competitive environment; and a lack of a sense of belonging within the engineering program. Additionally, they found that confusion about the differences between engineering disciplines, a lack of context for the subject matter, and uncertainty regarding what engineers actually do, leads to challenges in recruiting students to engineering majors and facilitating successful navigation through their program. They suggest that these issues are a cause for concern, especially in terms of attracting and retaining diverse students in order to meet the growing need for more engineers.

Challenges specific to women and underrepresented minority students in persisting in engineering programs were noted in other studies as well. Malcom (2008) found that faculty focusing on their deficiencies, different and/or lower expectations, and an image of engineers as white males had a negative impact on the retention of women and minority engineering students. Anderson-Rowland, Bernstein, and Russo (2007) found that the assumptions women faced about their plans for marriage and having children and conflicts from their multiple roles also had a negative impact on their continued enrollment in engineering programs.
Many scholars have referred to the attrition of underrepresented minorities and women students from STEM programs as a “leaky pipe” where at each stage of educational attainment students leak out of the pipeline. This results in the number of underrepresented doctoral students being far lower than the number of undergraduates who could potentially go on to earn a graduate degree (Atkin, Green & McLaughlin, 2002; Durant, 2004; Kilty, 2003; Kuck, 2001; Wickware, 1997). Manderscheid (2007) referred to the flow of underrepresented students out of continued higher education in STEM fields as a “burst pipe” causing significantly more damage than a mere leak.

While the pipeline metaphor has been effective in stimulating interventions to increase diversity in science and engineering fields, it oversimplifies the complex interactions of identity, cognitive development and career choice (Watson & Froyd, 2007). Stevens, O’Connor, Garrison, Jocuns, and Amos (2008) call for new ways of conceptualizing enrollment trends in STEM fields:

The pipeline metaphor has certainly been useful for showing that, in the aggregate, the flow into and out of technical fields like engineering are out of balance, certainly with respect to women and under-represented minorities and probably, were we to look more closely, with respect to other important dimensions of diversity. Now that the general pipeline message is clearly established, we believe this metaphor does more harm than good and should be honorably retired. (p. 365)

Fortunately, a new metaphor for understanding enrollment trends in STEM fields has emerged.
**What are the Pathways to the Engineering PhD?**

An alternative to the leaky pipeline metaphor for conceptualizing enrollment trends in doctoral STEM programs was suggested by Wendler et al. (2010):

The route to graduate education should be thought of as a *pathway* rather than a *pipeline*. A *pipeline* implies a system in which a student enters at one end and comes out at the other. There is only one entry point, and once a student leaves the pipeline there is no way back in. A *pathway*, however, suggests a less linear approach in which a student may meander at times, but where leaving the main path does not mean that is will be impossible to reenter it later. (p. 5)

The pathway metaphor was expanded by Stevens, O’Connor, Garrison, Jocuns, and Amos (2008) to include a compass “that guides one to make a pathway through engineering” (p. 365). Without a properly functioning compass, students face even more difficulty in navigating through a competitive and intense field. By exploring individual student pathways through engineering using qualitative ethnography methods, Stevens et al. (2008) found that “different students navigate differently through engineering, and these differences can be consequential not only for where they end up, but also for the duration of their undergraduate experience, the social networks they create, and the quality and substance of their identification with engineering” (p. 357).

While pathways are unique and multi-faceted, there is still value in quantitative inquiry that seeks to identify factors that predict interest (or even enrollment) in doctoral engineering programs. Perna (2004) used data from the 1997 follow-up to the Baccalaureate and Beyond survey to show how proxies of cultural and social capital improve the explanatory power of econometric models to predict post-graduate...
Interest in the Engineering PhD

enrollment across all majors. Because this was a longitudinal study (five years after receiving the bachelor’s degree) she was able to develop her model based on actual enrollments in graduate programs. Unfortunately, there were not enough students enrolled in doctoral programs to conduct any analysis on that group, so her findings were limited to master’s level programs and professional degrees such as the MBA.

Sax (2001) also used longitudinal data to model factors that predict enrollment specifically in STEM graduate programs as evidenced by enrollment in either a master’s or doctoral level program. Data were collected by the Cooperative Institutional Research Program (CIRP) in 1985 (freshman year), 1989, and 1994. Although this study is based on data collected over 20 years ago, it does provide some clues for understanding enrollment trends in engineering PhD programs, since her study was limited specifically to STEM majors. Sax found that the salient factors for continued study in STEM fields were commitment to scientific inquiry, a peer environment that values science, and high academic involvement (p. 167). She also conducted specific analysis to explore gender differences in graduate school enrollment pattern. For both men and women, the following factors were significant predictors of graduate school enrollment in STEM fields: first-year science aspirations, peer group orientation towards science, college grades, interaction with faculty and a commitment to making a theoretical contribution to science. For women, a desire to help others, affect social change, make a contribution to society, and a high priority on raising a family were all negative predictors for graduate school enrollment in STEM fields.

Fouad and Singhs’ “Project on Women Engineers’ Retention” (POWER) (2011) studied the pathways that lead women out of engineering careers. They conducted a
quantitative survey with nearly 4,000 women who had completed undergraduate engineering degrees and either never obtained employment in engineering, obtained engineering employment for some period of time but then left the field of engineering, or were currently employed in the field of engineering. They found that women “who were highly confident of their engineering abilities as well as their ability to juggle multiple roles were least likely to want to leave engineering” (Fouad & Singh, 2011, p. 52).

Unfortunately, for women who became disenchanted with their engineering job were more likely to consider leaving the field of engineering altogether, rather than seek a different position with the field of engineering.

The pathway metaphor also served as a framework for a million dollar, multi-year study funded by the National Science Foundation conducted by the Center for the Advancement of Engineering Education (Atman et al., 2010; Sheppard et al., 2010). The Academic Pathways of People Learning Engineering Survey (APPLES) recognized that a “broad understanding of the engineering student experience involves thinking about diverse academic pathways, navigation of these pathways, and decision points-how students choose engineering programs, navigate through their programs, and then move on to jobs and careers” (Atman et al., 2010, p. 1). The pathway metaphor also acknowledged that “engineering is increasingly viewed as a flexible platform for a variety of career options; a singular career trajectory is increasingly uncommon given today’s professional and economic realities” (Sheppard et al., 2010, p. 90). In addition to conceptualizing the multiple pathways through engineering education, the study also noted that “supporting less-traveled pathways has the potential for broadening participation in engineering” (Atman et al., 2010, p. 2).
The APPLES survey was a 10-minute online survey with over 4,000 completed responses from undergraduate students currently, previously, or intending to study engineering from 21 different institutions. One item on the survey asked students how likely they would be to go to graduate school in an engineering discipline. The response options were definitely not, probably not, not sure, probably yes, and definitely yes. As reported in Sheppard et al., (2010) the following independent variables had predictive ability of interest in engineering graduate school: intrinsic psychological motivation; intrinsic behavioral motivation; academic involvement in engineering courses, and GPA index. Although GPA is one of the top predictors of interest in engineering graduate school, it is difficult to say if the relationship is due to a student’s inherent interest in and talent for engineering, or if reflects the increased likelihood of faculty encouragement to consider graduate school among students with higher GPAs. There was a negative predictive relationship with confidence in professional and interpersonal skills and a weak negative predictive relationship with the frequency of non-engineering extracurricular participation. They did not find any predictive relationship with exposure to the engineering profession and financial motivation. When comparing first year student responses with seniors, the percentage of students who see themselves as very likely to pursue a graduate engineering degree remains constant at 40%. However, the percentage of students who are not likely to pursue a graduate degree in engineering increases from 19% to 31%. It appears that during the course of their engineering education, a significant number of students will rule out graduate programs in engineering, but there is not any growth in the group of students seriously considering graduate school in engineering. The authors ponder this trend and wonder, “are students,
by the time they reach their senior year, gaining a more realistic view of themselves in relationship to engineering graduate school? Or are they excited to leave school, enter the engineering work world, and begin earning an income?” (Sheppard et al., 2010, p. 115). These important questions are critical to understanding domestic student interest in doctoral engineering programs.

Related research has focused on doctoral education across all STEM fields. One study found that formal and informal interaction with senior students and faculty was more significant in terms of factors that retain students than the structured curriculum for doctoral students in the sciences (Campbell, 2003). Another study focused on career aspirations, such as non-academic industry positions, teaching positions or research positions for STEM doctoral students and found that choice of career path was mitigated not only by the individual student’s interests, but also by his or her perceived expectation for success in a particular career path (Fox & Stephan, 2001).

Other studies have examined pilot programs that introduce novel curricular or programmatic elements to engineering PhD programs, such as integrating economics and management in a multi-disciplinary environment (Ewing, Kruse, & Thompson, 2009; Kurkalova, Schimmel & Johnston, 2008), creating a network for doctoral student researchers (Powell, Pyrtle, & Williamson-Whitney, 2005; Rhodes & Valerdi, 2007), developing the business skills necessary for entrepreneurial ventures and technology management consulting (Kerr & Ivey, 2003; Mishima, 2004), and training in college teaching principles (Streveler, Pavelich & Miller, 2002). While these studies directly researched improving engineering PhD programs, they did not address issues of
recruiting engineering PhD students or increasing interest in engineering PhD programs, and therefore are not relevant to this particular study.

Even though the studies above were not exploring the particular dependent variable of this study, interest in the engineering PhD, they articulated potentially relevant independent variables. Table 1 provides a summary of these variables.
Table 1: Potential Variables Identified in the Literature

<table>
<thead>
<tr>
<th>First author, year</th>
<th>Target Population</th>
<th>Dependent Variable</th>
<th>Independent Variables</th>
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<tbody>
<tr>
<td>Stevens, 2008</td>
<td>UG Engineering Majors</td>
<td>Retention</td>
<td>quality of social networks</td>
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<td>quality and substance of identification with engineering</td>
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<td>Sax, 2001</td>
<td>UG STEM Majors</td>
<td>Grad school enrollment</td>
<td>commitment to scientific inquiry</td>
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<td>peer environment that values science</td>
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<td>high academic involvement</td>
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<td>first-year science aspirations</td>
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<td>college grades</td>
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<td>interaction with faculty</td>
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<td>Fouad, 2011</td>
<td>Women in Engineering Careers</td>
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<td>confident of their engineering abilities as well as</td>
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<td>confident of their ability to juggle multiple roles</td>
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<td>Atman and Sheppard, 2010</td>
<td>UG Engineering Majors</td>
<td>Interest in engineering grad school</td>
<td>intrinsic psychological motivation</td>
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<td>intrinsic behavioral motivation</td>
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<td>academic involvement in engineering courses</td>
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<td>GPA index</td>
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<td>Campbell, 2003</td>
<td>PhD STEM</td>
<td>Retention</td>
<td>formal and informal interaction with senior students and faculty</td>
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<td>Atman and Sheppard, 2010</td>
<td>UG Engineering Majors</td>
<td>Interest in engineering grad school</td>
<td>exposure to the engineering profession</td>
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<td>financial motivation</td>
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<td>Fox, 2001</td>
<td>PhD STEM</td>
<td>Career choice</td>
<td>individual student’s interests</td>
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<td>perceived expectation for success in a particular career path</td>
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<td>Marra, 2007</td>
<td>UG Engineering</td>
<td>Retention</td>
<td>curriculum: boring, too narrow, not creative or people oriented</td>
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<td>loss of academic self-confidence from the intense workload</td>
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<td>lack of a sense of belonging in engineering</td>
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<td>confusion about the different engineering disciplines</td>
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<td>a lack of context for the subject matter</td>
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<td>uncertainty regarding what engineers actually do</td>
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<td>Malcom, 2008</td>
<td>UG Engineering Women and</td>
<td>Retention</td>
<td>faculty focusing on their deficiencies</td>
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<td>Minorities</td>
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<td>different and/or lower expectations</td>
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<td>an image of engineers as white males</td>
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<td>Anderson-Rowland, 2007</td>
<td>UG Engineering Women</td>
<td>Retention</td>
<td>assumptions about their plans for marriage and having children</td>
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<td>conflicts from their multiple roles</td>
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<td>Sax, 2001</td>
<td>UG STEM Women Majors</td>
<td>Grad school enrollment</td>
<td>desire to help others</td>
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<td>affect social change</td>
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<td>make a contribution to society</td>
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<td></td>
<td></td>
<td></td>
<td>high priority on raising a family</td>
</tr>
<tr>
<td>Atman and Sheppard, 2010</td>
<td>UG Engineering Majors</td>
<td>Interest in engineering grad school</td>
<td>confidence in professional and interpersonal skills</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>frequency of non-engineering extracurricular participation</td>
</tr>
<tr>
<td>Seymour, 1997</td>
<td>UG SME majors</td>
<td>Retention</td>
<td>loss of interest in science</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>belief that non-SEM majors are more interesting</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>poor teaching by SEM faculty</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>feeling overwhelmed by workload</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>limited participation in family and social life</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>feeling uncertain whether they belong (for women and minorities)</td>
</tr>
</tbody>
</table>
What is the Need for this Study?

The missing perspective among engineering education literature is specific attention to interest in doctoral-level engineering programs. While the findings of several of the described studies may be extrapolated into doctoral programs, it is unclear to what extent they are truly relevant. Is “graduate school” an equivalent proxy for “PhD”? Do non-engineering STEM majors have different concerns about pursuing a PhD than engineers do? How do personal factors such as gender and ethnicity correlate with interest in pursuing an engineering PhD? Such empirical knowledge is a necessary prerequisite to designing valid strategies to increase domestic PhD enrollments.

The National Science Foundation issued a request for proposals for exploratory projects that addressed these specific questions: “Why are fewer domestic students pursuing a Ph.D. in engineering? What are the barriers? How do undergraduates view this opportunity?” (National Science Foundation, 08-610, 2008).

The most common anecdotal explanation is that engineers with a bachelor’s degree are not motivated to seek graduate degrees due to a lack of financial incentive. For most disciplines, the economic benefit of obtaining a PhD is clear. According to the United States Census Bureau (2006), individuals with a PhD earn almost 60% more than bachelor’s degree recipients. However, PhDs in engineering earn only 30% more than those who hold a bachelor’s degree (National Association of Colleges and Employers [NACE], 2008). This financial disincentive is exacerbated by the income lost during graduate school. Based on data provided via personal communication with NACE, Table 2 provides a very general calculation of the net-present values of salaries for mechanical engineering majors as an example. This table was generated based on the 2005 BS and the 2010 PhD average starting salaries with a 3% cost of living raise each year. The PhD
program was estimated at five years long, with an annual salary of $18,000. Using this simple model, it would take 15 years post-bachelor’s degree for the net-value of the PhD to exceed that of the BS.

Table 2: Salary Comparisons for Mechanical Engineering

<table>
<thead>
<tr>
<th>Year</th>
<th>Years since BS</th>
<th>BS salary</th>
<th>Cumulative BS salary</th>
<th>PhD Salary</th>
<th>Cumulative PhD salary</th>
</tr>
</thead>
<tbody>
<tr>
<td>2005</td>
<td>0</td>
<td>$50,175</td>
<td>$50,175</td>
<td>$18,000</td>
<td>$18,000</td>
</tr>
<tr>
<td>2006</td>
<td>1</td>
<td>$51,680</td>
<td>$101,855</td>
<td>$18,000</td>
<td>$36,000</td>
</tr>
<tr>
<td>2007</td>
<td>2</td>
<td>$53,231</td>
<td>$155,086</td>
<td>$18,000</td>
<td>$54,000</td>
</tr>
<tr>
<td>2008</td>
<td>3</td>
<td>$54,828</td>
<td>$209,913</td>
<td>$18,000</td>
<td>$72,000</td>
</tr>
<tr>
<td>2009</td>
<td>4</td>
<td>$56,472</td>
<td>$266,386</td>
<td>$18,000</td>
<td>$90,000</td>
</tr>
<tr>
<td>2010</td>
<td>5</td>
<td>$58,167</td>
<td>$324,552</td>
<td>$73,036</td>
<td>$163,036</td>
</tr>
<tr>
<td>2011</td>
<td>6</td>
<td>$59,912</td>
<td>$384,464</td>
<td>$75,227</td>
<td>$238,263</td>
</tr>
<tr>
<td>2012</td>
<td>7</td>
<td>$61,709</td>
<td>$446,173</td>
<td>$77,484</td>
<td>$315,747</td>
</tr>
<tr>
<td>2013</td>
<td>8</td>
<td>$63,560</td>
<td>$509,733</td>
<td>$79,808</td>
<td>$395,555</td>
</tr>
<tr>
<td>2014</td>
<td>9</td>
<td>$65,467</td>
<td>$575,200</td>
<td>$82,203</td>
<td>$477,758</td>
</tr>
<tr>
<td>2015</td>
<td>10</td>
<td>$67,431</td>
<td>$642,631</td>
<td>$84,669</td>
<td>$562,427</td>
</tr>
<tr>
<td>2016</td>
<td>11</td>
<td>$69,454</td>
<td>$712,085</td>
<td>$87,209</td>
<td>$649,636</td>
</tr>
<tr>
<td>2017</td>
<td>12</td>
<td>$71,538</td>
<td>$783,623</td>
<td>$89,825</td>
<td>$739,461</td>
</tr>
<tr>
<td>2018</td>
<td>13</td>
<td>$73,684</td>
<td>$857,306</td>
<td>$92,520</td>
<td>$831,980</td>
</tr>
<tr>
<td>2019</td>
<td>14</td>
<td>$75,894</td>
<td>$933,201</td>
<td>$95,295</td>
<td>$927,276</td>
</tr>
<tr>
<td>2020</td>
<td>15</td>
<td>$78,171</td>
<td>$1,011,372</td>
<td>$98,154</td>
<td>$1,025,430</td>
</tr>
<tr>
<td>2021</td>
<td>16</td>
<td>$80,516</td>
<td>$1,091,888</td>
<td>$101,099</td>
<td>$1,126,529</td>
</tr>
<tr>
<td>2022</td>
<td>17</td>
<td>$82,932</td>
<td>$1,174,819</td>
<td>$104,132</td>
<td>$1,230,661</td>
</tr>
<tr>
<td>2023</td>
<td>18</td>
<td>$85,420</td>
<td>$1,260,239</td>
<td>$107,256</td>
<td>$1,337,917</td>
</tr>
<tr>
<td>2024</td>
<td>19</td>
<td>$87,982</td>
<td>$1,348,221</td>
<td>$110,474</td>
<td>$1,448,390</td>
</tr>
<tr>
<td>2025</td>
<td>20</td>
<td>$90,622</td>
<td>$1,438,843</td>
<td>$113,788</td>
<td>$1,562,178</td>
</tr>
</tbody>
</table>

# 2005 BS average starting salary based on 1,427 offers (NACE, 2011, personal communication)
*2010 PhD average starting salary based on 25 offers (NACE, 2011, personal communication)

Clearly the financial hypothesis is worth examining. In addition, it is likely that other factors also inhibit interest in the engineering doctorate. Acute specialization, impractical content, length of program, disillusionment with the undergraduate experience, lack of encouragement from faculty, and lack of demand for PhDs by non-academic employers have also been suggested as potential barriers (Advantages, 2004; Azuma, 2003; Complete the PhD, 2004; Green, 2008; Intel, 2006; Rhymes with ouch, 2007; Rowe, 2008; What does a PhD, 2008;). None of these hypothetical factors have been empirically examined.
Mullen, Goyette, and Soares (2003) observed that “the two most comprehensive research frameworks on education and stratification, the status attainment and the social reproduction models, have generated a substantial body of theoretical and empirical literature on undergraduate education but have directed little attention toward graduate education” (p. 144). Researchers involved with the APPLES project have noted the need to “better understand how students conceptualize their engineering education in relation to multifaceted or ‘hopscotch’ pathways beyond college” (Sheppard et al. p. 116).

Developing a theoretical framework for conceptualizing interest in the engineering PhD moves us closer to a central theory that spans all levels of engineering education (Redish & Smith, 2008).

This study will contribute new lines of inquiry to the literature of engineering education by researching and analyzing the experiences of undergraduate engineering majors, engineering PhD students, engineering faculty, and industry professionals who have earned a PhD in engineering. This analysis will lead to the development of a theory that describes the process of increasing interest in the engineering PhD. By presenting a complete and accurate understanding of the factors that underlie the decision to pursue or forego an engineering PhD, engineering programs will be able to develop and prioritize new strategies for increasing domestic PhD enrollments.
Chapter 3: Methods

Overview of Mixed Methods Instrument Development Designs

This study uses mixed methods approach to exploring interest in the engineering PhD among domestic undergraduate engineering students. Mixed methods is an evolving methodology with a growing taxonomy that reflects both the research design and philosophical assumptions of the research process. Creswell and Plano Clark (2007) defined mixed methods as follows:

Mixed methods research is a research design with philosophical assumptions as well as methods of inquiry. As a methodology, it involves philosophical assumptions that guide the direction of the collection and analysis of data and the mixture of qualitative and quantitative approaches in many phases of the research process. As a method, it focuses on collecting, analyzing and mixing both quantitative and qualitative data in a single study or series of studies. Its central premise is that the use of quantitative and qualitative approaches in combination provides a better understanding of research problems than either approach alone. (p. 5)

In addition to collecting and analyzing both quantitative and qualitative data, Creswell and Plano Clark note that mixed methods approaches can answer more complex research questions in more comprehensive ways by combining the strengths of each approach in ways that offset the limitations of single methods.

The particular mixed method design for this study will be a sequential exploratory instrument development design (Figure 6).
Sequential exploratory designs are characterized by an initial qualitative phase that explores the central phenomenon which then informs a second quantitative phase (Creswell & Plano Clark, 2007). The instrument development variant uses the exploratory qualitative phase to identify variables and then develop an instrument for use in the subsequent quantitative phase. Traditionally, an instrument development design places more emphasis on the quantitative phase of the study (Creswell & Plano Clark, 2007). However, in developing the Instrument Development and Construct Validation (IDCV) model, Onwegbuzie, Bustamante, and Nelson (2010) make explicit the value of both quantitative and qualitative data in scale development procedures. This study will use a rigorous grounded theory approach in the qualitative phase, thus elevating the role of the qualitative phase to be equal with the quantitative phase and adding to the overall rigor of the study. Using the notation system developed by Morse (1991) the design of this study can be represented by QUAL → QUAN, which indicates the sequential ordering of the two equally important methods. In addition to elevating the status of the qualitative phase, the design of this study places emphasis on the instrument development process by conceptualizing it as a distinct phase of the study. Finally, this design is
enhanced by a fourth, synthesis, phase where the qualitative and quantitative results are integrated, the methodology is reviewed, and the results are disseminated.

**Rationale.** Mixed methods approaches to research are not new to the field of engineering education. The benefits of mixed methods in engineering education research were noted by Leydens, Moskal, and Pavelich (2004) who advocated that “combining research that focuses on a few variables and many cases (quantitative) and research that focuses on many variables and few cases (qualitative) can unite the primary advantages of each – namely, breadth and depth” (p. 69). The National Science Foundation, the agency funding this study, also has a long history of supporting and funding mixed methods studies. The approach of combining qualitative and quantitative approaches for the purpose of developing a reliable and valid instrument has been titled “instrument fidelity” (Collins, Onwuegbuzie & Sutton, 2006, p. 77).

Based on the review of over 30 empirical mixed methods instrument development studies across a variety of fields, it is apparent that scant discussion of the rationale for using a mixed methods design or the research paradigm is generally provided. In the case when a rationale is provided it is often very general, such as a desire to be “participant centered” and letting the voice of the participants be heard. Participants are viewed as “credible experts” who can increase the understanding of the researcher and improve the quality of the research and the scale validity by directly incorporating the participant’s ideas and vocabulary (Miller, Kean & Littrell 1999; Nassar-McMillam, Wyer, Oliver-Hoyo, & Ryder-Burge, 2010; Moreira, 1995; Rowan & Wulff, 2007; Willgerodt, 2003). Wallendorf and Arnould (1988) specifically asserted that “scale development should be based on thorough ethnographic studies of meaning and expression of [the focal
construct] in that culture’’ (p. 543). Since a primary outcome of this study is the
development and testing of a theory that explains interest in the engineering PhD by
domestic students, a grounded theory approach is more appropriate than an ethnographic
approach. However, the immersion in the experiences of a group of people through the
grounded theory process will have the same positive effect in developing a more relevant
scale.

Methodological expansion is another rationale mentioned in mixed methods
instrument development studies. This rationale is often presented in context of the lack of
an existing instrument to measure the construct (Myers, MacPherson, Jones, & Aarons,
2007; Nilsson, Aringsen, Andersson, & Ejlertsson, 2010). The desire to add to the
methodological perspectives and contribute to the process of scholarly inquiry is another
aspect of this rational (Ledbetter, 2009; Turkel & Ray, 2001; Myers et al., 2007).
Occasionally, the researcher has a specific methodological interest that motivates their
choice of this rationale, such as measuring the amount of novel information that is gained
by using mixed methods (Kramer, 2011). Broader implications for the study, such as
effective participant recruitment and incentive strategies, were another example of a
methodological contribution of rationales used in mixed methods instrument
development studies (O’Donnell, Lutfey, Marceau, & McKinlay, 2007). Perhaps most
importantly, a methodological expansion rationale in instrument development studies
provides an opportunity to demonstrate the empirical benefits of mixed methods
approaches (Weitzman, & Levkoff, 2000). As noted by Knafl et al. (2007), qualitative
interviews for the purpose of instrument development “provide additional evidence that
items address salient aspects of target participants’ experiences, thereby strengthening content validity” (p. 225).

The rationale for using a sequential exploratory instrument development design in this study is both participant focus and methodological expansion. Focusing on the voice of the participants increases the content validity of the instrument. Developing a theoretical model based on qualitative data and then transforming that theory into quantitative variables will provide a better measure of those variables. Additionally, this approach will expand research methodology by providing a detailed description of this process.

**Phase I: Qualitative Grounded Theory**

Qualitative research methods are commonly used to understand educational phenomena and improve the educational process through inductive and interpretive processes (Creswell, 2008; Hatch, 2002; Merriam, 2009). Denzin and Lincoln (2005) provide the following definition of qualitative research:

Qualitative research involves an interpretive, naturalistic approach to the world. This means that qualitative researchers study things in their natural settings, attempting to make sense of, or interpret, phenomena in terms of the meanings people bring to them. (p.3)

It is important to note the emphasis on the setting: Qualitative research occurs in the participant’s environment, not a laboratory. Further, the goal of the research is to understand the meaning that the participants make for themselves, not to impose a meaning regarding a complex human phenomenon. It is characterized by focusing on broad “how” or “what” questions as related to a relatively small numbers of cases,
whereas quantitative research tends to focus on narrow “why” questions for a large number of cases (Creswell, 2007).

Creswell (2007) suggests several rationales for choosing a qualitative approach that are relevant for this study: 1) This study is examining a complex human process and it lends itself to the rich description that characterizes qualitative research; 2) No literature currently exists specific to this phenomenon, therefore, using a qualitative approach to identify variables or discover a novel theory is appropriate for this study; and 3) The researcher’s role will be that of an active partner in telling the participant’s stories. Qualitative methods were selected for the first phase of the study based on their ability to fully explore a phenomenon, illuminate participant perspectives, focus on meaning and process, gain understanding through time spent in the field, capture the detail and complexity of the phenomena, utilize an emergent and flexible research process, analyze data inductively, and build a theory (Creswell, 2007; Hatch, 2002; Patton, 2002).

**Grounded theory.** Grounded theory methodology is a qualitative inquiry approach that is used to build theory through a “systematic, inductive, and comparative” process (Bryant & Charmaz, 2007, p. 1). The intent of the grounded theory research process is to produce strong substantive or formal theories where none existed previously (Glaser, 2007; Glaser & Strauss, 1967; Kearney, 2007). A grounded theory approach was selected for this study because the aim of this project was to generate a theory about the process of developing interest in engineering PhD programs for engineers. This theory was then the basis for developing an instrument to measure the theory. The tradition of grounded theory research has evolved with many scholars expanding and reshaping the methods and concepts. More recently, Charmaz (2006) has proposed that the purpose of
grounded theory is to serve “as a way to learn about the worlds we study and a method for developing theories to understand them” (p. 10). Unlike Glaser and Strauss’ approach to separating the scientific observer from the emerging theory in the data, Charmaz (2006) assumes:

neither data nor theories are discovered. Rather, we are part of the world we study and the data we collect. We construct our grounded theories through our past and present involvements and interactions with people, perspectives, and research practices. (p. 10)

Grounded theory is characterized by theoretical sampling where data are jointly collected, coded and analyzed in order to develop the theory as it emerges using a method of constant comparative analysis to ensure the saturation of relevant categories (Glaser & Strauss, 1967). This constant comparison, or zigzag process as Creswell (2007) refers to it, allows the researcher to deeply analyze the data for themes and categories through a highly structured coding process that will then inform the evolving theory. This particular approach is appropriate for this study, since this is a new area of inquiry with little in the literature to illuminate the process of becoming interested in the engineering PhD among domestic students. There is a need for a theory that describes this process in order to be more effective in developing interventions to increase interest in the engineering PhD. Allowing for an evolving interview protocol and a theoretical sampling approach provides a flexible structure through which to explore this phenomenon.

These methods allowed the research team to examine the statements of engineers, engineering students and faculty to produce a theoretical explanation solidly grounded in the data from these participants and to transcend a simple listing of the facilitating and
inhibiting factors of attaining a PhD degree in engineering. “Generating theories about a phenomena, rather than just generating a set of findings, is important to the development of a field of knowledge” (Strauss & Corbin, 1998, p. 22-23). The research team wanted to craft a theory as well as actionable steps to impact the number of engineers who earn doctoral degrees. “A theory does more than provide understanding or paint a vivid picture. It enables users to explain and predict events, thereby providing guides to action” (Strauss & Corbin, 1998, p. 25). In this study, the theoretical model served as the foundation of a new instrument that provided evidence to guide the development of interventions by engineering faculty and administrators.

Sampling method. There were two stages of sampling that occurred during the qualitative phase; institutional sites that would allow access for both the qualitative and quantitative phases of the study and for participants within those sites for the qualitative phase.

Institutional sites. In order to ensure that the qualitative study results reflect the diversity of experiences of engineering students across the country, a maximal variation sampling strategy was employed. A maximal variation sampling approach identifies particular criteria and then selects cases to represent the diversity across the criteria (Creswell, 2008). For this study, institutional size, student body demographics, geographic region, and institutional reputation were all considered when selecting sites to invite to participate in the study. A total of 22 institutions were identified as potential sites. The Dean of Engineering or equivalently titled individual was contacted with a letter from the Graduate Dean and Associate Dean of Engineering at the host campus. E-mail and phone calls were used to follow-up with each site. Appendix A includes a
sample invitation. Accesses to the sites proved to be a challenging part of the data collection process. Many universities were approached and either failed to respond to repeated communications or declined to participate. Specific data collection targets of institutions in the southeast and mid-Atlantic regions were not met. Additionally, none of the Historically Black College and Universities approached for the study agreed to participate. Finally, the top-tier doctoral-granting engineering programs approached for the study declined to participate. A few institutions cited participation in other studies and the desire to limit the requests to their students as reasons for not participating in this study. Most institutions simply did not respond to repeated contacts. Characteristics from the seven participating data collection sites are summarized in Table 3.
Table 3: Characteristics of Participating Data Collection Sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Apx. Student Body Size</th>
<th>Geographic Area</th>
<th>Public/Private</th>
<th>Engineering Ranking*</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2,000</td>
<td>Mid-West</td>
<td>Public</td>
<td>Not ranked</td>
<td>Engineering focused</td>
</tr>
<tr>
<td>2</td>
<td>2,000</td>
<td>Mid-West</td>
<td>Private</td>
<td>Top 10</td>
<td>Engineering focused</td>
</tr>
<tr>
<td>3</td>
<td>2,500</td>
<td>Mid-West</td>
<td>Private</td>
<td>Top 20</td>
<td>Engineering focused Special co-op programs</td>
</tr>
<tr>
<td>4</td>
<td>30,000</td>
<td>South-West</td>
<td>Public</td>
<td>Not ranked</td>
<td>Very high research activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hispanic Serving Institution (HSI)</td>
</tr>
<tr>
<td>5</td>
<td>20,000</td>
<td>West Coast</td>
<td>Public</td>
<td>Top 20</td>
<td>Master's level graduate programs</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Hispanic Serving Institution (HSI)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Special diversity programs</td>
</tr>
<tr>
<td>6</td>
<td>30,000</td>
<td>Mid-West</td>
<td>Public</td>
<td>Top 50</td>
<td>Very high research activity</td>
</tr>
<tr>
<td>7</td>
<td>25,000</td>
<td>Mid-West</td>
<td>Public</td>
<td>Top 100</td>
<td>Very high research activity</td>
</tr>
</tbody>
</table>

*U.S. News and World Report, 2011, undergraduate engineering program rankings

**Participant sampling.** Glaser and Strauss (1967) suggested that the scope of the study should include enough participants to fully saturate the categories, or in other words, to interview enough participants in order to have a complete understanding of the phenomenon. Maximal variation sampling was used when selecting individuals to invite to participate in the qualitative phase of the study. Theoretical sampling was used to identify four different groups of participants as being necessary for informing the theoretical model: undergraduate engineering students, PhD engineering students, engineering faculty and industry PhDs. Through the various perspectives of these different groups, a complete picture of interest in the engineering PhD degree could be gained. Within these four groups gender, ethnicity, major/discipline, and status (e.g. junior/senior or assistant/associate/full professor) were all considered when selecting individuals to invite to participate in the study, in order to ensure maximal variation within each group.
Undergraduate participants. Two focus groups were held at each site for a total of 14 focus groups. Participation in the focus groups was limited to domestic junior and senior engineering majors with a minimum 3.0 GPA. Participation was limited to juniors and seniors so that they would have more experience within their program and be a more informed participant. The GPA requirement ensured that the students participating in the study were not overly struggling with their undergraduate program. In most cases the site provided an e-mail list of qualifying students and potential participants were contacted directly by the research team via e-mail. Appendix A includes a sample invitation. Two of the campuses chose to contact potential participants themselves. Women and underrepresented minorities were over sampled when invited to participate to ensure that their perspectives were included. For each focus group a total of 50 students were invited to participate, with attendance ranging from 8 – 12 students per focus group. Undergraduate participants were offered a $25 gift card to their campus bookstore as compensation for their participation and pizza was provided during the focus group. A total of 14 focus groups (two at each site) were held with 8 – 12 domestic undergraduate engineering students participating in each focus group. Focus groups were 60 minutes in length, including time for eating pizza and conducting introductions.

Faculty participants. Individual interviews were conducted at each site with engineering faculty. Approximately 12 faculty were invited via e-mail at each site with a range of four to ten participants at each campus. Potential faculty were identified by publicly available information on institutional Web sites and were selected to represent a balance of departments and academic ranks, with some oversampling of women and underrepresented minorities. Faculty were contacted via e-mail. Appendix A includes a
sample invitation. Faculty were not required to be U.S. citizens to participate in the study. No incentive was offered to faculty participants. In-depth interviews were conducted with 32 engineering faculty, lasting between 15 – 30 minutes each.

*PhD student participants.* Individual interviews with domestic engineering PhD students were conducted at the three sites that offered the PhD in engineering degree. One site arranged for PhD students to participate in the interviews while the other two sites provided an e-mail list of qualifying students and potential participants were contacted directly by the research team. Students were selected to represent a diversity of majors, with some oversampling of women and minority students. Since the majority of the participating sites did not offer a PhD in engineering, additional PhD students were recruited to participate via personal contacts and by publicly available information on institutional Web sites. The additional PhD students were also contacted via e-mail. Appendix A includes a sample invitation. All potential participants were invited to participate via e-mail. Engineering PhD students were offered a $25 gift card to their campus bookstore (for site visits) or $25 gift card to Amazon.com (for phone interviews) as compensation for their participation. In-depth interviews were conducted with 16 engineering PhD students, lasting between 15 – 30 minutes each.

*Industry PhDs.* Individuals with engineering PhDs who work in industry were recruited via personal contacts and networking. Industry PhDs were contacted via e-mail and invited to participate in the study. Appendix A includes a sample invitation. Industry PhDs were required to be US citizens or permanent residents in order to participate. No incentive was offered to industry PhDs. In-depth interviews were conducted with six
people with PhDs in engineering who are working in industry, lasting between 15 – 30 minutes each.

**Data collection.** Data collection occurred over the course of the 2009-2010 academic year. Data were collected during site visits at each university and through phone interviews. During the multi-day campus visits, interviews and focus groups were conducted with students and faculty. A total of 14 focus groups (two at each site) were held with 8 – 12 domestic undergraduate engineering students participating in each focus group. Focus groups were 60 minutes in length, including time for eating pizza and conducting introductions. In-depth interviews were conducted with 16 engineering PhD students, 32 engineering faculty and six people with PhDs in engineering who are working in industry. Individual interviews were 15 – 30 minutes in length.

Interview protocols were developed based on issues noted in the engineering education literature and feedback from engineering faculty at the host campus. While the core protocol did not change significantly throughout the course of the study, the areas probed for additional information fluctuated in response to previously collected data to ensure that themes were fully explored. Protocols for each interview group may be found in Appendix B. Interviews occurred during the 2009-2010 academic year and were conducted by the lead researcher (Howell Smith) with the exception of one site where interviews were conducted by a graduate research assistant (Wang) on the project. All interviews were digitally recorded, with the exception of one focus group where the recorder failed and one faculty interview that occurred via the telephone without the recorder connected.
**Data analysis.** All 13 focus groups that were recorded were transcribed verbatim. Individual interviews were selected for transcription based on their contribution to the project and unique perspectives provided. Of the 61 individual interviews, 34 were transcribed verbatim. All transcription was completed by professional transcriptionists who signed the appropriate confidentiality agreements. In all, 505 pages of interview data were transcribed for analysis.

Transcripts from the focus groups and individual interviews were loaded into MAXQDA 10, a qualitative data analysis software package. Qualitative data analysis software provides a vehicle for organizing the data and retrieving particular data segments for comparison or additional analysis efficiently based on the researchers’ coding. The software facilitates qualitative data analysis; it does not conduct qualitative data analysis. MAXQDA 10 was selected as the qualitative data analysis software based on the familiarity of the research team members with this software and the recent addition of mixed methods features to the software.

Data analysis was conducted by a research team consisting of the lead researcher (Howell Smith) and two graduate research assistants (Garrett and Wang). Research team meetings were digitally recorded in order to capture key discussions, insights and decisions made by the team.

The data analysis followed the format outlined by Charmaz (2006), consisting of two main phases:

1) An initial phase involving naming each word, line or segment of data followed by 2) A focused selective phase that uses the most significant or
frequent initial codes to sort, synthesize, integrate and organize large amounts of data. (p. 46)

In the initial stage of analysis, Chesler (1987) suggests employing in vivo coding “that uses informants own language and imagery, done directly on the text, line by line” (p. 8). This is accomplished by underlining key terms in the data and then restating these as key phrases in the margin of the transcript. Charmaz (2006) also advocates for in vivo coding in order to “preserve participants’ meanings of their views” (p. 55). MAXQDA has a special feature to facilitate in vivo coding, and in vivo coding was used whenever possible.

In the selective phase of coding Chesler (1987) describes the process as “reducing the wording of key phrases and organizing them into clusters” (p. 10). Charmaz (2006) describes the process as pinpointing the most salient categories, “Theoretical integration begins with focused coding and proceeds through all your subsequent analytic steps” (Charmaz, 2006, p. 46). The original in vivo codes from the initial phase were reduced to selective codes, with an attempt to retain as much of the in vivo codes as possible. Although these codes represent the overall themes present in the data, they are not in themselves a theoretical model, nor were all of these codes necessarily used in the evolving theoretical model.

In the final stage of analysis, the selective codes were then evaluated and shaped into what Charmaz (2006) refers to as an “interpretive theory”. Unlike the positivists views of theory as deterministic explanations that emphasize generality and universality, “interpretive theory calls for the imaginative understanding of the studied phenomenon”
Interest in the Engineering PhD (Charmaz, 2006, p. 126). By evaluating the selective codes and the draft theoretical models, an overall theoretical model will emerge.

Transcripts were organized within MAXQDA by participant type. For this project, the initial and selective phases of coding occurred somewhat concurrently, with initial coding occurring within the first few transcripts of each group, but as the research team became more immersed in the data, the codes were organized and categorized into themes.

The undergraduate focus groups were analyzed first, since undergraduates were the primary target for the study. One focus group was selected and all three members of the researcher team coded the data independently in order to begin to build a code list. These initial codes were reviewed and combined into a master code list that was agreed upon by the research team, although codes continued to be added or refined as necessary throughout the coding process. Memos were written to as a record of the definition, description, and evolution of the codes.

Two additional focus groups were coded by all three members of the research team using the established code list and were reviewed in research team meetings for the purpose of establishing inter-rater agreement. After this process, the research team felt comfortable dividing up the remaining focus groups for coding by an individual team member, with a review of the coding by another team member. Issues from the coding were discussed during research team meetings to ensure consistency across coders and to allow the code list to evolve to reflect new developments from the data. During the research team meetings, the codes started to be organized into groups around the emerging themes, and drafts of a theoretical model were created based on those themes.
The coding process was repeated for the remaining three groups of data (faculty, PhD students and industry PhDs). An initial interview was selected for coding by all members of the research team using the previously established code list. Additions and refinements to the code list were made based on the new data source and then additional interviews were selected for coding by all members of the research team. Once the team was comfortable with the revised code list, the remaining interviews were assigned to individual team members and were checked by another team member. New drafts of theoretical models were completed based on each group of participants. Once all of the individual interviews were coded and reviewed, the coding of the focus group data were reviewed using the final version of the code list. Throughout the coding process, the code list continued to be refined and organized so that once all of the coding was complete the code list reflected the themes and salient issues presented in the data. Appendix C includes the final code list.

Throughout the coding process, specific strategies evolved which helped to facilitate the refinement of the code list and the translation of that list into a theoretical model. First, the research team agreed to code whole paragraphs rather than individual phrases. This allowed for greater efficiency in reviewing inter-rater agreement, since the software package flagged even small differences in coded segments, and it focused the analysis on the broader meaning of a paragraph instead of individual phrases. Although most codes were organized into thematic groups, there were some codes that did not initially cluster around the evolving themes. A “bucket code” theme was established within MAXQDA to allow for these individual codes to be grouped together temporarily, not because of a thematic relationship, but only as an acknowledgement that the codes
had not found a place within the evolving model. Some of the bucket codes eventually were folded into existing themes, such as “Quality of Life” was merged into the “Economic and Personal Costs” theme. Some bucket codes became themes of their own, such as “Anticipated Pathways” and “Trigger Event/Happenstance” which evolved into the core phenomenon. Some bucket codes, such as “MBA” ended up not being relevant to the theoretical model. There were even bucket codes that stayed as bucket codes, but were used in other ways than establishing the theoretical model. The “important quote” code was used as a secondary code to note particularly vivid quotes by participants. Because the “important quotes” were coded across all themes, they provided a succinct and powerful synthesis of the theoretical model. Data coded as “Recommendations” were used to develop the recommendation section.

Memoing was another important strategy during the coding process that provided a systematic approach to interpreting the data. Memos were created to clarify the meaning of the codes and facilitate refining the analysis using the codes. The memos also documented the evolution of each code’s definition. Memos were frequently referred to by members of the research team throughout the coding process to ensure consistent use of the codes. Changes and additions to the memos were discussed during team meetings.

Developing the theoretical model occurred concurrently with the coding process. Once the initial code list was developed, each code was written on a brightly-colored post-it note and placed on a blank piece of foam-core board that was brought to each research team meeting. The post-it notes allowed the research team to easily group and regroup the codes and to move groups of codes in relation to each other. As the organization and hierarchy of the codes became more settled, the codes were re-written
onto new post-it notes which were color-coded by groups. This process provided an early and ongoing visual representation of the evolving theoretical model. As a precaution, photos of the “theory board” were taken at the end of each team meeting to document the current model in case the post-it notes fell off the board in transit to or from the team meetings. Once the theoretical model seemed to stabilize, the visual model moved to a computer graphic program and additional refinements were made in this format.

The central concept of the theoretical model, pathways to the engineering PhD, emerged early in the coding process while the code list was being created and refined. A PhD pathway code was created but later deleted because it seemed too broad and too much of the data were being coded into this category. The idea of an educational or career path seemed important early on to the research team, but was difficult to capture since this process was very unique for each individual. Throughout the transcripts, large sections of text were thought to be descriptive of the pathway in direct and indirect ways. In essence, each interview seemed to encapsulate one person’s journey. Since the pathway was seen as such a pervasive element, the research team focused our attention on coding the salient elements that either supported or undermined an individuals’ interest in doctoral education. Through reading memos, drafting diagrams, and discussing categories in research team meetings, the pathway concept was revisited and put forward as the central concept of the study as it existed frequently in the data, it offered a logical justification, it was abstract, it had the capacity to provide a strong explanation through its connections with other categories, and it was able to incorporate variation (Strauss & Corbin, 1998).
**Data validation.** As in quantitative studies, validation is an important step in qualitative studies in order to establish the credibility and thoroughness of the findings. Several validation strategies were employed by the researchers of this study to ensure the findings were an accurate representation of the participants’ lived experience: prolonged engagement, triangulation, rich description, member checking, and clarifying researcher biases (Creswell, 2007; Creswell & Miller, 2000).

**Prolonged engagement.** Prolonged engagement involves building trust with participants while learning about their culture (Creswell, 2007). While most commonly associated with ethnographic research, the scope of this grounded theory study provided an opportunity for prolonged engagement with data collection occurring at seven sites across four groups of participants lasting one to two days.

**Triangulation.** Triangulation involves the use of different sources of information in order to provide corroborating evidence (Creswell, 2007). Because data were gathered from approximately 200 individuals representing four distinct types of participants, it was possible to triangulate the multiple data sources and have corroborating evidence from more than one participant. While each participant group had their own unique perspective of engineering PhD programs, there was a great consistency among the groups overall.

**Rich description.** By providing a rich, thick description of the qualitative data, readers are enabled to evaluate the data for themselves and determine its applicability in other settings (Creswell, 2007). All articles and presentations of data from the qualitative phase strive to include vivid descriptions of the participants’ experiences.

**Member checking.** Member checking involves soliciting participant feedback on the credibility of the findings (Creswell, 2007). Member checking was conducted with
participants in the individual interviews for whom we had contact information. Since contact information was not recorded for undergraduate participants, additional undergraduate engineering students and engineers with a bachelor’s degree in engineering were recruited as proxies for actual study participants for member checking. Rather than ask participants to review transcripts for accuracy (all were transcribed verbatim by professional transcriptionists in order to preserve the accuracy of each participant’s contribution to the study) both groups were provided with a preliminary summary of the findings from the qualitative data and the emerging theoretical model. We invited them to provide feedback regarding these documents. This additional layer of member checking was essential to ensuring that the evolving theory accurately reflected the participants’ experience, and not just the research team’s interpretation of their experiences. Feedback from the member checking was generally positive and yielded some additional refinements to the model.

**Clarifying researcher biases.** In qualitative research, the researcher often serves as an instrument of both data collection and interpretation. It is especially important that the reader understand any potential biases or assumptions of the researcher that may impact the credibility of the study (Creswell, 2007). As ethical researchers, it was important as members of the research team to set aside our own personal biases as we coded and analyzed the qualitative data gathered for this project. The method of inquiry requires the themes and categories to evolve from the data, not from our preconceived notions of what we think was occurring. Charmaz (2006) points out that “just as the methods we choose influence what we see, what we bring to the study also influences what we can see…Nevertheless, researchers…are obligated to be reflexive about what
we bring to the scene, what we see and how we see it” (p. 15). Although it was not possible to remove ourselves completely from the process of analysis, we had frequent discussions of our individual biases regarding engineers and the field of engineering and then we helped each other to focus on what the data presented. Although our perspective as researchers were limited by our non-engineering backgrounds, Green, Creswell, Shope, and Plano Clark (2007) note that by raising our “self awareness, knowledge, skills, and sensitivity throughout the process will greatly enhance one’s own ability to uncover salient diversity concepts to inform emerging theory” (p. 480). By establishing rapport with the participants, listening closely to their stories, and probing for more information in order to understand their unique experiences and perspectives, we were able to expand our own perspective of what it means to be an engineer and thus minimize the influence of our preconceived notions.

**Ethical concerns.** In order to protect the rights of all participants, each participant signed an informed consent form as approved by the IRB (see Appendix D) and had the option to withdraw from the study at any time. The backgrounds of the participants were reported in aggregate, describing the group as a whole, rather than describing each individual in order to protect their identity. The participating sites are only described by broad descriptors and are not named as an additional protection of confidentiality. Since the study was concerned with understanding the participants’ perceptions of the engineering PhD, which was not a particularly sensitive topic, it was not expected that participating in this study had any negative impact on the participants.

The interviews were recorded on a digital recorder and then transcribed by a transcriptionist who has signed a confidentiality statement. The audio files and
subsequent transcripts are stored on a password-protected computer in a locked office. Only authorized research team members have access to these materials. The transcriptions will be kept no longer than three years beyond the conclusion of the study.

**Phase II: Instrument Development**

For the purpose of this dissertation, instrument development is being presented as its own distinct phase. In a mixed methods framework, this phase represents the “mixing” of the qualitative and quantitative phases, or the explicit relation of the qualitative and quantitative data (Creswell & Plano Clark, 2007). In an instrument development design the data is not “mixed” in the literal sense, as the qualitative data analysis serves as the foundation for the quantitative data collection. However, the phases are “connected” through the process of transforming the qualitative themes or theories into quantitative items. Because the transformation process has received relatively little attention in the literature, conceptualizing it as its own unique phase places an increased emphasis on the process of translating qualitative themes into quantitative items. Instrument development was conducted by the lead researcher and one research assistant. Statistical analysis of the scale’s reliability and validity, in addition to analysis of the significant predictors are presented in the Phase III: Quantitative section.

**Overview of scale development.** The framework for developing the Exploring Engineering Interest Inventory (EEII) generally followed the first five of steps for developing measurement scales identified by DeVellis (2003): (1) Determine clearly what you want to measure; (2) Generate an item pool; (3) Determine the format of the measure; (4) Have experts review the initial item pool, (5) Consider the inclusion of validation items. (pp. 61-87). The remaining three steps will be discussed in the Phase III
Determine clearly what you want to measure. The importance of having a well-defined construct as the foundation for any scale development endeavor has been noted by several researchers (e.g. Campbell & Fiske, 1959; DeVellis, 2003; Fowler, 1995; Worthington & Whittaker, 2006). The purpose of the EEII scale is to measure interest in the engineering PhD and how that is influenced by internal characteristics, cognitive structures and experiences that emerged from the grounded theory study. The grounded theory phase of this study served to provide the theoretical foundation for the development of the EEII scale. (Refer to Chapter 4 for a complete description of this analysis.)

The theoretical model indicated three potential factors with two or three sub-factors for a total of seven potential sub-scales. These potential sub-scales (independent variables) included: misperceptions of graduate education, misperceptions of economic and personal costs, misperceptions of engineering work, undergraduate educational environment, interpersonal environment, belief in self, and interests and skills. The “misperceptions of graduate education” sub-scale was merged with the “undergraduate educational environment” sub-scale, since many of the misperceptions stem from projections based in the undergraduate experience. The “belief in self” and “interests and skills” sub-scales were also combined to form a single personal characteristics sub-scale, as these concepts did not seem conceptually strong enough to support their own sub-scale. The following five sub-scales were then used as a framework for the Exploring
Engineering Interest Inventory: (1) misperceptions of economic and personal costs – an assessment of perceptions of and awareness about the costs of doctoral programs; (2) misperceptions of engineering work – an assessment of perceptions of the kind of work engineers do with different levels of education; (3) educational environment – an assessment of experience as an undergraduate engineering student; (4) interpersonal environment – an assessment of relevant support systems; and (5) personal characteristics – an assessment of key personal factors relevant to the model. These five potential factors/sub-scales form the core of the EEII. Table 4 shows the relationship of these potential factors to independent variables previously identified in the literature review section.

Table 4: Potential Factors and Previous Variables

<table>
<thead>
<tr>
<th>Potential Factors</th>
<th>Previous Independent Variables</th>
</tr>
</thead>
<tbody>
<tr>
<td>personal characteristics</td>
<td>desire to help others, make a contribution to society (-)</td>
</tr>
<tr>
<td></td>
<td>commitment to scientific inquiry, loss of interest in science</td>
</tr>
<tr>
<td></td>
<td>quality and substance of identification with engineering</td>
</tr>
<tr>
<td></td>
<td>confidence in engineering abilities and interpersonal skills (-)</td>
</tr>
<tr>
<td>educational environment</td>
<td>academic involvement in engineering courses</td>
</tr>
<tr>
<td></td>
<td>curriculum: boring, too narrow, not creative, not people oriented</td>
</tr>
<tr>
<td></td>
<td>feeling overwhelmed by workload</td>
</tr>
<tr>
<td></td>
<td>high academic involvement/formal and informal interaction with senior students and faculty</td>
</tr>
<tr>
<td></td>
<td>frequency of non-engineering extracurricular participation</td>
</tr>
<tr>
<td>interpersonal environment</td>
<td>conflicts from their multiple roles</td>
</tr>
<tr>
<td></td>
<td>lack of a sense of belonging in engineering</td>
</tr>
<tr>
<td></td>
<td>feeling uncertain whether they belong (for women and minorities)</td>
</tr>
<tr>
<td></td>
<td>peer environment that values science/peer group orientation towards science</td>
</tr>
<tr>
<td>engineering work</td>
<td>lack of context for the subject matter</td>
</tr>
<tr>
<td></td>
<td>confusion about the differences between engineering disciplines/uncertainty regarding what engineers actually do</td>
</tr>
<tr>
<td></td>
<td>exposure to the engineering profession</td>
</tr>
<tr>
<td>economic and personal costs</td>
<td>financial motivation</td>
</tr>
<tr>
<td></td>
<td>limited participation in family and social life/high priority on raising a family</td>
</tr>
<tr>
<td></td>
<td>perceived expectation for success in a particular career path</td>
</tr>
</tbody>
</table>

Additional independent variables were identified for inclusion in the instrument: (a) engineering experience – an assessment of participation in a variety of experiences
related to interest in the engineering PhD; (b) demographic information – a collection of demographic factors for the purpose of group comparisons. These items consisted of conceptually independent items and were not designed to be used as a sub-scale, but will serve as individual independent variables. The dependent variable for this study as identified in the study proposal was “interest in the engineering PhD.”

A note about GPA as a potential independent variable. The independent variable of GPA was mentioned in several previous studies as being relevant to retention of undergraduate engineering students and interest in graduate education (e.g. Atwell et al., 2010; Sax, 2001; Sheppard et al., 2010). Although this variable may also be relevant for inclusion in measuring interest in the engineering PhD, it was intentionally not included for several reasons. First, we felt that asking a student to report their GPA required a higher degree of self-disclosure than the other items in the EEII. Some respondents may have been uncomfortable in providing that information, while other students may be concerned about the congruence (or lack thereof) of their previous responses with their GPA. Secondly, as noted by Sheppard et al. (2010), students with higher GPAs may receive more encouragement from faculty to pursue graduate school. We believed that by including GPA in our regression models, it may mask other significant effects that we were more interested in studying. Finally, although GPA is certainly a factor in graduate school admission decisions, one faculty member noted that “there’s this misconception that I have to be brilliant to be able to do this [earn a PhD in engineering].” Over-emphasis on GPA may serve as a barrier to students who would otherwise be strong candidates for doctoral programs. One PhD student who was particularly self-aware commented that the reason for her success in her doctoral program was “not because I’m
The expected measurement model for the construct is depicted in Figure 7.

**Figure 7: Model for Theoretical Construct Validation**

*Generate an item pool.* Item generation is the process of writing questions. Ideally, the questions will “produce answers that are reliable and valid measures of something else [a construct] we want to describe” (Fowler, 1995, p. 2). This process is not often described in empirical mixed methods instrument development studies. Many studies made vague references that items were generated from the qualitative data, with no specific information provided (Gelinas, Fillion, & Puntillo, 2009; Hitchcock et al., 2006; Kutner, Steiner, Corbett, Jahnigen, & Barton, 1999; Myers, MacPherson, Jones, & Aarons, 2007; Rowan & Wulff, 2007; Tashiro, 2002; Weitzman & Levkoff, 2000). Other studies provided slightly more information about their item generation process by specifically referencing the use of the participants’ own words or issues related to translating items to and/or from English (Betancourt, Flynn, Riggs, & Garberoglio, 2001;
Interest in the Engineering PhD

Writing items that covered the breadth of the construct, themes and categories was also mentioned in several studies (Ledbetter, 2009; Mak & Marshall, 2004; Miller, Kean, & Littrell, 1999; Skodol Wilson, Hutchinson, & Holzemer, 1997; Turkel, & Ray, 2001; Willgerodt, 2003). Some researchers took a personal approach to item generation such as Gilgun (2004) who used her own life history study and personal knowledge as the basis for writing items. Others leveraged the resources of their research team, such as Chen, Ervin, Kim, and Vonderheid (1999) by having each member write five to eight items for each code using the participant’s terms and phrases as much as possible.

As a general overview of their item generation processes, Nassar-McMillam, Wyer, Oliver-Hoyo, and Ryder-Burge (2010) described that they "employed several simultaneous steps in our item generation stage, creating a pool of items based on a thorough literature review, existing scales, and our own expertise; rigorous review and revision by our experienced research team; and consulting with participants” (p. 1623). Mizrahi and Rosenthal (2001) described a similar process where they used their own experiences in addition to preliminary data when writing items. Milton, Watkins, Studdard, and Burch (2003) provided a table of example items and relevant quotes that illustrated the transformation from qualitative data into quantitative items. While they did not provide a table, Meijer, Verloop and Beijaard (2001) described listing quotes for each category then using that quote as the content of the questions. They also mentioned that their items were specifically written for an agreement (Likert) scale. After deciding to discard a preliminary scale based on existing instruments, Anderson, Uman, Keenan, Koniak-Griffin, and Kasey (1996) turned to the theoretical framework and content of the
project to compose items with a standardized format. The specific strategies employed in generating items for the EEII are described below.

The qualitative analysis software used for this project, MAXQDA, was a helpful resource in generating the item pool. The software allowed the research team to easily extract relevant data for each of the identified factors. These data groups were then divided among the research team and reviewed for sub-themes and relevant concepts. A matrix showing the themes, sub-themes, and representational quotes was developed to guide the item writing process and to ensure that all elements of the construct were included. Table 5 shows an example of this matrix.
Table 5: Item Generation Matrix

<table>
<thead>
<tr>
<th>Sub-Theme</th>
<th>Quote</th>
<th>Scale Items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Balance of Work, School, and Family Life</td>
<td>Most PhD programs are not structured for people that work. They just aren’t. And that makes it extremely difficult to pursue it. If you’re someone that has a family and has a job, and things go along with that like a house. It’s extremely difficult.</td>
<td>Family responsibilities would make it difficult for me to pursue a PhD in engineering. Balancing school, work and family time would be a factor in considering a PhD. I could work full-time while earning a PhD part-time.</td>
</tr>
<tr>
<td>Confidence &amp; Self-efficacy</td>
<td>And when you think that it’s unreachable or unattainable or you couldn’t—you know, it seems too hard or I’m not smart enough or something like—even though you’re doing fine.</td>
<td>I am smart enough to complete a PhD. My GPA is good enough to get admitted to a PhD program. I feel confident in my academic abilities.</td>
</tr>
<tr>
<td>Confidence &amp; Self-efficacy</td>
<td>If you could take away the scare from like the big dissertation.</td>
<td>I am intimidated by the thought of writing a dissertation.</td>
</tr>
<tr>
<td>Family Influence</td>
<td>My father-in-law has a PhD. I think that was helpful at least in a sense to me. I’m thinking well if he can do it I can too, and it’s worked out well for him.</td>
<td>What is the highest level of education completed by your parents or guardians? Growing up, was there anyone important to you who had earned a PhD in any field? I know people who are pursuing or have a PhD in engineering.</td>
</tr>
<tr>
<td>Institutional Programs &amp; Services</td>
<td>So we put together a workshop on ‘what the heck is this grad school thing?’ It includes things like, what’s the difference between a masters and a PhD, and what’s the difference between an RA and a TA and a fellowship.</td>
<td>I have attended a graduate school workshop.</td>
</tr>
<tr>
<td>Institutional Programs &amp; Services</td>
<td>I think if you had some of the current PhD students work with the undergrads and involve them in their research and maybe get them more interested in that and just let them see more what different things are out there, it would help.</td>
<td>I have interacted with engineering graduate students.</td>
</tr>
<tr>
<td>PhD-Level Engineering Work</td>
<td>I guess, um, they could make it more interesting to me if they could show a reason, a difference between being a, just a PE, or being a PE and having a PhD. Like I can’t see, I don’t know what difference there is adding your PhD, they pretty much can do the same thing.</td>
<td>A Professional Engineering license is more valued by industry than a PhD. I understand the kind of work that engineers with PhDs do. I think people with a PhD in engineering are overqualified for most engineering jobs. I can do the same kind of work with a bachelor’s degree that an engineer with a PhD can do.</td>
</tr>
<tr>
<td>Professors/Mentors</td>
<td>I think the teachers themselves are the best, uh, advocates for continuing to get a PhD... I think, if they talk more about it, you guys get your PhD, your doctor’s, even more students would be interested in it.</td>
<td>No one at my undergraduate program ever talked about earning a PhD as a possibility. Professors have described the importance of the PhD in the engineering field. Professors have discussed earning a PhD as an option in one or more of my classes. Professors in my undergraduate program encouraged me to pursue a PhD in engineering.</td>
</tr>
</tbody>
</table>

To facilitate item writing and ensure the relevance of the vocabulary use in the items, the qualitative data were once again reviewed. Whenever possible, in vivo codes,
or the participants own words, were used when constructing items. These in vivo items provide a richness and depth to the final measurement instrument that would not otherwise be possible for an instrument developed based solely on the literature. The utility of the items was also a primary concern in the item generation phase. That is to say, items were written with a focus on providing useful information relevant to a particular site or group.

DeVellis (2003) provides additional guidelines for writing good scale items that were incorporated in the item generation process. In general, the items were written in the most parsimonious form and at a basic reading level to make them easier to understand. The use of jargon was avoided unless it was particularly relevant to the target population. Doubled-barreled questions with multiple parts were also avoided. The goal of the item writing phase was to develop an adequate item pool to review for inclusion in the scale. The potential factors/sub-scales had associated sub-themes that reflected the breadth of their construct domain. In general, two to three items were drafted for each of these sub-themes.

The use of reverse-coded items generated much discussion among the research team. As noted by Hersche and Engelland (1996), reverse coded items have the tendency to load on a separate factor not as a result of relationships among the theoretical content of the items, but due to method bias created by reverse-coding. To address this issue, it was decided to write the items from the perspective of a typical undergraduate student based on the qualitative data. An example of this approach can be found in the item “I feel burned out by the amount of work required by the undergraduate engineering curriculum.” The concept of feeling “burned out” is generally considered a negative
emotion, however the qualitative data had example after example of students using that phrase to describe their experience. So even though the item may appear to be negatively worded (and therefore in need of reverse-coding) we anticipate the majority of students to have some level of agreement with this item. The EEII does not contain any items that are reverse-coded by design, but the “negatively worded” items needed to be closely examined for possible response bias.

**Determine the format of the measure.** Given the target population for the EEII (undergraduate engineering students) one of the early decisions of the research team was to construct the EEII in an online environment. An online survey provides a standardized way to collect data, a convenient way for participants to record responses, and a reliable method for researchers to export the data. Online surveys have been shown to improve response rates in college-aged populations (Lonsdale, Hodge & Rose, 2006). This effect has held true across gender and race (Sax, Gilmartin, Lee & Hagedorn, 2008). Because they are sophisticated users of technology, engineering students are likely to be comfortable using an online survey.

The items in the core instrument, comprised of the five potential factors/sub-scales, were written for use with a Likert scale. That is to say the items were written as declarative sentences with response options to indicate the degree of agreement with the statement; a common approach when measuring attitudes, beliefs, and opinions (DeVellis, 2003). Because the dependent variable, interest in the engineering PhD, was likely to be a topic that most of the respondents have not considered, the research team decided to not include a neutral response option in order to avoid a lack of variability in the data. Originally the response choices provided four categories (Strongly Agree,
Agree, Disagree, and Strongly Disagree) however two additional response options (Somewhat Agree and Somewhat Disagree) were added upon the suggestion of a colleague to give respondents an opportunity to express a mild preference. The engineering experience items used a binary yes/no response format for students to indicate whether or not they have had a particular experience. Demographic items were written to include relevant response options for the population. In particular, the demographic questions regarding race and ethnicity were modeled after the U.S. Department of Education’s (2008) two part format in order to provide consistency with other national data collection protocols.

In order to facilitate respondents completing the survey, items were grouped together in sections around the five hypothesized factors as suggested by Dillman, Smyth, and Christian (2009). The sections of the survey were ordered as follows: introductory and screening questions, personal characteristics, educational environment, interpersonal environment, engineering work, economic and personal costs, engineering experience, engineering interest, and demographic information. This order was selected to place non-threatening and easy to answer questions at the beginning of the survey to build rapport with the respondent and more complex and personal questions toward the end of the survey (Clark & Schober, 1992; Dillman, Smyth & Christian, 2009). The items in the introductory, engineering interest and demographic sections were all in a fixed sequence to maintain continuity while the items in the remaining sections were randomized within each section to attenuate any priming effects (Podsakoff, MacKenzie, Lee, & Podsakoff, 2003).
**Have experts review the initial item pool.** The concept of expert review is evident in several approaches to scale development (DeVellis, 2003; Worthington & Whittaker, 2006; Onwuegbuzie, Bustamante & Nelson, 2010). Most instrument development studies reference some type of process for reviewing items once the initial item pool has been developed. DeVellis (2003) refers to this stage as being an “expert review” but mixed methods instrument development studies tend to take a broader view. Item review may be done quantitatively, qualitatively or using mixed methods. Contributors to the review process may include the research team, identified/credentialed experts, the participants (either from a previous qualitative phase or from the population for whom the scale is intended) or a combination of tactics.

A review of empirical mixed methods instrument development studies revealed that qualitative data collected for the purpose of item review includes general feedback from participants and/or experts (Gilgun, 2004; Meijer, Verloop, & Beijaard, 2001; Milton, Watkins, Studdard & Burch, 2003), field notes and participant observations (Kramer, 2011) and focus groups (Myers, MacPherson, Jones & Aarons, 2007; Nassar-McMillam, Wyer, Oliver-Hoyo, & Ryder-Burge, 2010; Tashiro, 2002; Weitzman & Levkoff, 2000; Willgerodt, 2003). Mizrahi and Rosenthal (2001) included open-ended options with their pilot to solicit qualitative data for their item review. Four studies (Anderson, Uman, Keenan, Koniak-Griffin, & Casey, 1996; Kramer, 2011; Ledbetter, 2009; O’Donnell, Lutfey, Marceau, & McKinlay, 2007) utilized a cognitive interview process, either as individual interviews or as part of a focus group activity. Cognitive interviews provide information about how target populations “understand, mentally process, and respond” (Willis, 2004, p.3) to the questions, and to “evaluate targeted
survey questions, with the goal of modifying these questions when indicated” (Willis, 2004, p. 23).

For this study, three separate groups were involved in the item review process: the research team, colleagues in a psychometric graduate program, and representative undergraduate engineers. This revision procedure was an iterative process in which comments and ideas from various sources were continually being incorporated into the survey and reviewed by others. Student experts and survey specialists were highly skilled reviewers of the survey. They provided the research team members with ample ideas to refine the survey in meaningful ways. All suggested changes were thoughtfully considered by the research team and many were incorporated during this process. During the revision phase alone, eight survey drafts were created. While each type of revision process is discussed separately, it should be noted that each process influenced the others and was not a distinct step but part of the holistic process.

Research team review. The first step of the review process was for the research team to take a critical look at the item pool. Since the original pool of items was much larger than the final instrument was intended to be, the research team identified items for potential deletion or revision. The goal of this phase of the review process was to create as clean of an instrument as possible to provide to others for feedback. Research team members continually revised survey items individually, in team meetings, and during student interviews. This process of continual change resulted in the large errors being corrected early in the process allowing for other smaller corrections to be noticed and corrected by subsequent participants. As recommended by Onwegbuzie et al. (2010) the
research team reflected on process and progress throughout the instrument development phase.

*Psychometric colleague review.* An executive summary of the qualitative findings and a hard copy of the scale were shared with 12 advanced graduate students and recent alumni in a psychometric program with expertise in survey research and research methodology. This group was asked to look specifically at the clarity of item wordings, the coverage of the construct as presented in the executive summary and the response options for relevance and interpretability. Their perspectives on formatting, layout, and scale use were especially sought. Six individuals provided written and oral comments to the research team.

*Undergraduate engineering student review.* Due to the recruitment procedures and the lack of any identifiable information about the undergraduate participants from the Phase I qualitative study, actual participants were not able to be invited to participate in the review process. As a proxy, additional undergraduate engineering students were recruited to provide feedback on the EEII scale. Involving undergraduate engineering students in the scale review not only provided an additional opportunity for member checking and increasing the validity of the qualitative phase of the study, but also provided valuable feedback in selecting items that would resonate with the target population.

Students were recruited through fliers placed in the engineering buildings at one of the participating sites. Appendix E includes a copy of the recruitment flier. In order to be eligible to participate in the validation phase, students had to be U.S. citizens majoring in engineering and have junior or senior status. In all, 14 students participated. Of those 3
were female, 11 were male; 6 were juniors, 8 were seniors; 7 different engineering majors
were represented. Students received a $25 gift card to the university’s bookstore as
compensation for their time.

Each student was scheduled for an individual appointment to review the survey
and provide feedback. The appointments were held in a study room of the engineering
library in order to provide a convenient location for the students to meet with the research
team. The survey was displayed in “preview mode” which allowed the students to take
the survey in a natural way by selecting and marking an answer, but no data were
collected by the survey. The intent was to gather information on the questions, not the
responses. Students were asked to discuss the content of the survey questions with the
research team as they were taking the survey.

In a traditional cognitive interview, each item is reviewed individually with the
participant with several probes to get a complete picture of the participant’s thought
process while completing the scale (Knafl et al., 2007). Given the time constraints for
engineering students, a more streamlined “iterative feedback interview” approach was
developed and the interviews lasted approximately 30 minutes. In particular, students
were asked to examine the survey for items they thought were too long, irritating,
embarrassing, confusing, contained unclear wording, were not understandable, or
included words they did not understand. Students could also nominate questions they
wanted to delete, add, or rewrite. At the conclusion of the survey, students were asked
additional questions regarding the content, the relevance of the experiences described in
the questions, the scale, the organization, their comfort level in answering the questions,
their ability to give honest and not merely social desirable answers, the length, and any
other important issues that may have been overlooked as suggested by Iarossi (2006).

These comments were frequently probed by the research team members for more information and suggestions for how to improve the items. Appendix F includes a copy of the iterative feedback interview protocol.

The meetings occurred over a one week period of time. Although these meetings were digitally recorded, they were not transcribed. Only the researchers’ notes were used when evaluating the items. After each session of 3 – 4 students, their comments were reviewed by the research team and the scale was modified to address the concerns raised. With each iteration of the scale, fewer concerns emerged during the feedback interviews, yet students were able to make more subtle suggestions since the major flaws were corrected early on in the process. During the last round of interviews, slight modifications were made between each student. The students in the final group consistently commented that the length of the survey was appropriate. The final student was asked to simply take the assessment to see how long it would take to complete. Upon completion (in approximately eight minutes) the student was asked if there were any problems, concerns or suggestions regarding the scale or any technical difficulties with the online survey service. The student did not have any feedback and felt the scale was not in need of any additional revisions. In all, the scale went from 106 items at the outset of this process and ended with 72 items in addition to refinements to the demographic sections. The completion time of eight minutes was well under the threshold set by the research team of 15 minutes, so the overall length of the scale was deemed appropriate for the time constraints of this population.
Changes based on expert review. The review process of the EEII scale significantly shaped the content, wording, formatting, and survey design. These changes can be grouped into the following categories: deleting items, rewording items, merging items, shortening items, moving items, adding items, layout and formatting, and positive feedback.

Deleting items. A major goal of the item review phase was to eliminate items in order to match participants’ expectations of what is a reasonable length for a survey. The initial instrument included 106 content items in addition to demographic questions. In general, the participant response at this length was that the survey was a little too long, but not too bad. Once the instrument length dropped below 80 items, the participant feedback became much more positive about the length of the survey. In all, 34 items were deleted and the final instrument was 72 core items. Items were selected for deletion when they were overly redundant or problematic for participants to understand and answer and they could not be reworded. Some examples of items cut include, “Solving problems on a deeper level is satisfying for me” (ambiguous); and “I would not be viewed as an adult if I continued my education as a full-time student” (didn’t resonate with participants). The item, “I think PhD programs are not designed for people who want to have a life” was cut, even though the idea of having a life was a common idea from the qualitative data, it was not a concept that could be whittled down to a short phrase/item that was immediately understandable. A similar question regarding social life was retained and captured most of the meaning of this question. Another item that was deleted, “I don’t think my career interests will change” because participants were unclear about the time frame (just their college years, or whole professional life) their response should include.
Further, participants questioned whether changing jobs over the course of their working life would indicate a change in career interests.

Rewording items. Another goal of the cognitive interviews with the students was to assess the wording of the items, and several items were reworded based on student feedback. For example, “PhD engineers are invisible in the workplace” was changed to “Engineers with PhDs are not visible in the workplace.” This question was changed for two reasons. First “PhD engineers” as a phrase did not make sense to undergraduate students; they suggested “engineers with PhDs.” Second, “invisible” was a word that did not produce a clear meaning whereas “not visible” corrected this problem. Another example was “I would have to put my life on hold if I went to graduate school” was changed to “I would have to continue to put my life on hold if I went to graduate school” because of the sacrifices engineers already see themselves making. Some questions were changed so that there was increased consistency. For example, all questions with “faculty” or “faculty member” were changed to “professor” as this term was more relevant for students. “Earning a PhD in engineering would pigeonhole me into doing only one thing” was deemed confusing by many students and was changed to “Earning a PhD in engineering would limit my career possibilities to a few specialized positions.” “Niche markets” was changed to “specialized fields.” Finally, many “I think” and “I feel” segments were cut from questions so that they would be more direct.

Merging items. Some items were merged. For example, three questions “In my career, I can do anything I want with a bachelor’s degree in engineering”, “I can get any job I want with a bachelor’s degree in engineering”, and “A bachelor’s degree in
Interest in the Engineering PhD

80

engineering is all that I need to obtain a great job” were combined to become “A bachelor’s degree in engineering is all that I need to get any job I want.”

Shortening items. Some items were shortened. For instance, the question “Based on the messages from engineers in the workplace, on the job training is more important for me than a PhD in terms of career opportunities” was changed to “On the job training is more important than a PhD in terms of career opportunities.” Shortening items made them more direct and more easily readable for the students.

Moving items. Some items were moved out of a particular potential factor/sub-scale because they were a better fit with a dichotomous yes/no response than with the agreement scale. For instance, “I participated in an in-depth program to prepare me for graduate school, such as McNair, LSAMP, REU, or others” was originally in the educational environment section but was a better fit in the engineering experience section.

Adding items. Students had the opportunity to suggest items that they felt were missing from the survey based on their perception of the intent of the survey. A question regarding professional engineering license (PE) was added because for many engineering majors, the PE is considered the next step in their professional career and its absence was noticed by several students. The item “Growing up, was there anyone important to you who had earned a PhD in any field?” was added to help capture role models in addition to parents who might have influenced their interest in pursuing a PhD.

Layout and formatting. The engineering students who participated in the cognitive interviews as well as our survey methodology experts were very savvy about survey design and they made several helpful suggestions for improving the overall layout and
Students suggested limiting each “page” of items so that all items would fit on one screen and participants would not have to scroll to respond to items. Although we were not able to test the survey on every combination of operating systems, browsers, and monitor sizes, in general, we were able to meet this goal. Another idea from a participant was to add a progress or status bar to the survey. Students who reviewed the survey after that addition responded positively to it and liked the fact that it moved quickly. (Roughly each page of the survey represented about 10% of the total.) Students also made formatting suggestions such as consolidating long lists of response options (such as the list of majors) into a drop down box. One student suggested adding numbers to the response options in addition to the agreement word prompts. Another student suggested reversing the order of the scale from disagreement to agreement. This was not changed as all the other students and the survey experts advised against this change. Further, as noted by Dillman and Tarnai (1991) the order of the rating scale from excellent to poor or poor to excellent affects the distribution of responses. Several students commented on the lack of a neutral response option; however they felt they were able to answer the questions with the available choices. Given that the focal construct of the survey was likely something most undergraduate engineering students have not actively considered, a neutral option was not added in order to maintain the response variability.

Positive feedback. It was reassuring that students frequently made comments when they especially liked an item or it resonated with them in a meaningful way. This confirmed that we were effectively utilizing the voices of the engineering participants from the qualitative phase. In particular, students commented that they liked the option of
super senior/fifth year senior indicating that spending five years as an undergraduate student was a normative experience in engineering and that most surveys did not have this option.

Appendix G includes the initial EEII version and Appendix H includes the pilot EEII version.

Consider inclusion of validation items. The inclusion of items measuring response bias, such as a social desirability scale, is a common practice in scale development. Additionally scale developers might also include items regarding related constructs for the purpose of establishing construct validity. Worthington and Whittaker (2006) recommend against this approach and advise that initial scale development “keep the total questionnaire length as short as possible and directly related to the study’s central purpose” (p. 814) in order to increase completion rates of participants and to avoid any potential interaction effects caused by the additional items. Therefore, no validation items were included in this scale.

Phase III: Quantitative

The quantitative phase is based loosely on DeVellis’ (2003) final three steps of developing an instrument: (6) Administer items to development sample; (7) Evaluate the items; and (8) Optimize scale length (pp. 88-101). The administration of items is discussed in the sampling method and data collection sections below. Evaluation of items and optimizing scale length are discussed in the data analysis and validation section, in addition to the analysis of significant predictors and discriminators.

Sampling method. Participants in the quantitative phase of the study were domestic junior and senior engineering majors. Five of the original seven sites agreed to
participate in the quantitative phase. An enumeration sample method was used and all eligible students were invited to participate in the study via e-mail. Table 6 shows the sample size for each site, the number of responses and the response rate for each site, as well as the overall response rate. Appendix I includes a sample invitation and reminder messages. Deviations from the recruitment protocol that impacted the response rates are noted in the following section.

<table>
<thead>
<tr>
<th>Site</th>
<th>Sample</th>
<th>Responses</th>
<th>Response Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 2</td>
<td>829</td>
<td>191</td>
<td>23%</td>
</tr>
<tr>
<td>Site 3</td>
<td>919</td>
<td>287</td>
<td>31%</td>
</tr>
<tr>
<td>Site 4</td>
<td>1034</td>
<td>83</td>
<td>8%</td>
</tr>
<tr>
<td>Site 6</td>
<td>4773</td>
<td>702</td>
<td>15%</td>
</tr>
<tr>
<td>Site 7</td>
<td>877</td>
<td>196</td>
<td>22%</td>
</tr>
<tr>
<td>Total</td>
<td>8432</td>
<td>1459</td>
<td>17%</td>
</tr>
</tbody>
</table>

**Data collection.** Data for the Exploring Engineering Interest Inventory were collected using an online survey service. An online survey service provides a convenient method for participants to record their responses, and a reliable method for researchers to export the data, rather than doing data entry on paper and pencil surveys. Online surveys also provide a standardized approach for collecting the data. Since the participants were engineering students, it was likely they were very comfortable using the technology of this kind of format. SurveyMonkey was selected as the platform for data collection because it provided state of the art security infrastructure to make sure the data collected was safe via an enhanced SSL encryption package to protect the survey during transmission. SurveyMonkey also meet current U.S. Federal Section 508 certification guidelines for accessibility (SurveyMonkey, n.d.)

Given the nature of the engineering curriculum, special consideration was given to the timing of data collection on each campus. Academic calendars were reviewed and
for campuses on a semester schedule the first week after spring break was selected. Campuses on a quarter system were scheduled for data collection during the second week of the new quarter. The hope was that the workload during these periods might be slightly less for the students and that would have a positive impact on the response rate. Prior to the initial survey invitation, each campus was to send a survey announcement to eligible students from the Dean of Engineering or other appropriately titled individual. The announcement from a known and respected individual has been found to positively impact response quality, significantly lowering item omission rates (Bosnjak, Neubarth, Couper, Bandilla, & Kaczmarek, 2008; Porter & Whitcomb, 2007; Wright & Schwager, 2008). Site 2, Site 3 and Site 6 did in fact send an announcement message. Site 4 and Site 7 did not send an announcement message.

Personalized e-mail invitations were generated by SurveyMonkey and sent to all eligible participants at Site 2, Site 3, Site 6 and Site 7. Site 4 choose not to provide a list of e-mail addresses and first names, so eligible students were sent a mass e-mail from an engineering staff member with only one follow-up message. Initial invitations were scheduled for delivery at 10:00 am on Wednesday, based on Faught, Whitten, and Green’s (2004) finding of the efficacy of that particular date and time for response rate. The first reminder e-mail was delivered to non-responders on the following Friday afternoon at 10:00 am and the final message was delivered at 10:00 am on the next Monday. A 2-day reminder message was found to be marginally more effective with response rates and response speed (Crawford, Couper, & Lamias, 2001). A compressed timeline was deemed necessary since most responses occured within the first few days of administration. Schaefer and Dillman (1998) found that 76% of survey responses were
collected within the first four days of implementation. The response rate for a similar online survey of undergraduate engineering majors yielded a 14% response rate (Sheppard et al., 2010).

**Data cleaning and review.** Before data could be analyzed, they were cleaned using the following steps:

1. Variable “other engineering major” was cleaned by creating new codes for majors not on original list and a new variable for second majors, since several students used this field to indicate a double major.
2. A new variable “Minority” was created by re-coding “Race” and “Ethnicity” variables into one variable (Hispanic, American Indian or Alaska Native, Black or African American and Native Hawaiian or Other Pacific Islander = “minority”; Asian and White = “not minority”).
3. Re-coded “PellGrant” variable (Yes = Yes; No and Don’t Know = No). This variable served as a proxy for socio-economic status (SES).
4. A new variable “ParentPhD” was created by re-coding “parent’s education level” (Doctorate or PhD = “Yes”; all other = “No”).
5. A new variable “KnowPhD” was created by combining “ParentPhD” with “Growing up, was there anyone important to you who had earned a PhD in any field?” (Yes to either or both = Yes; No to both = No).
6. Re-coded site number to correspond with site number from the qualitative phase of the study.
7. A new variable “SiteType” was created by re-coding the site number. (Sites offering a PhD in engineering = “Yes”; Sites not offering a PhD in engineering = “No”).

8. Re-coded “What degree(s) do you PLAN to pursue/complete” (Doctorate or PhD in engineering field = Yes; All others = No).

Once cleaned, the data were reviewed for appropriateness to be used in the data analysis using the following steps:

1. Non-U.S. citizens were marked for exclusion.

2. Non-engineering majors were marked for exclusion.

3. Cases with missing data in 10 or more of the 72 core items were marked for deletion based on an analysis of missing data patterns. Recall that items were randomly ordered within each section. Within each section missing data appeared to be random, but there was a clear pattern of increased missing data from one section to the next. Figure 8 shows the average percent of missing data for the core sub-scales for the full database of 1459.
By deleting all cases with 10 or more items missing, the pattern of increased missing data by section was attenuated. The final 904 cases used in the analysis had less than 1% missing data across all five sub-scales.

4. Cases with unknown class standing and projected graduation of more than three years were marked for exclusion. Although only students who had junior standing or higher were invited to take the survey, some students did not consider themselves with at least junior standing. This may be due to students who enter college with advanced credit and obtain junior standing heading into their fourth semester but still consider themselves sophomores.

5. The time to complete the survey was reviewed for all remaining cases and none were marked for exclusion based solely on this variable.

6. A total of 300 cases of the remaining 904 were selected via random number generation for use with the EFA. The remaining 604 cases were marked for use with the CFA.
Table 7 provides a summary of the deleted cases while Table 8 summarizes the sample characteristics for all groups.

Table 7: Summary of Deleted Cases

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cases in Database</td>
<td>1459</td>
</tr>
<tr>
<td>Non-US citizens deleted</td>
<td>-60</td>
</tr>
<tr>
<td>Non-engineering majors deleted</td>
<td>-2</td>
</tr>
<tr>
<td>10 or more missing core items cases deleted</td>
<td>-384</td>
</tr>
<tr>
<td>Unknown class standing, graduating in more than 3 years deleted</td>
<td>-109</td>
</tr>
<tr>
<td>Total Cases Used</td>
<td>904</td>
</tr>
</tbody>
</table>
Table 8: Sample Characteristics for All Groups

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Deleted</th>
<th>Retained</th>
<th>EFA</th>
<th>CFA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Actual N</td>
<td>1459</td>
<td>555</td>
<td>904</td>
<td>300</td>
<td>604</td>
</tr>
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<td>US Citizens</td>
<td>1399</td>
<td>495</td>
<td>904</td>
<td>300</td>
<td>600</td>
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<tr>
<td>Non-US Citizens</td>
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<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Female</td>
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<td>39</td>
<td>251</td>
<td>77</td>
<td>174</td>
</tr>
<tr>
<td>Male</td>
<td>765</td>
<td>116</td>
<td>649</td>
<td>222</td>
<td>427</td>
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<td>Missing Gender</td>
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<td>1</td>
<td>3</td>
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<tr>
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<td>358</td>
<td>300</td>
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<tr>
<td>Not Minority</td>
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<td>145</td>
<td>582</td>
<td>37</td>
<td>545</td>
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<tr>
<td>Missing Minority</td>
<td>663</td>
<td>400</td>
<td>263</td>
<td>262</td>
<td>1</td>
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<tr>
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<td>615</td>
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<td>1</td>
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<td>17</td>
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<tr>
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<td>66</td>
<td>101</td>
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<td>107</td>
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<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Engineering Physics</td>
<td>3</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Environmental Engineering</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Industrial Engineering</td>
<td>63</td>
<td>25</td>
<td>38</td>
<td>18</td>
<td>20</td>
</tr>
<tr>
<td>Manufacturing Engineering</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Materials Engineering</td>
<td>40</td>
<td>21</td>
<td>19</td>
<td>4</td>
<td>15</td>
</tr>
<tr>
<td>Mechanical Engineering</td>
<td>484</td>
<td>149</td>
<td>335</td>
<td>109</td>
<td>226</td>
</tr>
<tr>
<td>Not Engineering</td>
<td>2</td>
<td>2</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nuclear Engineering</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>Optical Engineering</td>
<td>3</td>
<td>0</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Software Engineering</td>
<td>33</td>
<td>13</td>
<td>20</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>Undeclared Engineering</td>
<td>4</td>
<td>4</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Missing Major</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Data analysis and validation. When reviewing ten years of scale development in the counseling psychology field, Worthington and Whittaker (2006) caution against
allowing preconceptions to override statistical findings. They stress that a theoretical rationale should accompany any modification decisions in addition to statistical information. They also remind researchers to “clearly report all of the decisions, rationales, and procedures … in scale development research” (p. 834). The following analysis incorporates these suggestions. These analyses were conducted on the 72 core items.

**Exploratory factor analysis (EFA).** The purpose of EFA was to identify the factor structure of a scale (Worthington & Whittaker, 2006). Although the EEII scale was built to reflect the factor structure of the theoretical model generated during the qualitative grounded theory phase, conducting an EFA was still an important analysis to conduct in order to ascertain if the data did in fact create the five factors we had intended the instrument to measure. The EFA provided key information, such as the underlying factor structure of the data, necessary to test the replication of the factor structure with a CFA (Worthington & Whittaker, 2006).

**Sample size.** Generally sample sizes of 300 are sufficient for EFA (Worthington & Whittaker, 2006). A random sample of 300 of the survey respondents were selected for the EFA, using random number generation in SPSS.

**Extraction method.** Common-factor analysis (FA) was used as the extraction method for the EFA analysis. According to Worthington and Whittaker (2006), the purpose of FA is to “understand the latent factors or constructs that account for the shared variance among items” (p. 818), which is particularly appropriate when developing new scales. Although FA has been shown to produce similar results as principal-components
analysis (PCA), Worthington and Whittaker suggest that FA results tend to generalize more effectively to CFA.

**Rotational methods.** The initial EFA was conducted using an orthogonal (VARIMAX) rotation method in order to most clearly view potential factor solutions. Once a preliminary factor structure was identified, an additional EFA was conducted using an oblique (PROMAX) rotation to generate the factor correlation matrix (Table 9).

<table>
<thead>
<tr>
<th>Factor</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>.258</td>
<td>1.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-.222</td>
<td>-.247</td>
<td>1.00</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>-.118</td>
<td>-.087</td>
<td>.282</td>
<td>1.00</td>
</tr>
</tbody>
</table>

Table 9: Factor Correlation Matrix

Extraction Method: Principal Axis Factoring.
Rotation Method: Promax with Kaiser Normalization.

Although the factor correlation matrix indicated only low levels of correlation between the factors, an oblique rotation was used for the remaining iterations of the EFA in order to allow the factors to correlate and to most closely approximate simple structure, as suggested by Worthington and Whittaker (2006).

**Factorability of the correlation matrix.** As recommended by Worthington and Whittaker (2006) the factorability of the correlation matrix was evaluated using the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy. This procedure “indicates the extent to which a correlation matrix actually contains factors or simply chance correlations between a small subset of variables” (p. 818). Satisfactory values for KMO exceed 0.6 as recommended by Fabringer, Wegener, MacCallum, and Stahan (1999).

**Criteria for factor retention.** A variety of approaches were used to determine factor retention. Eigenvalues of less than 1.0 were considered for deletion, as that value
may indicate a potentially unstable factor (Kaiser, 1958). The relative values of the eigenvalues as shown on a scree test were also considered. Factors with eigenvalues that occurred after the break in the plot were considered for deletion as well (Cattell, 1966). The overarching criterion for factor retention was the degree to which the factor pattern approximates simple structure. Approximate simple structure occurs “(a) if several items load strongly on only one factor and (b) if items have small correlation to other factors in the solution” (Worthington & Whittaker, 2006, p. 821). Approximating simple structure during the EFA was advantageous for replicating the factor structure with CFA, since CFA assumes simple structure. In general, factors retained in the model will have a minimum of three items as suggested by Tabachnick and Fidell (2001).

Criteria for item retention. Because the items in the EEII have been validated through the cognitive interview process prior to data collection, the instrument had already undergone significant item deletion in an effort to optimize scale length. However, item loading and cross-loading on factors were a consideration in item retention in addition to item communalities as suggested by Worthington and Whittaker (2006). Items with loadings of less than .32 or cross-loadings larger than .32 were considered for deletion (Tabachnick & Fidell, 2001). Costello and Osborne (2005) suggest that item communalities between .40 to .70 are adequate for most social science research, so items with communalities below .40 were closely scrutinized for possible deletion.

Reliability analysis. Nunnally and Bernstein (1994) defined reliability as “freedom from random error, i.e., how repeatable observations are (1) when different persons make the measurement, (2) with alternative instruments intended to measure the
same thing, and (3) when incidental variation exists in the condition of measurement” (p. 213). To establish the reliability of the instrument, the Cronbach’s Alpha if item deleted was reviewed for each factor retained by the EFA procedure. Items whose removal significantly improved the Cronbach’s Alpha were considered for removal. Each item was deleted from the analysis one at a time, removing the worst items first, and then re-running item analysis after each deletion. This process continued until all items were deleted that significantly improved the reliability of the instrument, without sacrificing theoretical relevance of items in the construct domain. Cronbach’s Alpha above .7 was considered to be adequate, as suggested by George and Mallery (2003). Additional EFA analyses were run on the final items.

**Confirmatory factor analysis (CFA).** The purpose of the CFA was to confirm the factor structure as identified by the EFA in order to support the validity of the scale (Worthington & Whittaker, 2006).

**Sample size.** The remaining 604 cases of the cleaned database were selected for the CFA. In general, it is recommended to have at least 5 – 10 participants per parameter estimated (Worthington & Whittaker, 2006). The final model from the EFA had 52 parameters, translating to a range of 260 – 520 cases needed for the CFA. The remaining 604 cases were more than adequate to conduct CFA analysis.

**Approach to CFA.** The CFA used a robust maximum likelihood (MLR) estimator in order to account for non-normality in the data by adjusting standard errors and model fit indicies as suggested by Satorra and Bentler (1994).

**Criteria for model fit.** The fit indices indicated in Table 10 were used to evaluate model fit of the CFA using MLR estimation:
Table 10: Tests of Model Fit Recommended Values

<table>
<thead>
<tr>
<th>TEST OF MODEL FIT</th>
<th>Reference</th>
<th>Acceptable Fit Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square Value</td>
<td>Newcomb, 1994</td>
<td>Chi-square less than 2(DF)</td>
</tr>
<tr>
<td>Degrees of Freedom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Significance Level</td>
<td></td>
<td>Significantly different from zero chi-square</td>
</tr>
<tr>
<td>CFI (Comparative Fit Index)</td>
<td>Bryne, 2001</td>
<td>Above .90</td>
</tr>
<tr>
<td>TLI (Tucker-Lewis Index)</td>
<td>Bryne, 2001</td>
<td>Above .90</td>
</tr>
<tr>
<td>RMSEA (Root Mean Square Error of Approximation) with corresponding 90% Confidence Interval</td>
<td>Browne and Cudeck (1993)</td>
<td>Below .05</td>
</tr>
<tr>
<td></td>
<td>Hu and Bentler (1999)</td>
<td></td>
</tr>
<tr>
<td>SRMR (Standardized Root Mean Square Residual)</td>
<td>Hu and Bentler (1999)</td>
<td>Below .05</td>
</tr>
</tbody>
</table>

Chen, Curran, Bollen, Kirby, and Paxton (2008) caution against using any one test of model fit or any predetermined cut-off for acceptable fit, based on the complexity of structure and size of a model and the sample size. The researcher’s judgment is a necessary component of interpreting the tests of model fit. If the CFA did not demonstrate good fit, as determined by the combination of results from the tests of model fit, the modification indices were reviewed to look for problematic items for possible deletion. If the model was re-specified, the EFA was re-run using the new model, followed by another CFA (Worthington & Whittaker, 2006).

*Discriminant validity*. Modeled after Shen (2007), discriminant validity was assessed by a nested model approach using maximum likelihood estimators (ML) to compare the factor structure as identified by the EFA with other possible models. The chi-square difference test was used to evaluate the significance of the loss in fit as suggested by Worthington and Whittaker (2006) and Anderson and Gerbing (1988). A significant chi-square difference is considered evidence of discriminant validity of the
compared models. The estimated correlations between factors were also reviewed as suggested by Bagozzi and Yi (1988) and Kline (2005) for excessively high correlations. Moderate to low correlations are additional evidence for discriminant validity. The 95% confidence interval around the correlation estimate between two factors were reviewed as suggested by Anderson and Gerbing (1988) and Bagozzi, Yi, and Phillips (1991). Confidence intervals not including 1.0 serve as further evidence of discriminant validity.

Common Method Bias. Podsakoff, MacKenzie, Lee, and Podsakoff, (2003) suggested several strategies for minimizing common method variance, or “variance that is attributable to the measurement method rather than the constructs the measures represent” (p. 879). Prior to administration the EEII was reviewed by numerous groups of stakeholders and experts to limit potential variance from poorly constructed items. Items were written to avoid unfamiliar terms, vague concepts, double-barreled questions and complex syntax. In addition, all recruitment messages contained information regarding respondent anonymity in an effort to alleviate response biases such as social desirability, acquiescence or leniency. To minimize the priming effects of the items, the item order was randomly generated for each respondent within each particular section (i.e. potential factor) of the instrument. Given the initial stage of the scale development and to keep the instrument as relevant and parsimonious as possible for the potential respondents, proxy items or measures of latent factors such as social desirability, were not included in this administration. However, including items that would allow for statistical remedies for common method bias should be considered for future refinements of the scale.

Significant predictors. Before independent variables could be analyzed, the dependent variable first had to be defined. Three items were included in the survey as
Interest in the Engineering PhD

potential measures of dependant variables: What degrees have you CONSIDERED or thought about pursuing?; What degree(s) do you PLAN to pursue/complete?; and How likely are you to pursue a PhD DEGREE in engineering? If the respondent selected PhD in engineering field for the first two questions, it was coded as “yes”; all other responses were coded as no. The third question had a Likert scale with four options: very likely, somewhat likely, somewhat unlikely, and very unlikely. Of the 128 respondent who indicated that they were planning to pursue a PhD, all but four also indicated that that they had considered pursuing a PhD. Since the variable PhDPlan seemed to be a sub-set of PhDConsider, these two variables were re-coded into one variable with the following options: 2 = PhDPlan, 1 = PhDConsider (only), and 0 = no PhDPlan or PhDConsider. The responses from this new variable were compared with the PhDLikely variable in a cross-tab table (Table 11).

Table 11: Cross-tab Comparison of Potential Dependent Variables

<table>
<thead>
<tr>
<th></th>
<th>PhD Very Unlikely</th>
<th>PhD Somewhat Unlikely</th>
<th>PhD Somewhat Likely</th>
<th>PhD Very Likely</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No PhDPlan/Consider</td>
<td>361</td>
<td>161</td>
<td>22</td>
<td>3</td>
<td>547</td>
</tr>
<tr>
<td>PhDConsider</td>
<td>21</td>
<td>118</td>
<td>87</td>
<td>2</td>
<td>228</td>
</tr>
<tr>
<td>PhDPlan</td>
<td>1</td>
<td>6</td>
<td>57</td>
<td>64</td>
<td>128</td>
</tr>
<tr>
<td>Total</td>
<td>383</td>
<td>285</td>
<td>166</td>
<td>69</td>
<td>903</td>
</tr>
</tbody>
</table>

For the most part the responses were congruent. The cross-tab table revealed only a few inconsistent response patterns; three people who had not considered or planned to pursue a PhD indicated that they were very likely to pursue a PhD; and six people who planned to pursue a PhD indicated that they were somewhat or very unlikely to pursue a PhD. By reviewing the cross-tab table, it was apparent that PhDConsider would not be an appropriate outcome variable. Approximately 60% of the respondents who had considered the engineering PhD indicated that they were very or somewhat unlikely to
pursue a PhD. It would appear that while these students had at one time considered the engineering PhD, they were no longer interested. Although the variables PhDPlan and PhDLikely seemed to be helpful in measuring our outcome of “interest in the engineering PhD” there was no clear way to combine these variables into a single dependent variable. The response pattern for those who were planning to pursue the engineering PhD was a fairly even split between the very and somewhat likely response options. Conversely, the response pattern for those who were very or somewhat likely was relatively even split between those planning to pursue a PhD and those who did not indicate that they were planning to pursue a PhD. Therefore, each variable was used as a separate dependent variable when evaluating the relationships with the independent variables.

The first dependant variable, PhDPlan, was binary; therefore a logistic regression model was used to assess the significance of the independent variables with PhDPlan. The other dependant variable, PhDLikely, was continuous; therefore a linear regression model was used to assess the significance of the independent variables with PhDLikely. The following independent variables were used to build both regression models: scale scores of the factors retained by the EFA and confirmed by the CFA, engineering experiences, institution type, minority status, gender, socio-economic status (as approximated by Pell Grant eligibility), and whether someone important to the student had earned a PhD. The following hypotheses were tested:

1. \( H_0 \) = There is no relationship between the factor scale scores and interest in the engineering PhD (both PhDPlan and PhDLikely).

2. \( H_0 \) = There is no relationship between the engineering experiences, institution type, minority status, gender, socio-economic status, and whether someone
important to the student had earned a PhD and interest in the engineering PhD (both PhDPlan and PhDLikely).

A single logistic regression model using all independent variables simultaneously for each of the dependent variables was run in order to model the interaction of the different independent variables.

**Discriminant analysis.** In addition to the data collected from undergraduate engineering majors, a small group of domestic engineering PhD students and recent engineering PhD alumni from one of the sites were also invited to complete the survey. Ideally, the EEII would be able to correctly classify “novice” participants (i.e. the undergraduate students) from “expert” participants (i.e. the doctoral students and alumni), thus providing additional evidence of the validity of the instrument. This approach is based in part on the method used to develop the Maryland Physics Expectation (MPEX) survey (Redish, Saul, & Steinberg, 1998). In the case of the MPEX, high school and college level physics teachers were asked to complete the survey as they would hope their students would, and those data were used to establish the “expert” or “favorable” responses. Undergraduates in entry level calculus-based physics classes were then given the MPEX as a pre/post test at the beginning and end of the semester to measure their development from the “novice” or “unfavorable” view towards the “expert” view. The purpose of collecting data from PhD students and recent PhD alumni was to measure the extent to which group membership can be predicted based on responses to the core survey items (Tabachnick & Fidell, 2001). This group was recruited using similar messages as the undergraduate students as approved by the IRB (see Appendix I). The core items of the survey were consistent with those presented to the undergraduates, but
some of the demographic questions were altered slightly to reflect the current status of the person completing the survey.

Of the 74 PhD students and recent PhD alumni invited to take the survey only 29 (or 39%) completed the survey. Given the small N of the expert responders, only a preliminary comparison of the item means was conducted. Additional testing with a larger sample would be necessary to establish statistically significant discrimination among groups.

**Ethical concerns.** In order to protect the rights of all participants, each participant was provided with an electronic copy of the informed consent form as approved by the IRB (Appendix I) within the body of the initial invitation e-mail. As stated in the informed consent form, consent was implied in completing the online survey, as was assurance of being at least 19 years old. Additionally, since the undergraduate survey was sent only to college juniors and seniors, it was unlikely that any minors would be in the sample pool. Participants had the option to withdraw from the study at any time. The backgrounds of the participants were reported in aggregate, describing the group as a whole, rather than describing each individual in order to protect their identity. Personally identifiable information, including IP addresses, was not saved within the dataset. The participating sites are only described by broad descriptors and are not named as an additional protection of confidentiality. Since the study was concerned with understanding the participants’ perceptions of the engineering PhD, which is not a particularly sensitive topic, it was not expected that participating in this study would have any negative impact on the participants.
The data is stored on a password-protected computer in a locked office. Only authorized research team members have access to these materials. The data will be kept no longer than three years beyond the conclusion of the study.

**Phase IV: Synthesis**

*Mixed methods analysis.* The qualitative study results will be evaluated concurrently with the qualitative results to determine the extent to which the quantitative results confirm the qualitative findings. Additionally, the quantitative results will be used to prioritize the recommendations from the qualitative phase.

**Design Challenges**

Conducting a mixed methods instrument development design has several inherent challenges, and this project was no exception. First, conducting the grounded theory phase of the study was time consuming since a relatively large number of interviews were necessary to saturate the categories. Over 500 pages of single-spaced data were transcribed and it took a significant amount of time analyze the data. Access to the sites was also a challenge and required more time to obtain permission than anticipated. The time allotted for data analysis and instrument development was also originally underestimated.

Obtaining IRB approval was also a challenge in this study and ultimately each phase of the project was submitted independently for IRB approval. In addition to the IRB approval at the host campus, IRB approval was required by two other campuses. The remaining sites allowed both the qualitative and quantitative data collection to occur based on IRB approval at the host campus.
The expense of conducting such a large scale and long term study was also a challenge in this study design. Funding from the National Science Foundation and additional support from the University of Nebraska-Lincoln was necessary to make this study financially feasible.
Chapter 4: Findings and Results

This chapter presents the findings from Phase I, the qualitative grounded theory and Phase III, the quantitative study.

Phase I: Qualitative Grounded Theory Findings

The research questions for Phase I included:

1. What perceptions do domestic engineering students, engineering faculty members and other engineering PhDs hold about PhD education in engineering?

2. What factors facilitate or inhibit interest in the engineering PhD among domestic engineering students?
   a. What are the initial conditions of domestic engineering students that influence their interest in the engineering PhD?
   b. What is the context that supports the continuation of (or changes to) the level of interest of domestic engineering students in the engineering PhD?
   c. What are the intervening conditions that influence the level of interest of domestic engineering students in the engineering PhD?
   d. What strategies were reported that could be used to increase interest in the engineering PhD among domestic engineering students?

The grounded theory model identifying factors that facilitate or inhibit interest, describing the relationships among the factors, and explaining the process of developing interest in the engineering PhD is presented in Figure 9. Each element of the model is described in turn and hypotheses regarding the relationships among elements are stated.
Pathways to the Engineering PhD

Our description of the model begins with the pathways to the engineering PhD since it encompasses all other elements of the theoretical model. Doctoral-level education is considered a non-normative event for engineers. As one faculty member stated, “It’s a different career arc completely.” Most participants who were pursuing or had already earned a PhD in engineering described a lack of planning as undergraduates to pursue a PhD. One engineer summarized this, “I didn’t really have any plan of becoming a professor or getting a PhD.” Other PhD engineers were even more open about their lack of a path: “I tripped into my career” and “I sort of lucked into it.” The stories recounted by these participants indicate that there is no “one-size-fits-all academic path” that leads a person to have interest in earning a PhD in engineering.

Engineers who have earned PhDs could look back on their collective experiences and retrace the path that led them to an advanced educational track. Many times they
could articulate a specific trigger event or a more general set of circumstances that set
them on this path. These engineers have said that having the PhD as a goal may be an
important step. However, even with an end goal of the PhD in mind, there are many steps
along the way that are not clear for engineering students. One current doctoral student
explained this confusion, “I think you have to have a goal, certainly of, what you, what it
is you want to do, and…the best way to get there, I think, maybe it isn’t so clear for
people.” A thoughtful period of reflection over a period of time is another ingredient
along the pathway of considering advanced education. One doctoral student captured this
sentiment, “It’s a journey and I see it as a journey, not necessarily the race.”

Bachelor’s-level engineers do not have a clear path to work towards a PhD
because their goals are either unclear or center on obtaining a job after graduation. For
undergraduate engineering students, a PhD in engineering is simply not part of their
mindset. For the most part, the pathway to an engineering PhD is obscured from them by
the hyper-focus of obtaining a high-paying job upon graduation with their Bachelor’s
degree. They are not aware of the PhD as a possibility or what they would need to do to
progress down this pathway. Because the pathway to the PhD often involves the process
of time, life and work experience, and even unforeseen events, it is difficult for
undergraduate students to understand how to plan their pathway to the PhD. Long-term
educational goal setting is difficult for many undergraduate students. As one PhD student
reflected on his undergraduate experience, “I didn’t have a goal at that time of pursuing
academics or research. I just wanted to move on—you know, start my career.” An
undergraduate student described how she struggles with career and education decisions.
I may still need school…I’m not sure. I haven’t thought too much about that…I guess that’s too long term for me…I just think from day to day…It’s just too, too hard to tell on where I, where I want to be, uh, you know, I just want to roll with it and see, see where I end up.

Anticipating a career pathway with additional education is difficult when short-term goals are either uncertain or focused squarely on obtaining employment.

**Misperceptions**

Misperceptions, or the incorrect and incomplete beliefs that students have about the engineering PhD, work to shape the ways in which their personal characteristics are revealed. The prevalence of misperceptions undergraduate students have about the engineering PhD is widespread. Because these misperceptions are believed to be true, they serve as a major barrier to interest in the PhD. We have categorized them into three primary groups: graduate education, economic and personal costs, and nature of work.

**Graduate education misperceptions.** Almost universally we found that undergraduate engineering students had a lack of information, or even outright misinformation regarding engineering PhD programs. These misperceptions included the cost of graduate school, the workload and curriculum of the doctoral program, the length of the program, the types of careers available with a PhD, and the characteristics of the individuals earning PhD degrees in engineering.

**Education cost.** The actual cost of a graduate education is not well understood. A faculty member acknowledged that undergraduate students “think they have to pay for the tuition.” Indeed many students in this study believed they would have to pay graduate school tuition just as they paid for their undergraduate tuition. Most students do
not know about fellowships, assistantship stipends, and tuition remission opportunities, and those that do assume the funding is not enough to support them (and their families) adequately during their studies.

**Workload and curriculum.** Graduate workload was largely viewed in a negative light. Based on their undergraduate experiences as a reference, undergraduate students believed that the graduate workload would be unrelenting. Undergraduate students did not want to be “stuck in a lab…doing equations all the time” or use their “will power to keep working and always be studying.” Students thought graduate school curriculum was more focused and theoretical compared with their undergraduate experience. Engineering students projected that the graduate curriculum would be more “independent” and “self-directed.” They recognized that there would be more choice in “what you work on” in terms of the classes and research experiences and that you “don’t take as many classes.” While some students would appreciate this specialization, others saw it as an increase in isolation and didn’t want to “lose social interaction” from their classes. They seemed to acknowledge the strong presence of research in the graduate program, realizing there would be “a lot more research.” They were skeptical about the increase in research as this was seen as taking away time and resources from “practical knowledge.” Undergraduate students highly value their applied skills and want to become an “actual engineer” and not a “book engineer.” So there is a negative perception of what research is, or as one student said there is a “stigma on research.”

**Program length.** The length of a graduate program is seen as indefinitely long. Students thought it would take them many years to finish a PhD. One student joked, “I think if you’re going to get a PhD you’re going to be in school for what, like 28 years or
something.” Some students found it difficult to articulate the exact amount of time it would take to obtain a graduate degree. “Isn’t it roughly like six years to get to your PhD?” Current PhD students felt anxious and fearful that they would be in school “forever.” The program length was also viewed as interfering with other life goals such as having a family. One current PhD student spoke of her concern of losing out on this aspect of life;

Culture tells, at least women, that you need to find that husband, you need to get married, you need to have children. And so like a lot of my friends have started to get married, and started thinking about families. And I’m like wait, where did I miss the boat?

**PhD career possibilities.** Students viewed advanced doctoral education primarily for those individuals who want to go into academic careers involving teaching and research. One student boldly stated the commonly assumed limitations of the PhD. “A PhD is really only necessary if you want to teach or remain in academia.” There is a clear disconnect for undergraduate students between advanced education and a career in industry. One student spells out the view of academic jobs as the only career option for engineers with PhDs, “I don’t think people that choose to get a PhD are planning on getting into the industry and working as an engineer. I think they’re planning on researching.” Therefore, if undergraduate students do not feel a strong connection to teaching and research, they are much less likely to contemplate earning a PhD in engineering.

**PhD student characteristics.** Students described engineering PhD students in incredibly positive, almost idealistic, ways. They saw these students as perpetual learners
who possessed “undying curiosity,” were exceedingly “studious,” and “very smart.”

Dovetailing with their “love of school” and “capacity to learn” was their “determination.”

Students went on to describe doctoral students as “dedicated,” “very focused,”

“persevering,” and “disciplined.” Besides having a superior intellect and “tenacity,”
other characteristics of PhD engineering students were far ranging. A PhD student was
seen as a person who “takes the lead in groups” and has good “communication skills.”

PhD engineering students were also seen having “creativity,” “insightfulness,” and
“patience.” PhD students were also considered “independent” and “self-motivated.”

Perhaps because undergraduate students had such lofty views of PhD students, they were
likely not to see themselves as possessing all of these characteristics, which may
discourage them from considering a PhD.

**Economic and personal costs misperceptions.** Money does play a part in the
decision to pursue a PhD in engineering, but it does so in complex ways. Engineers
contemplate a variety of economic and life considerations when deciding whether or not
to further their education in the field. They consider such things as the student loan debt
they have, the income and opportunities they would forgo while in school, the financial
commitments they have, and their quality of life. These concerns can best be broken
down into three categories: undergraduate debt, the opportunity cost of advanced
education, and quality of life.

**Undergraduate debt.** Engineers, like many college graduates, have student loan
debt to pay back after graduation from their bachelor’s degree program. Many have large
sums and wish to begin paying this down as soon as possible. Others have personal loans
from their families and also want to begin making payments and supporting their
families. Students wanted to erase these debts and were very hesitant to incur more debt by continuing on with their education. A faculty member recognized that many of his graduating students wanted to “get a job to start alleviating all these loans.” The costs incurred during the bachelor’s degree were real and engineers kept them in mind when making future decisions.

**Opportunity cost of advanced education.** Since engineers with a bachelor’s degree can command large salaries, the opportunity cost of forgoing this money to pursue advanced education is high. As one engineer succinctly said, “a lot of people make a lot of money without a PhD.” Engineers have recognized that it is not just the salary but also the benefits that are lost when education is chosen over employment. One engineer commented about the loss of perks, “They’re losing out on pay, they’re losing out on 401(k)s, and they’re losing out on bonuses and raises and work experience.”

Many recent graduates feel the need to get a job after graduation. One student candidly admitted that he was “really tired of being poor…and wanted to get a real job and make some money.” This idea of working is reinforced through job fairs in which engineers are pursued and often guaranteed positions upon graduation. Another engineer summarized the disparity in pay between engineers in the workforce and engineers following an educational path, “Coming out of school you have the option of going to graduate school and making $20,000 a year or working and making $60,000.” Since the income gap is so wide, many have calculated that they never “recoup” the money. Any financial advantage with increased education is nothing more than a “net wash” in the end.
Advanced education is not always compatible with the employment sector since many engineers would have to give up their current career in order to obtain more education. While some companies encourage advanced education through supportive policies like flexible work schedules and by paying the tuition bill, this model rarely holds for doctoral-level education. One engineer described the flaws in the educational structure for doctoral education.

Most PhD programs are not structured for people that work. They just aren’t. And that makes it extremely difficult to pursue it. And I don’t think it has to be that way. I don’t think you have to work 100% of the time for the university, live inside of the university building, and in order to get the experience that you need to hold a PhD… but if you’re someone that has a family and has a job, and things go along with that like a house, it’s extremely difficult to find a structure that fits that.

The increased time necessary for independent research and dissertation writing are usually more than a full time employee can successfully manage. Engineers already out in the workforce are left with only one option, leaving their job to attend graduate school. This is a sizeable sacrifice that many are not willing or able to make. Thus, advanced education at the master’s level is possible for many working engineers, but doctoral-level education is oftentimes not viable.

*Quality of life.* Engineers spoke about the weight of their personal financial obligations. Many engineers had mortgages, car payments, and other financial responsibilities. Others planned to make large purchases and life decisions upon graduation. Many engineers had plans to start families or already had families to support.
These financial commitments limited the possibility of advanced education because many engineers would have to drastically change their lifestyle to continue on with their engineering education. Engineers hit by the recession or by company downsizing were more open to reevaluating their career goals and starting over by acquiring more education.

Engineers also spoke of more intangible types of influences regarding their quality of life that weighed on their decision to earn an advanced education. Many engineers were looking forward to the freedom a career would offer after spending several grueling years putting in long hours at their engineering school. They looked forward to enjoying the fruits of their labor and living a more balanced life that included reconnecting with hobbies and spending time with family and friends. They were excited to work a set number of hours, which would allow them to “have a social life” spending time with friends and enjoying their life. Many engineers were simply ready for the next chapter of their lives to begin. They were eager to “move on” and not “put your life on hold” by completing more school. Engineers in the work force or those planning to enter it viewed the incentives of the working life as something they looked forward to and would find very hard to give up. Engineers saw graduate education as limiting their life in terms of their time and money.

**Nature of work misperceptions.** One of the most clear themes from the qualitative data were that undergraduate engineering students’ perceptions of doctoral-level engineering work was much different than the work described by engineering PhDs. Doctoral-level engineers see themselves as leaders who have a great deal of responsibility in managing people and projects as well as pressure to be accountable for their work.
They were working in “high impact jobs.” Engineers with advanced education spend a lot of time on research-based projects where they were making “original contributions” and “pushing the envelope” of the current knowledge base. These engineers were conducting important and novel work that they viewed as “interesting” and “stimulating.” Engineers of this level considered themselves deep thinkers who were innovative and took “entire fields to new places.” These engineers could not only solve problems but also define the problems that would be tackled in the future. They utilized their “broad perspective” from their advanced education to conduct true “scientific discovery.” There was a prestige factor with this highest level engineer. Many felt that these engineers had “status” and were important because they were at the “top of their field.” A final characteristic of PhD-level engineering work was that it was deemed as more flexible in terms of time and also in the level of freedom to work in a self-directed fashion.

However, undergraduate students had a much different perception of doctoral-level engineering work. On one hand, Bachelors-level engineers believe that they “can do anything” with their degree. They believe their employer will invest in them and teach them the necessary skills to thrive in the workplace. On-the-job training and professional licensure (for some engineering fields) is perceived as more valued than advanced education. These engineers do not understand why a company would hire someone with more education to do the same work they could do. One student describes this belief, “Why would you pay someone twice what you could pay a fresh college student if they can do that same job?”

On the other hand, undergraduates saw doctoral-level work as “not real engineering” being so advanced and “theoretical,” that engineers with PhDs were seen as
detached and unable to “relate to the real world.” Engineers with doctoral degrees were seen to have limited job prospects because of their increased specialization by Bachelor’s-level engineers, although PhD engineers did not see specialization as a negative circumstance. PhD engineers explained how they were highly sought after for their skills. One engineer revealed his personal experience of finding a niche, “There were two companies that were very interested in hiring me…I happened to be one of the very few specialized people in the world….Specialization helped me fit into a niche that was in demand.” Certain types of careers, such as those in research and development, necessitate doctoral-level education. In these instances, the only way to obtain such a job is by earning a PhD. As one PhD student summarized, “The PhD gets you places that you have no hopes of getting to with a master’s degree.” Therefore, the PhD degree may limit your career prospects for more basic or standard positions, but it “focuses your career opportunities” to the types of positions that would be most desirable to these candidates.

**Environment**

The two types of environmental influences on interest in the engineering PhD found in this study were the undergraduate education environment and interpersonal environments.

**Undergraduate educational environment.** Comments about the educational environment centered on the undergraduate engineering experience: overwhelming work load and demanding and difficult curriculum, both significant detractors from interest in pursuing a PhD. Institutional programs and services encouraging graduate school have a
positive effect on increasing interest in the engineering PhD, but the absence of these kinds of programs has a negative effect.

**Work load and curriculum.** The work load of undergraduate engineering students is perceived as difficult and time consuming. Students shared their frustrations with the volume of work they had to do and the time commitment it takes to be an engineering student. Yet their complaining was also laced with a sense of pride in learning how to be successful in such a demanding environment.

Each semester, it’s always the hope, is it going to get easier? Is it going to get easier? I don’t know, just, for me each step, each semester, it’s just harder and harder and harder, but I guess, I mean, you get used to it. It doesn’t get easier, you just get used to it as you go. You just learn to love the pain.

Many students, however, expressed the consequence of such a demanding work load was burn-out; they just wanted to be done with school and “have a life.”

The educational environment also includes references to the curriculum and pedagogy of engineering programs. Some students voiced concerns about having to wait to begin courses in their major until their Junior or Senior year. “I think that they don’t immerse you in engineering soon enough.” Students who experienced this delayed engineering instruction were often frustrated by the long time period for non-engineering core courses, and therefore less interested in the engineering PhD. Other students, however, spoke positively about the curriculum when they were engaged in engineering projects early in their educational career.

A paradigm shift to a more learning-centered and interactive curriculum was mentioned by faculty at several institutions, most notably with a focus on a problem-based
Interest in the Engineering PhD

curriculum that teaches broad concepts and critical thinking. This approach seems to encourage students to think about life-long learning and may have a positive effect on interest in the engineering PhD.

**Institutional programs and services**. Institutional programs and services encompass a broad array of both formal and informal activities designed to encourage undergraduates to pursue a PhD in engineering. While not geared specifically at encouraging advanced degrees, some institutions provide support services to help retain their undergraduates, such as special tutors in the residence halls, test banks, and review sessions. Students frequently commented on the accessibility of faculty (providing cell phone numbers or being available via e-mail late at night) as an indication of the institution’s commitment to their success. These programs have a positive effect on minimizing feelings of burnout.

There are many ways in which institutions create opportunities to promote graduate education: workshops, mentoring programs, and guest lecturers. Workshops and classroom presentations about a variety of graduate school issues such as the impact a graduate degree can have on your career, financing graduate school, the process of applying to graduate school, are all informative. A mentoring program, where students are paired with faculty or graduate students to learn about graduate school and career possibilities is another example of an institutional program. Guest speakers who are recent alumni or even peers who have participated in research experiences at other campuses seem to have a great deal of credibility with undergraduate students. A doctoral student recalled a dinner at his undergraduate institution as being a significant factor in deciding to go to graduate school.
They sort of gave this presentation of why you should go to graduate school and it was this clear expectation of “you are qualified to go to graduate school. Here are all the reasons why you should do it. Here’s what’s involved. Go do it.” …But it was really sort of beneficial to me to think, “oh well if they think I can do it, I’m qualified, then maybe I am. Why not?”

Formal programs, often federally funded, such as McNair, LSAMP and REUs, provide a longer term, more structured and in-depth experience for students. The value of these programs is clear, as one student stated “I was involved in the McNair program and that really—from that program, I decided I was going to go to graduate school.”

Unfortunately, the lack of informal and formal programs and therefore the lack of information about graduate school was frequently cited as a deterrent to advanced education.

They don’t put a lot out there about the PhD program. I know here, I don’t hear much about it, but I’ve seen like one or two things on the wall, at that. It’s like a small little poster…It’s an eight by ten paper that says, graduate programs or PhD programs. It’s on the third floor. They really want us to get a job, so that’s kind of where they’re focusing.

The absence of graduate preparation programs was noted by another undergraduate student,

I was thinking it’s kind of interested how like, they have career fairs, and they have industry coming and trying to take us into their companies, but we don’t really have any grad schools coming in and saying ‘Come look into our program.’
This is even more of a challenge on campuses where they have limited graduate engineering programs, so undergraduates have fewer opportunities to interact with graduate students in the lab, the classroom or other situations. The lack of exposure to graduate school opportunities has to compete with the encouragement to obtain a high paying position after completing a bachelor’s degree.

There are not a lot of researchers that we have been exposed to. Everyone that comes to talk to us that we see even, I mean, minus professors, everyone’s in the industry working, making bukoo bucks, which is a plus, but, yeah, I’m definitely swayed, I’m a push over, I see that and there’s really nothing to compare it against.

**Interpersonal environment.** Many people (family members, peers, those in industry, professors and mentors, and the views of the broader public) influenced engineers’ career paths and thus their educational interest. These individuals and groups influenced engineering students and professionals in a variety of supportive and obstructive ways, with various levels and types of influence.

**Family and friends.** Engineers considering advanced education were often influenced by their family of origin (the family they grew up with) as well as by their own families (for those who were married, had children, etc.) and by their friends, peers and classmates. Students told of their engineering lineages as many had parents or other relatives with engineering backgrounds. Engineers explained that they came from a “long line of engineers” and that engineering “runs in my family.” Additionally, many parents encouraged a bachelor’s degree in engineering for their children by steering them toward this field by “planting this seed” and pushing them to “excel in school.” While
undergraduate work in engineering was encouraged, graduate education was often openly
discouraged both by the parents and by the student’s partner and children due to the
financial pressures of supporting a family and paying off existing student loans.

Individuals from families with advanced educational attainment, whether in the
engineering field or in another field, were more likely to consider graduate education. As
one doctoral student described, “People who don’t know other people who have graduate
degrees are less likely to imaging themselves doing it, to want to do it, to think they’re
capable of it, or to see why it has any appeal.” Therefore, having familial role models
and being exposed to this environment appears to have an impact on whether a student
will continue on with higher education in engineering. The awareness of educational
opportunities may be less understood in minority households, particularly in first
generation families.

Students earning a bachelor’s degree in engineering typically had relatively few
friends or peers who had advanced education or were planning to pursue this. In the few
cases when this was true, engineers utilized these relationships to learn about different
graduate school programs, the professors, the curriculum and research requirements, and
the overall graduate school experience. Using these peer relationships, students were able
to make more informed decisions about graduate school.

**Industry.** Bachelors-level engineers intersected with industry professionals
through internships, co-op experiences, and in their careers. Based on the specific
experience, engineers were encouraged or discouraged from further education. In
situations where students or engineers interacted with professionals with master’s degrees
and doctorate degrees, advanced education was encouraged. Environments where
“everybody there had PhDs” gave students reason to thoughtfully consider their long-term career goals and the education necessary for such a position.

Conversely, in workplaces where students saw only bachelors-level engineers or few individuals with a master’s or doctorate degrees, there was less support for and even open discouragement of higher education. Where education was mentioned, it was suggested that students begin their career and then start a graduate program so they could specialize in “something more related to the company.” Others in industry have stated that salary and promotions are based more heavily on longevity than on educational level. As one industry professional described, advanced education “doesn’t change your grade,” meaning that a worker with a graduate education would be at roughly the same level as someone with a bachelor’s degree who worked for the company upon graduation.

**Professors and mentors.** Individuals with advanced engineering degrees often described the sizeable impact professors had on their pursuit of additional engineering education. The depth of this influence ranged from exposing students to the opportunities afforded by a graduate education to truly engaging with and working alongside students in a mentoring capacity. Faculty members described how they intentionally mentioned graduate school as an option for their students. One faculty member purposefully discussed graduate education with all students in her classes. “I talk to the entire group…about graduate school what it can do, what it can’t do and I try to encourage them to think beyond what their maybe preconceptions are.” Some faculty members openly shared their “entire life story” or career path. A few faculty tried to spark interest in advanced education by speaking about the value of advanced education in engineering. One faculty member speaks to the merit in continuing engineering education, “I try to
instill in my students, the importance of pursuing a higher education and hopefully facilitate that as well.” Creating graduate school workshops explaining what graduate school is, how students can receive funding, and the types of careers available with advanced education are other ways faculty have disseminated information about advanced engineering education. Some faculty members have actively pursued students they see as having potential by questioning them about their future plans and career aspirations. One PhD student described how she was repeatedly asked about her educational plans, “I had a faculty member who grabbed me and said ‘why aren’t you going for grad school?’” The ensuing discussion between this faculty member and student answered many questions and unblocked some barriers she saw in attaining advanced education and working in this type of career.

The most proactive faculty members demonstrated a passion for training the next generation of engineers through mentoring. These faculty members not only asked students if they were planning to advance their education but openly asked them to do so. These faculty members made themselves available to their students and supported them. Students paired with these types of mentors detailed how they believed their professors were “invested in your life” and provided a helpful guiding influence. These professors took time to “talk to students one-on-one” and instill a sense of confidence in them. One PhD student described the words shared by one of her faculty members regarding faith in her abilities, “you’re capable, don’t be afraid…she gave me the wings to- told me, not gave me, told me hey you have wings.” These hands-on faculty members invited students to work with them on their research projects. It is not surprising then that educators were considered influential in encouraging more students to continue their
education up through the doctoral level. One student summarized, “I think the teachers themselves are the best advocates for continuing to get a PhD.”

**Societal views.** Those with doctorate degrees in engineering as well as those still pursuing their bachelor’s degree conjectured that there are cultural values that may discourage individuals in pursuing a doctorate degree in engineering. There are several pervasive views that the public holds about engineers and the engineering profession: no one understands the work engineers do, engineering is viewed as a terminal degree, and there is a lack of a national force driving students into engineering as there has been in the past. What engineers of all levels do in their daily work or what they contribute to society is not well understood. It is unlikely that people will pursue a career path they do not understand or know exists.

Another message that is commonly part of the belief system regarding engineering is that education beyond the bachelor’s degree is not necessary because you can and should work as an engineer after earning a bachelor’s degree. Therefore, graduate education in engineering is seen as a needless investment. An industry professional with a PhD speculated that “education is more highly valued in other cultures” where advanced education is considered normative. Another industry professional cites our nation’s collective values as having a “focus on near term returns” rather than a longer view. This can be exemplified by our students who “can’t wait to get out of school so they can start earning money.”

Finally, there is not a national push to encourage engineering as an important career. While some believe that there is prestige in being an engineer, many feel that engineers are “not viewed as glamorous or sexy.” A noble cause can be a powerful
interest to pursue an engineering degree, but as one faculty member stated, “We don’t have an Apollo.” The lack of a noble cause such as sending a man to the moon certainly does not help to increase interest in the engineering PhD.

**Personal Characteristics**

Personal characteristics include the internal personal qualities that may prompt an individual to be interested (or not) in pursuing a PhD in engineering. They can be grouped into the following broad categories: Belief in self and interests and skills.

**Belief in self.** The belief in self theme encompassed two sub-categories: self-efficacy and confidence, and motivation and initiative.

**Confidence and self-efficacy.** Concerns about their self-efficacy and confidence in their academic abilities were expressed by undergraduates and doctoral students alike. Many students questioned their intellect when considering graduate school. The PhD appears “unreachable or unattainable…it seems too hard.” Undergraduates often expressed concern in their ability not only to complete a doctoral program (the dissertation is “intimidating”) but to even get admitted to a program (“I’m not smart enough.”) Engineering faculty acknowledge this lack of confidence in their students, but try to reassure them that they do not have to be a “genius” to get a PhD. One faculty member, when encouraging a student, said,

> If you remember what you were like as a freshman and what you’re like now as a senior, how far has your ability to think transformed? That same type of transformation will happen through the graduate program. So you don’t walk into a PhD program being able to do PhD type of research. You gotta get there.

Faculty can provide opportunities for students to develop their self confidence by
including undergraduates on their research team. One student, reflecting on his undergraduate research experience explained,

Sometimes you put the faculty member stuff on a pedestal….But when you work on someone’s project, collecting data or something, you see there’s tools I can learn and I can apply them. And this could be a career path for me.

The master’s degree is another even more common vehicle for students to develop the confidence to pursue a PhD. One doctoral student described his experience as a master’s degree student, noting

I started taking the graduate level classes, and I had the sense that I can do this, this is achievable. So I guess that it was the more exposure I had to graduate school and the PhD, then the less intimidating it became.

Motivation and initiative. Motivation and initiative are other characteristics that are associated with interest in obtaining a PhD degree. Doctoral students, engineering faculty and industry PhDs commonly note that the ability to take initiative and be self-motivated are key to thriving in conducting independent research. One doctoral student observed, “I think that makes you much more successful if you’re kind of self motivated and you can do things without a lot of guidance once you kind of get the basics.” It requires “persistence and tenacity” to navigate departmental politics, failed experiments and other challenges inherent in doctoral education. As one doctoral student noted, self-motivation and a strong work ethic were critical to her success in her doctoral program: “I can say I’m not here because I’m that much intelligent. I’m a very hard worker and I know if I wasn’t this hard working or patient, I wouldn’t be here, I wouldn’t have lasted the first two years.” In order to overcome the long duration of a graduate program,
students thought one needed a great deal of commitment to persist. One student stated, “You definitely have to be passionate to be able to dedicate that many years of your life.” Another student added, “You really, really have to want to do what you’re doing.” Undergraduate students who feel uncomfortable taking initiative or who struggle to motivate themselves are less likely to be drawn to an engineering PhD program.

**Interests and skills.** Interests and skills encompass three sub-themes: curiosity and love of learning, interest in research or teaching, and problem solving.

**Curiosity and love of learning.** A curiosity and love of learning were personal characteristics frequently cited by doctoral students, engineering faculty and engineering PhDs working in industry as fostering interest in advanced education. One faculty member commented that “some people really love to learn. I’ve been told by some people, they say ‘I could go to school my entire life’, and those are the types of people that get PhD’s. They just love to learn.” A doctoral student summed up her motivation to get a PhD as, “I just see it [the PhD] as the license to always learn. The license for perpetual learning.” Many faculty look for this quality when deciding who to encourage to consider graduate school:

I can kind of tell, particularly if they do undergraduate research…whether they’re kind of going through the motions to get it on their resume or it’s like they’re curious, and the ones that are curious, that’s the ones that I say, ‘You know, you really need to, to think about this [the PhD].’

Often the desire to know things on a deeper level is coupled with a passion for research and/or teaching. This passion becomes the fuel that propels them through a doctoral program. Undergraduates are aware that passion is a key ingredient to a
successful doctoral program, but they often have not found anything to be passionate about.

**Interest in research and teaching.** An interest in research and/or teaching was often cited as a reason someone did or might want to pursue a PhD in engineering. Undergraduates, for the most part, have limited exposure to research or teaching experiences. Working with a faculty mentor helps to provide exposure to the possibilities of a career in research more in depth. The opportunities to gain experience teaching are even more limited for undergraduates, typically taking the form of informal opportunities, such as tutoring and leading study groups. Often times it is teaching or research experience at the master’s level that illuminates an interest in doing that kind of work. For one faculty member, covering a singular lecture for his advisor was a defining moment. He realized that “once I got in the classroom I was hooked” and he abandoned his plans to return to industry and pursued a PhD and an academic career.

**Problem solving.** Engineers at all levels acknowledge that an interest and aptitude for problem solving is a common and necessary trait for engineers. They enjoy the challenge of finding creative solutions that require out-of-the-box thinking to implement. One person commented, “typically people who go into engineering want to solve problems.” A distinguishing characteristic between Bachelor’s level and doctoral level problem solving is that Bachelor’s level problems are most likely presented to them to solve. Doctoral level problem solving, on the other hand, often have to be discovered and rely on deeper and more complex solutions. An engineering faculty member observed that “you’ve got to learn how to go out and find the problems, not just solve the problem that somebody presents to you.”
Reflection and Career Alignment

Reflection and career alignment are the methods engineers use to process and make meaning out of their exposure to the factors that influence interest in the engineering PhD: personal characteristics (who they are); environment (where they are physically and socially); and misperceptions (what they believe). These factors actively intersect through the value system of the individual engineer to produce a trajectory, encouraging or discouraging interest in the engineering PhD.

Developmental maturity, or knowing yourself well enough to know what it is that you really want to do, is a critical element in this stage of the theory. Many students chose engineering as an undergraduate major because they like math and science, problem solving, figuring out how things work and building things. Frequently they have been encouraged to pursue engineering by a family member or other mentor. Often it is selected as a major and career path without a great deal of thought or consideration. It just seems like the thing to do given their interests. This common experience is exemplified by this undergraduate student’s experience: “I’m not even entirely sure why I went to a college of engineering except my guidance counselor said you’re good at math and science. You should be an engineer. I had no idea what that meant.” This lack of self-awareness and developmental maturity makes it difficult for many undergraduate engineering students to even begin to consider the PhD.

While students may select engineering as an undergraduate major without fully understanding the nature of what they will be doing, the decision to pursue a PhD in engineering requires more maturity and self-awareness. Many of the doctoral students, faculty and PhDs working in industry experienced a sense of boredom with bachelors-
level work and realized that they had deeper interests and were willing to pursue those in
spite of any financial or opportunity costs. One faculty member shared that “it took
several years of maturing and growing old and to realize that I can’t do that [work at a
boring job] my whole life.” Sometimes undergraduates have this realization through their
internship or co-op experiences. As one undergraduate student noted, “the internship I
had this summer, I loved the money, and loved the days off, but I really didn’t care for
the work I did. It wasn’t challenging enough.” More frequently, the sense of boredom
with mundane work emerges with more experience, as it did for this faculty member. “It
really took a couple of years, two or three years, for me being in the workplace to realize
that learning and studying and taking exams is actually very stimulating compared to
working in industry.”

In many ways, engineers approach the reflection process and finding career
alignment as they do their “homeworks” – systematically and methodically. Either
figuratively or literally, they assign different values or coefficients to the factors in a way
that is consistent with his or her own personal value system to critically evaluate the
benefits and costs associated with advanced education. Just as each student has unique
values and goals, the “equations” reflect the context of the individual. So what may be
seen as a barrier by one student may not be an issue for another. Likewise, what would
encourage one student may not have an impact on another.

Within the context of their assigned values, engineers consider their cumulative
level of exposure and engagement to the salient factors. In general, high levels of
exposure and active engagement with the factors leads to a serious consideration of or
interest in the PhD; whereas low levels of exposure and engagement result in maintaining
a lack of consideration of and interest in earning a PhD in engineering. However, if particular elements are especially salient to a person, it may take only one or two factors to create interest. So it is not only the amount but the importance of the factors for the engineers that is critical to interest in doctoral-level engineering education.

Experiences and interactions that occur before undergraduates have deeply committed to a career path towards a high paying job can be very beneficial. However, later interventions can also be successful in fostering interest in the PhD as engineers reconsider their future. In many cases, a period of time for reflection is needed for the individual to process his or her experiences and begin to consider the PhD as a potential path.

**Engineering Interest**

The outcome of this model is the level of interest in the engineering PhD degree. Interest in the engineering PhD has already been described as the non-normative path, yet it is a necessary precursor to active consideration and making the decision to pursue an engineering PhD. One could conceptualize the outcome of this model as the first stage in a model to describe increased enrollments in engineering PhD programs.

The default setting for most undergraduate engineering students is a lack of interest in the engineering PhD. This is the status quo. Engineers with a lack of interest are not actively thinking about the pursuit of advanced education. They may not have considered all the factors thoroughly or they may not value such an investment in their life at this time. It is possible for engineers with a lack of interest in the engineering PhD to experience some kind of dissonance with their career choice and reenter the model and actively reconsider their interest in the PhD by reentering the strategies stage. For
example, an engineer could have gone into the workforce after graduation and realized through her experiences at work that she wanted a different career that necessitates advanced education. So although the model focuses on the undergraduate engineering experience, it does take into account post-graduate reconsideration.

**Hypotheses for Examining Interest in the Engineering PhD**

Based on the analysis of the qualitative data the following hypotheses are offered to interconnect the categories of the theory.

1. Misperceptions regarding the nature of PhD-level engineering work are negatively related to interest in the engineering PhD.

2. Misperceptions regarding the costs of obtaining an engineering PhD are negatively related to interest in the engineering PhD.

3. Supportive educational environments are positively related to interest in the engineering PhD; discouraging environments are negatively related to interest in the engineering PhD.

4. Supportive interpersonal relationships are positively related to interest in the engineering PhD; discouraging relationships are negatively related to interest in the engineering PhD.

5. Self-confidence is positively related to interest in the engineering PhD.

6. Interest in research, teaching or life-long learning is positively related to interest in the engineering PhD.
Phase III: Quantitative Results

The quantitative results span the exploratory factor analysis, confirmatory factor analysis and substantive analysis conducted for this study. These analyses address the following research questions:

1. What is the factor structure of the instrument, as determined from a sub-set of the available cases (n=300)?

2. What are the reliability measures for the factors retained by the EFA? Which items detract from the reliability of the scores from each factor?

3. Is the factor structure of the instrument validated and retained by the remaining cases (n=604)?

4. Which factors retained by the EFA and confirmed by the CFA are significantly related to interest in pursuing a PhD in engineering?
   a. $H_0$ = There is no relationship between the factor scale scores and interest in the engineering PhD.

5. What additional characteristics and experiences are significantly related to interest in pursuing a PhD in engineering? (e.g. engineering experiences, institution type, minority status, gender, socio-economic status, and whether someone important to the student had earned a PhD)
   a. $H_0$ = There is no relationship between the engineering experiences, institution type, minority status, gender, socio-economic status, and whether or not someone important to the student had earned a PhD and interest in the engineering PhD.

6. Does the instrument discriminate between undergraduates (novice) and PhD students/recent PhD alumni (experts)?
The EFA and CFA analyses were conducted using the responses to the following scale items from the EEII survey:

**Personal Characteristics (PC).**

1. I am a naturally curious person.
2. I am intimidated by the thought of writing a dissertation.
3. I consider myself a good problem solver.
4. I am smart enough to complete a PhD.
5. I love to learn new things.
6. My GPA is good enough to get admitted to a PhD program.
7. I know how to motivate myself to get things done.
8. I have clear career goals.
9. I feel confident in my academic abilities.
10. I have had enough experience to know what kind of work I want to do.

**Educational Environment (EE).**

11. I feel burned out by the amount of work required by the undergraduate engineering curriculum.
12. I have had a lot of experience with problem solving in my engineering classes.
13. Engineering clubs/organizations are helpful in finding career information.
14. My undergraduate program is geared towards helping me get a good job after graduation.
15. Graduate school classes focus more on specific topics than undergraduate classes.
16. I think earning a PhD is even harder than earning a bachelor’s degree in engineering.
17. My classes have helped me to develop my critical thinking skills.
18. There are opportunities to conduct research in my undergraduate program.

19. I know what it would take to get admitted to a PhD program.

20. No one at my undergraduate program ever talked about earning a PhD as a possibility.

21. The amount of time I would have to put into a PhD would be overwhelming for me.

22. In general, engineering courses provide a lot of “hands on” experience.

23. My undergraduate program includes seminars/workshops about graduate school.

24. Resources and support in finding an internship/co-op are readily available at my undergraduate program.

25. Graduate school classes are just like undergraduate classes, only a lot more work.

**Interpersonal Environment (IE).**

26. My family would support me pursuing a PhD in engineering.

27. I believe engineers with PhDs are essential for the future of our society.

28. My family encouraged me to pursue a bachelor’s degree in engineering.

29. My peers are more interested in getting a good job than earning a PhD.

30. I know people who are pursuing or have a PhD in engineering.

31. Family responsibilities would make it difficult for me to pursue a PhD in engineering.

32. Not many of my friends are thinking about earning a PhD.

33. I think engineering is a prestigious career regardless of the educational level.

34. I have worked closely with a professor on a research project.

35. Professors have described the importance of the PhD in the engineering field.

36. In general, engineers in industry encourage earning a PhD in engineering.

37. A Professional Engineering license is more valued by industry than a PhD.
38. Professors have discussed earning a PhD as an option in one or more of my classes.

39. On the job training is more important than a PhD in terms of career opportunities.

40. A professor has taken interest in my future plans or career aspirations.

41. A professor has shared his/her career path with me.

42. There are few engineers who have earned a PhD working in industry.

43. Professors in my undergraduate program encouraged me to pursue a PhD in engineering.

   **Engineering Work (EW).**

44. The only thing you can do with a PhD in engineering is become a professor.

45. Earning a PhD in engineering would reduce my employment opportunities.

46. I understand the kind of work that engineers with PhDs do.

47. For me, engineers with PhDs do not do “real” engineering work.

48. In order to get a good job I need to continue my education beyond a bachelor’s degree.

49. I think engineers with a PhD mainly do theoretical research and development.

50. A bachelor’s degree in engineering is all that I need to get any job I want.

51. I believe engineers with a PhD are innovative thinkers.

52. A PhD may be the only way for a person to obtain the specific career he/she desires.

53. Engineers with a PhD have more freedom to choose the projects they work on.

54. I think people with a PhD in engineering are overqualified for most engineering jobs.

55. Engineers with a PhD are highly sought after for their skills in certain specialized fields.

56. PhD level engineering work is interesting and stimulating.
57. I can do the same kind of work with a bachelor’s degree that an engineer with a PhD can do.

58. Earning a PhD in engineering would limit my career possibilities to a few specialized positions.

**Economic and Personal Costs (EPC).**

59. I would need to take out loans to pay for a PhD.

60. I would be willing to make less money in the short term in order to work in a career I find rewarding.

61. I am aware of the funding opportunities such as fellowships and assistantships that pay for PhD programs.

62. Balancing school, work and family time would be a factor in considering a PhD.

63. I think PhD programs are expensive.

64. I would delay taking a good job in order to get the education necessary for the career I want.

65. I think it would be financially difficult to start a family while working towards a PhD.

66. I would be unable to make a major purchase (such as a car or house) if I were a full-time graduate student.

67. The debt I have incurred for my bachelor’s degree is a consideration in whether I would pursue a PhD.

68. A PhD in engineering seems like a needless investment to me.

69. I would consider graduate school if my employer paid for it.

70. I could work full-time while earning a PhD part-time.

71. I would have to continue to put my life on hold if I pursued a PhD.
72. I would have to give up having fun and having a social life if I worked towards a PhD.

**Exploratory factor analysis (EFA).** An exploratory factor analysis was conducted to establish the factor structure of the EEII.

**Factorability of the correlation matrix.** Kaiser-Meyer-Olkin (KMO) is a measure of sampling adequacy. Using the criteria of KMO values above 0.6 as recommended by Fabringer, Wegener, MacCallum, and Stahan (1999), both the original 5-factor/72-item EFA (KMO = .767) and the final 4-factor/23-item EFA (KMO = .789) had satisfactory levels of sampling adequacy.

**Criteria for factor retention.** Initially a 5-factor solution (FA/VARIMAX) was selected because the EEII was based on 5 hypothesized factors from the grounded theory. Appendix J shows the results from this EFA. As shown in Figure 10, using the criteria of Eigenvalues over 1, there were 20 statistical factors identified. Using the criteria of Eigenvalues over 2, there were seven statistical factors identified. Using the criteria of Eigenvalues over 3, there were 4 statistical factors identified. Because the 5th factor had relatively low loadings, a 4-factor solution (using Eigenvalues above 3) seemed to make statistical sense.
In addition to having relatively low factor loadings, the fifth factor was also lacking theoretical coherence as it contained unrelated items from 4 of the 5 hypothesized factors. The other factors were also examined for theoretical relevance. It appeared that the factor IE (interpersonal environment) had broken apart and the “people” referred to in the items drove the item loadings on other factors: faculty loaded with EE (educational environment), family with PC (personal characteristics), and employers/coworkers with EW (engineering work).

Based on both the statistical and theoretical information, the EFA was run with 4-factor solution (FA/VARIMAX). Appendix K shows the results from this EFA. The 4-factor solution seemed to be appropriate on both the statistical and theoretical levels, so the 4-factor model was further refined through item deletion.

**Criteria for item retention.** Additional EFAs (FA/PROMAX) were conducted to further refine the factor structure of the instrument. Item communalities, factor loading and cross-loadings were considered when selecting items for possible deletion. Items with communalities below .40 (Costello & Osborne, 2005), loadings of less than .32 or
cross-loadings larger than .32 (Tabachnick & Fidell, 2001) were considered for deletion. Appendix L contains a table of the items deleted, noting which round of the EFA they were deleted, the statistical reason for the deletion (low item communality, low loading, or cross-loadings) and the theoretical reason for the deletion, if there was one. Of the 49 items deleted, 19 simply performed poorly and did not provide any useful information. However, there were some trends in the theoretical problems with the remaining 30 items that were deleted. Table 12 highlights some of these trends.

Table 12: Theoretical Rationales for Item Deletions

<table>
<thead>
<tr>
<th>Theoretical Rationale</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>confusing wording</td>
<td>EE10: No one at my undergraduate program ever talked about earning a PhD as a possibility.</td>
</tr>
<tr>
<td>not relevant</td>
<td>IE6: Family responsibilities would make it difficult for me to pursue a PhD in engineering.</td>
</tr>
<tr>
<td>pseudo double barreled</td>
<td>EE9: I know what it would take to get admitted to a PhD program.</td>
</tr>
<tr>
<td></td>
<td>IE1: My family would support me pursuing a PhD in engineering.</td>
</tr>
<tr>
<td>speculation</td>
<td>EPC2: I would be willing to make less money in the short term in order to work in a career I find rewarding.</td>
</tr>
<tr>
<td>wrong section</td>
<td>IE9: I have worked closely with a professor on a research project.</td>
</tr>
<tr>
<td></td>
<td>IE5: I know people who are pursuing or have a PhD in engineering.</td>
</tr>
<tr>
<td>not a big topic in qual data</td>
<td>IE4: My peers are more interested in getting a good job than earning a PhD.</td>
</tr>
<tr>
<td></td>
<td>EE3: Engineering clubs/organizations are helpful in finding career information.</td>
</tr>
<tr>
<td></td>
<td>IE12: A Professional Engineering license is more valued by industry than a PhD.</td>
</tr>
<tr>
<td>big topic in qual data that just performed poorly</td>
<td>EW14: I can do the same kind of work with a bachelor’s degree that an engineer with a PhD can do.</td>
</tr>
<tr>
<td></td>
<td>EPC13: I would have to continue to put my life on hold if I pursued a PhD.</td>
</tr>
<tr>
<td>mod indicies</td>
<td>EW2: Earning a PhD in engineering would reduce my employment opportunities.</td>
</tr>
<tr>
<td></td>
<td>PC1: I am a naturally curious person.</td>
</tr>
</tbody>
</table>
Some items were deleted due to confusing wording ("no one ever") or lack of relevance to traditional undergraduate engineering students. Other items seemed to be pseudo-double barreled in that they could be interpreted in different ways, so they tended to cross-load. Items that required students to speculate on what they might do tended to perform poorly and were deleted. A few items were judged to be in the wrong section, as they were replicating items in the engineering or demographic experience sections. Some items were deleted because they were not strong topics in the qualitative data, so their poor performance was not surprising. One item in particular regarding the Professional Engineering license was retained through several rounds of the EFA despite its poor performance. This item was added during the review of the instrument by undergraduate students, but simply never had a strong enough loading to justify its retention. Other items were deleted that were strong topics in the qualitative data, but their poor performance could not be improved, even though they were retained through several rounds.

After three rounds of EFA analyses, preliminary CFA analyses were conducted for additional information provided in the modification indices. Two items had significant correlations with other items in their respective factor, and since the content of the items was very similar, these items were deleted. A sixth and final EFA containing 23 items was conducted, and the results from the factor matrix are reported in Table 13. The total variance explained of 30.427 in the original 5-factor/72-item model was improved to 50.575 in the final 4-factor model. Appendix M contains the complete validated EEII.
Table 13: EFA Rotated Factor Matrix (4-factor Solution, 23 items)

<table>
<thead>
<tr>
<th>Cumulative Variance Explained: 50.575</th>
<th>Engineer Work</th>
<th>Personal Character</th>
<th>Econ &amp; Personal Costs</th>
<th>Ed Environ</th>
</tr>
</thead>
<tbody>
<tr>
<td>EW15: Earning a PhD in engineering would limit my career possibilities to a few specialized positions.</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW4: For me, engineers with PhDs do not do &quot;real&quot; engineering work.</td>
<td>0.65</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW1: The only thing you can do with a PhD in engineering is become a professor.</td>
<td>0.63</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW11: I think people with a PhD in engineering are for most engineering jobs.</td>
<td>0.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW6: I think engineers with a PhD mainly do theoretical research and development.</td>
<td>0.51</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE17: There are few engineers who have earned a PhD working in industry.</td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE14: On the job training is more important than a PhD in terms of career opportunities.</td>
<td>0.35</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC9: I feel confident in my academic abilities.</td>
<td>0.74</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC4: I am smart enough to complete a PhD.</td>
<td>0.73</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC3: I consider myself a good problem solver.</td>
<td>0.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC6: My GPA is good enough to get admitted to a PhD program.</td>
<td>0.61</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PC5: I love to learn new things.</td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC1: I would need to take out loans to pay for a PhD.</td>
<td>0.80</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC5: I think PhD programs are expensive.</td>
<td>0.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC7: I think it would be financially difficult to start a family while working towards a PhD.</td>
<td>0.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC8: I would be unable to make a major purchase (such as a car or house) if I were a full-time graduate student.</td>
<td>0.58</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC9: The debt I have incurred for my bachelor's degree is a consideration in whether I would pursue a PhD.</td>
<td>0.53</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC4: Balancing school, work and family time would be a factor in considering a PhD.</td>
<td>0.42</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE10: Professors have described the importance of the PhD in the engineering field.</td>
<td>0.76</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE18: Professors in my undergraduate program encouraged me to pursue a PhD in engineering.</td>
<td>0.71</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE13: Professors have discussed earning a PhD as an option in one or more of my classes.</td>
<td>0.68</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE15: A professor has taken interest in my future plans or career aspirations.</td>
<td>0.56</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EE13: My undergraduate program includes seminars/workshops about graduate school.</td>
<td>0.43</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Extraction Method: Principal Axis Factoring.
Rotation Method: Oblimin with Kaiser Normalization.
Interest in the Engineering PhD 140

Reliability analysis. To establish the reliability of the instrument the Cronbach’s Alpha if item deleted was reviewed for each factor as retained by the EFA procedure. As show in Table 14, all factors had Cronbach’s alpha values above .7, which is considered to be adequate, as suggested by George and Mallery (2003). Only two items had alpha-if-deleted values above the factor alpha value, but the increase was negligible and the items’ content was relevant to the theoretical structure of the instrument. Therefore no items were deleted based on review of the reliability of the scores.

Table 14: EFA Factor Reliability Measures

<table>
<thead>
<tr>
<th>Factor</th>
<th>Cronbach's Alpha</th>
<th>Scale Mean if Item Deleted</th>
<th>Scale Variance if Item Deleted</th>
<th>Corrected Item-Total Correlation</th>
<th>Cronbach's Alpha if Item Deleted</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE</td>
<td>.783</td>
<td>15.15</td>
<td>14.607</td>
<td>.623</td>
<td>.720</td>
</tr>
<tr>
<td>IE13</td>
<td></td>
<td>14.86</td>
<td>14.532</td>
<td>.676</td>
<td>.704</td>
</tr>
<tr>
<td>IE18</td>
<td></td>
<td>14.70</td>
<td>15.257</td>
<td>.642</td>
<td>.718</td>
</tr>
<tr>
<td>IE10</td>
<td></td>
<td>15.45</td>
<td>14.510</td>
<td>.511</td>
<td>.763</td>
</tr>
<tr>
<td>IE15</td>
<td></td>
<td>15.40</td>
<td>17.189</td>
<td>.374</td>
<td>.798</td>
</tr>
<tr>
<td>IE1</td>
<td></td>
<td>11.71</td>
<td>17.753</td>
<td>.646</td>
<td>.719</td>
</tr>
<tr>
<td>EPC</td>
<td></td>
<td>11.82</td>
<td>20.525</td>
<td>.524</td>
<td>.753</td>
</tr>
<tr>
<td>EPC5</td>
<td></td>
<td>11.67</td>
<td>19.462</td>
<td>.621</td>
<td>.730</td>
</tr>
<tr>
<td>EPC7</td>
<td></td>
<td>12.02</td>
<td>21.354</td>
<td>.530</td>
<td>.755</td>
</tr>
<tr>
<td>EPC9</td>
<td></td>
<td>11.17</td>
<td>16.860</td>
<td>.533</td>
<td>.763</td>
</tr>
<tr>
<td>EPC4</td>
<td></td>
<td>11.93</td>
<td>21.842</td>
<td>.407</td>
<td>.777</td>
</tr>
<tr>
<td>PC</td>
<td></td>
<td>8.33</td>
<td>8.851</td>
<td>.495</td>
<td>.701</td>
</tr>
<tr>
<td>PC3</td>
<td></td>
<td>8.11</td>
<td>7.563</td>
<td>.643</td>
<td>.641</td>
</tr>
<tr>
<td>PC9</td>
<td></td>
<td>8.66</td>
<td>9.590</td>
<td>.364</td>
<td>.737</td>
</tr>
<tr>
<td>PC5</td>
<td></td>
<td>7.98</td>
<td>6.780</td>
<td>.623</td>
<td>.637</td>
</tr>
<tr>
<td>PC4</td>
<td></td>
<td>7.49</td>
<td>6.006</td>
<td>.505</td>
<td>.723</td>
</tr>
<tr>
<td>PC6</td>
<td></td>
<td>20.09</td>
<td>21.146</td>
<td>.527</td>
<td>.721</td>
</tr>
<tr>
<td>EW15</td>
<td></td>
<td>20.44</td>
<td>22.316</td>
<td>.472</td>
<td>.733</td>
</tr>
<tr>
<td>EW11</td>
<td></td>
<td>20.84</td>
<td>22.751</td>
<td>.487</td>
<td>.730</td>
</tr>
<tr>
<td>EW6</td>
<td></td>
<td>19.36</td>
<td>20.668</td>
<td>.573</td>
<td>.710</td>
</tr>
<tr>
<td>EW1</td>
<td></td>
<td>20.39</td>
<td>23.857</td>
<td>.346</td>
<td>.759</td>
</tr>
<tr>
<td>IE17</td>
<td></td>
<td>19.42</td>
<td>21.963</td>
<td>.525</td>
<td>.722</td>
</tr>
<tr>
<td>IE14</td>
<td></td>
<td>21.12</td>
<td>23.660</td>
<td>.422</td>
<td>.743</td>
</tr>
</tbody>
</table>
Confirmatory factor analysis (CFA). The following fit indices (Table 15) using MLR were obtained when evaluating model fit of the CFA:

<table>
<thead>
<tr>
<th></th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-Square value</td>
<td>562.024</td>
</tr>
<tr>
<td>Degrees of Freedom</td>
<td>224</td>
</tr>
<tr>
<td>Chi-Square P-Value</td>
<td>0.0000</td>
</tr>
<tr>
<td>CFI</td>
<td>.90</td>
</tr>
<tr>
<td>TLI</td>
<td>.89</td>
</tr>
<tr>
<td>RMSEA</td>
<td>.05</td>
</tr>
<tr>
<td>SRMR</td>
<td>.05</td>
</tr>
</tbody>
</table>

Although the chi-square value was significant, its sensitivity to sample size lessens the importance of this particular test of model fit in relation to the other goodness-of-fit measures (Bryne, 2001). Newcomb’s (1994) “real-world” approach of accepting a model in which the chi-square value is less than twice the degrees of freedom also did not demonstrate good fit. The remaining tests, CFI, TLI, RMSEA and SRMR all demonstrated good fit. The combination of these results indicated that the 4-factor/23-item model adequately fit the data.

Discriminant validity. Three tests were used to examine the discriminant validity of the EEII. As suggested by Anderson and Gerbing (1988) a nested model approach using maximum likelihood estimators (ML) was conducted in order to perform a chi-square difference test between the 4-factor model suggested by the EFA and other possible factor structures. Three 2-factor models were created by combining the four individual factors into different parings. Each 2-factor model was tested independently so that their results would not be influenced or obscured by the other 2-factor models. The results of the chi-square difference tests are shown in Table 16.
Table 16: CFA Chi-square Difference Test (ML)

<table>
<thead>
<tr>
<th></th>
<th>Chi-square Value</th>
<th>Degrees of Freedom</th>
<th>Chi-square difference from 4-factor model (594.770)</th>
<th>DF difference from 4-factor model (224)</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-factor solution</td>
<td>1834.588</td>
<td>229</td>
<td>1239.818</td>
<td>5</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>(EE&amp;EW; EPC&amp;PC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-factor solution</td>
<td>1862.691</td>
<td>229</td>
<td>1267.921</td>
<td>5</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>(EE&amp;EPC; EW&amp;PC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2-factor solution</td>
<td>1766.809</td>
<td>229</td>
<td>1172.039</td>
<td>5</td>
<td>&lt;.01</td>
</tr>
<tr>
<td>(EE&amp;PC; EW&amp;EPC)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The significant P values of all three tests provide evidence of discriminant validity of the 4-factor model from each of the possible 2-factor solutions.

The correlation matrix between factors (Table 17) was also examined for evidence of discriminant validity.

Table 17: Correlation Matrix between Factors

<table>
<thead>
<tr>
<th></th>
<th>EE</th>
<th>EPC</th>
<th>PC</th>
<th>EW</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE</td>
<td>1</td>
<td>-0.357</td>
<td>0.285</td>
<td>-0.234</td>
</tr>
<tr>
<td>EPC</td>
<td>-0.357</td>
<td>1</td>
<td>-0.293</td>
<td>-0.260</td>
</tr>
<tr>
<td>PC</td>
<td>0.285</td>
<td>-0.293</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>EW</td>
<td>-0.234</td>
<td>0.288</td>
<td>-0.260</td>
<td>1</td>
</tr>
</tbody>
</table>

The relatively low correlations between factors (.234 - .357) provided additional evidence of discriminant validity (Bagozzi & Yi, 1988; Kline, 2005).

Finally, the 95% confidence interval around the correlation estimate between two factors was reviewed as suggested by Anderson and Gerbing (1988) and Bagozzi, Yi, and Phillips (1991). The results are presented in Table 18.
Table 18: Correlation Estimates between Factors

<table>
<thead>
<tr>
<th></th>
<th>CI lower</th>
<th>CI upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>EPC WITH EE</td>
<td>-0.455</td>
<td>-0.259</td>
</tr>
<tr>
<td>PC WITH EE</td>
<td>0.185</td>
<td>0.385</td>
</tr>
<tr>
<td>PC WITH EPC</td>
<td>-0.393</td>
<td>-0.193</td>
</tr>
<tr>
<td>EW WITH EE</td>
<td>-0.340</td>
<td>-0.128</td>
</tr>
<tr>
<td>EW WITH EPC</td>
<td>0.182</td>
<td>0.394</td>
</tr>
<tr>
<td>EW WITH PC</td>
<td>-0.370</td>
<td>-0.150</td>
</tr>
</tbody>
</table>

The correlation estimates provide additional evidence of discriminant validity since the 95% confidence interval did not include 1.0.

The consistent evidence for discriminant validity provided by all three approaches (Chi-square difference tests, factor correlations, and 95% confidence intervals of factor correlations) provides adequate evidence for the discriminant validity of the factors within the EEII.

**Significant predictors.** The substantive value of the EEII is its ability to measure the hypothesized factors from the grounded theory and the utility of that measurement to informing strategies for increasing domestic student enrollment in doctoral engineering programs. The outcome of this study is interest in the engineering PhD. Two items from the EEII were used to measure this outcome:

What degree(s) do you PLAN to pursue/complete?

- Master’s degree in engineering field
- Doctorate or PhD in engineering field
- MBA
- Master’s degree in other field (not engineering or business)
- Doctorate or PhD in other field
- Other advanced degree (law, medicine, etc.)
None of the above

How likely are you to pursue a PhD in engineering?

Very likely

Somewhat likely

Somewhat unlikely

Very unlikely

Because it was reasonable to believe that there would be interactions among these independent variables, a single regression model was built for each of the outcome variables (PhDPlan and PhDLikely). PhDPlan was a dichotomous variable, so a logistic regression model was used for this outcome variable. PhDLikely was a categorical variable, so a linear regression model was used for this outcome variable.

Based on hypotheses generated from the qualitative data, it would be reasonable to expect that a supportive educational environment that encourages consideration of the engineering PhD and personal characteristics such as a desire to be a life-long learner and an interest in the process of scientific discovery would have a positive relationship with higher levels of interest in engineering PhD programs; Misperceptions about the economic and personal costs associated doctoral education and the nature of doctoral-level work would have a negative relationship with higher levels of interest in engineering PhD programs. The null hypothesis to test these relationships was:

\[ H_0 = \text{There is no relationship between the factor scale scores and interest in the engineering PhD (both PhDPlan and PhDLikely).} \]

It was clear from the qualitative data interest in the engineering PhD was influenced not only by the hypothesized factors, but also individual characteristics such
as gender, race and ethnicity, socio-economic status, whether someone important to the student (e.g. parent) had earned a PhD, and a variety of experiences, such as conducting undergraduate research, teaching experience and engaging in graduate school preparation activities. The nature and direction of the relationship of these characteristics with interest in the engineering PhD was not clear. The following demographic items were used as additional independent variables as possible predictors of interest in the engineering PhD:

**Exp1 Workshop:** I have attended a graduate school workshop.

**Exp2 PrepProg:** I have participated in a graduate school preparation program, such as McNair, LSAMP, REU or others.

**Exp3 Research:** I have participated in undergraduate research.

**Exp4 CoOp:** I have participated in an engineering internship or co-op.

**Exp5 TeachAsst:** I have worked as an undergraduate teaching assistant.

**Exp6 LedStudyGrp:** I have lead study groups.

**Exp7 Tutored:** I have tutored others formally or informally.

**Exp8 Grading:** I have assisted with grading.

**Exp9 GradFair:** I have attended a graduate school fair to meet recruiters or professors from graduate programs.

**Exp10 Interact:** I have interacted with engineering graduate students.

**KnowPhD:** Combined these two items:

What is the highest level of education completed by your parents or guardians?

- Some high school
- High school graduate
Some college
Two-year college degree
Four-year college degree
Some graduate or professional school
Graduate or professional degree
Doctorate or PhD

Growing up, was there anyone important to you who had earned a PhD in any field?

Yes
No

Gender: What is your gender?

Male
Female
Transgender

Minority: Combined these two items:

Are you Hispanic/Latino?

No, not Hispanic/Latino
Yes, Hispanic/Latino

Race (choose one or more, regardless of ethnicity status selected above)++

American Indian or Alaska Native
Asian
Black or African American
Native Hawaiian or Other Pacific Islander
White
**PellGrant**: Have you ever been eligible for a federal Pell Grant?

Yes

No

Don’t Know

**SiteType**: Does the respondent’s institution offer a PhD in engineering? (coded by research team based on student institution)

Yes

No

The null hypothesis to test these relationships was:

\[ H_0 = \text{There is no relationship between the engineering experiences, institution type, minority status, gender, socio-economic status, and whether someone important to the student had earned a PhD and interest in the engineering PhD (both PhDPlan and PhDLikely).} \]
The results are presented in Table 19 and Table 20:

Table 19: Logistic Regression Results for PhDPlan

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>S.E.</th>
<th>Wald</th>
<th>df</th>
<th>Sig.</th>
<th>Exp(B)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Educational Environment</td>
<td>-0.239</td>
<td>0.127</td>
<td>3.543</td>
<td>1</td>
<td>0.060</td>
<td>0.787</td>
</tr>
<tr>
<td>Economic Personal Costs</td>
<td>0.501</td>
<td>0.133</td>
<td>14.097</td>
<td>1</td>
<td>0.000</td>
<td>1.650</td>
</tr>
<tr>
<td>Personal Characteristics</td>
<td>-0.839</td>
<td>0.207</td>
<td>16.384</td>
<td>1</td>
<td>0.000</td>
<td>0.432</td>
</tr>
<tr>
<td>Engineering Work</td>
<td>0.544</td>
<td>0.154</td>
<td>12.470</td>
<td>1</td>
<td>0.000</td>
<td>1.723</td>
</tr>
<tr>
<td>Exp1 Workshop</td>
<td>-0.027</td>
<td>0.290</td>
<td>0.009</td>
<td>1</td>
<td>0.926</td>
<td>0.973</td>
</tr>
<tr>
<td>Exp2 PrepProg</td>
<td>-0.143</td>
<td>0.442</td>
<td>0.105</td>
<td>1</td>
<td>0.746</td>
<td>0.867</td>
</tr>
<tr>
<td>Exp3 Research</td>
<td>0.184</td>
<td>0.245</td>
<td>0.564</td>
<td>1</td>
<td>0.452</td>
<td>1.202</td>
</tr>
<tr>
<td>Exp4 CoOp</td>
<td>-0.544</td>
<td>0.241</td>
<td>5.098</td>
<td>1</td>
<td>0.024</td>
<td>0.581</td>
</tr>
<tr>
<td>Exp5 TeachAsst</td>
<td>-0.257</td>
<td>0.397</td>
<td>0.419</td>
<td>1</td>
<td>0.518</td>
<td>0.773</td>
</tr>
<tr>
<td>Exp6 LedStudyGrp</td>
<td>0.335</td>
<td>0.245</td>
<td>1.872</td>
<td>1</td>
<td>0.171</td>
<td>1.398</td>
</tr>
<tr>
<td>Exp7 Tutored</td>
<td>0.374</td>
<td>0.433</td>
<td>0.747</td>
<td>1</td>
<td>0.388</td>
<td>1.454</td>
</tr>
<tr>
<td>Exp8 Grading</td>
<td>-0.076</td>
<td>0.310</td>
<td>0.000</td>
<td>1</td>
<td>0.927</td>
<td>1.070</td>
</tr>
<tr>
<td>Exp9 GradFair</td>
<td>1.101</td>
<td>0.269</td>
<td>16.709</td>
<td>1</td>
<td>0.000</td>
<td>3.007</td>
</tr>
<tr>
<td>Exp10 Interact</td>
<td>-0.067</td>
<td>0.320</td>
<td>0.043</td>
<td>1</td>
<td>0.835</td>
<td>0.935</td>
</tr>
<tr>
<td>Gender</td>
<td>0.217</td>
<td>0.257</td>
<td>0.716</td>
<td>1</td>
<td>0.397</td>
<td>1.242</td>
</tr>
<tr>
<td>Minority</td>
<td>0.301</td>
<td>0.330</td>
<td>0.832</td>
<td>1</td>
<td>0.362</td>
<td>1.351</td>
</tr>
<tr>
<td>PellGrant</td>
<td>0.431</td>
<td>0.244</td>
<td>3.119</td>
<td>1</td>
<td>0.077</td>
<td>1.538</td>
</tr>
<tr>
<td>KnowPhD</td>
<td>0.577</td>
<td>0.237</td>
<td>3.913</td>
<td>1</td>
<td>0.015</td>
<td>1.780</td>
</tr>
<tr>
<td>SiteType</td>
<td>-0.022</td>
<td>0.250</td>
<td>0.007</td>
<td>1</td>
<td>0.931</td>
<td>0.997</td>
</tr>
<tr>
<td>Constant</td>
<td>-3.598</td>
<td>1.107</td>
<td>10.561</td>
<td>1</td>
<td>0.001</td>
<td>0.027</td>
</tr>
</tbody>
</table>

Table 20: Linear Regression Results for PhDLikely

<table>
<thead>
<tr>
<th>Variables</th>
<th>Unstd. B</th>
<th>Unstd. S.E.</th>
<th>Std. Beta</th>
<th>t</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Constant)</td>
<td>3.297</td>
<td>0.269</td>
<td></td>
<td>12.276</td>
<td>0.00</td>
</tr>
<tr>
<td>Educational Environment</td>
<td>0.098</td>
<td>0.033</td>
<td>0.098</td>
<td>2.961</td>
<td>0.003</td>
</tr>
<tr>
<td>Economic Personal Costs</td>
<td>-0.149</td>
<td>0.036</td>
<td>-0.136</td>
<td>-4.139</td>
<td>0.000</td>
</tr>
<tr>
<td>Personal Characteristics</td>
<td>0.299</td>
<td>0.045</td>
<td>0.212</td>
<td>6.679</td>
<td>0.000</td>
</tr>
<tr>
<td>Engineering Work</td>
<td>-0.192</td>
<td>0.038</td>
<td>-0.157</td>
<td>-5.126</td>
<td>0.000</td>
</tr>
<tr>
<td>Exp1 Workshop</td>
<td>-0.045</td>
<td>0.085</td>
<td>-0.018</td>
<td>-0.532</td>
<td>0.595</td>
</tr>
<tr>
<td>Exp2 PrepProg</td>
<td>-0.384</td>
<td>0.143</td>
<td>-0.086</td>
<td>-2.684</td>
<td>0.007</td>
</tr>
<tr>
<td>Exp3 Research</td>
<td>-0.048</td>
<td>0.063</td>
<td>-0.025</td>
<td>-0.767</td>
<td>0.444</td>
</tr>
<tr>
<td>Exp4 CoOp</td>
<td>0.149</td>
<td>0.062</td>
<td>0.077</td>
<td>2.383</td>
<td>0.017</td>
</tr>
<tr>
<td>Exp5 TeachAsst</td>
<td>0.122</td>
<td>0.108</td>
<td>0.038</td>
<td>1.131</td>
<td>0.258</td>
</tr>
<tr>
<td>Exp6 LedStudyGrp</td>
<td>-0.113</td>
<td>0.061</td>
<td>-0.059</td>
<td>-1.864</td>
<td>0.063</td>
</tr>
<tr>
<td>Exp7 Tutored</td>
<td>-0.114</td>
<td>0.084</td>
<td>-0.043</td>
<td>-1.357</td>
<td>0.175</td>
</tr>
<tr>
<td>Exp8 Grading</td>
<td>-0.085</td>
<td>0.083</td>
<td>-0.035</td>
<td>-1.021</td>
<td>0.307</td>
</tr>
<tr>
<td>Exp9 GradFair</td>
<td>-0.221</td>
<td>0.083</td>
<td>-0.090</td>
<td>-2.661</td>
<td>0.008</td>
</tr>
<tr>
<td>Exp10 Interact</td>
<td>0.121</td>
<td>0.071</td>
<td>0.054</td>
<td>1.716</td>
<td>0.086</td>
</tr>
<tr>
<td>Gender</td>
<td>-0.088</td>
<td>0.063</td>
<td>-0.042</td>
<td>-1.410</td>
<td>0.159</td>
</tr>
<tr>
<td>Minority</td>
<td>-0.302</td>
<td>0.093</td>
<td>-0.098</td>
<td>-3.241</td>
<td>0.001</td>
</tr>
<tr>
<td>PellGrant</td>
<td>-0.069</td>
<td>0.062</td>
<td>-0.034</td>
<td>-1.128</td>
<td>0.260</td>
</tr>
<tr>
<td>KnowPhD</td>
<td>-0.125</td>
<td>0.067</td>
<td>-0.056</td>
<td>-1.867</td>
<td>0.062</td>
</tr>
<tr>
<td>SiteType</td>
<td>0.049</td>
<td>0.063</td>
<td>0.025</td>
<td>0.776</td>
<td>0.438</td>
</tr>
</tbody>
</table>
Summary of significant predictors. Independent variables with alpha levels at or below .05 were considered significant. Three of the four factors had significant relationships with both outcome variables. Misperceptions about the economic and personal costs of an engineering PhD and misperceptions about the nature of engineering work based on degree levels were negative predictors of interest in the engineering PhD. That is to say, the more misperceptions a student has, the lower his or her interest in the engineering PhD. Personal characteristics was also a significant factor for both outcome variables, but with a positive relationship. The remaining factor, educational environment, was only significant for the PhDLikely outcome variable, but not the PhDPlan outcome variable.

Two engineering experiences were also significant for both outcome variables. Participating in a graduate school fair had a positive significant relationship with both outcome variables and participating in a co-op or engineering internship had a negative significant relationship with both outcome variables. Participating in a graduate school preparation program, such as McNair, LSAMP or REUs had a positive significant relationship with PhDLikely, but was not significant for PhDPlan.

Two demographic factors also had significant relationships with one of the outcome variables. Knowing someone such as a parent or other important figure growing up had a positive significant relationship for PhDPlan, but was not significant for PhDLikely. Being an underrepresented minority (Hispanic, African American, American Indian, Native Hawaiian or other Pacific Islander) had a positive significant relationship with PhDLikely but was not significant for PhDPlan.
**Discriminant analysis.** Due to the low number of “expert” respondents (N=39) discriminant analysis was not conducted. However, Figure 11 shows the difference between the factor means for “expert” or PhD students and recent PhD alumni and “novice” or engineering junior and senior respondents. The difference between the mean scale scores indicates that there may be a difference in the mean scores of the expert and novice respondents, especially with the economic and personal costs and educational environment factors. However, additional study with larger samples is necessary to ascertain if these differences are significant enough to be able to discriminate group membership.
Chapter 5: Discussion and Implications for Practice

This chapter presents both a summary of and recommendations from each of the four phases of the study (qualitative grounded theory, instrument development, quantitative, and synthesis) and suggestions for future research.

Phase I: Qualitative Grounded Theory Summary and Recommendations

Phase I, the qualitative grounded theory study, involved over 200 engineering students, faculty and professionals at seven educational institutions and industrial settings across the country in answering the following research questions:

1. What perceptions do domestic engineering students, engineering faculty members and other engineering PhDs hold about PhD education in engineering?
2. What factors facilitate or inhibit interest in the engineering PhD among domestic engineering students?
   a. What are the initial conditions of domestic engineering students that influence their interest in the engineering PhD?
   b. What is the context that supports the continuation of (or changes to) the level of interest of domestic engineering students in the engineering PhD?
   c. What are the intervening conditions that influence the level of interest of domestic engineering students in the engineering PhD?
3. What strategies were reported that could be used to increase interest in the engineering PhD among domestic engineering students?

In answering the first research question, this study identified a number of misperceptions that undergraduate engineering students have regarding the engineering PhD, when compared to the perceptions of PhD students, faculty and engineers with PhDs who work
in industry. These misperceptions include assumptions about the nature of work that PhD engineers do and the economic and personal costs associated with pursuing a PhD in engineering. Undergraduate students feel that they can do the same kind of work that a PhD engineer does, so they do not see any value in paying more money and doing more academic work to earn a PhD. Although undergraduates are aware that there are PhD engineers working in industry, they think that the only reason to earn a PhD is to become a faculty member. When asked specifically about industry PhDs, undergraduates view them as not “real” engineers with limited career opportunities due to the increased specialization of the PhD. Engineers pursuing a PhD or who have already earned a PhD have a much different view of the engineering PhD. Their decision to pursue a PhD was rarely made for financial reasons. Many of them spoke of the increased satisfaction of being able to identify and pursue complex problems at a deeper level. They mention an appreciation of the freedom to direct their work and for faculty, the joy of working with students.

In response to the second research question, several factors were identified that facilitated and/or inhibited interest in the engineering PhD. These factors comprise the theoretical model for understanding the process for developing an interest in the engineering PhD. In general, the model describes the pathways to the engineering PhD much as the APPLES project describes the pathway through the undergraduate engineering program (Atman et al., 2010; Shepperd et al., 2010). The model includes three factors that feed into a process of reflection and career alignment. These factors generally relate to research questions 2.a. through 2.c.; personal characteristics represent the initial conditions of undergraduate engineering students; the environment represents
the context; and misperceptions, or rather the correction of misperceptions represents the intervening conditions. Once the inputs are synthesized, the result is either continued disinterest or consideration of the engineering PhD. The model itself is a contribution to the field of engineering education, since it is the first one to directly address interest in the engineering PhD. However, many of the concepts included in the model are consistent with previous engineering education literature regarding retention of undergraduate engineering students such as self-confidence, overwhelming workload, exposure to the engineering profession, financial motivation and a sense of belonging.

The grounded theory model contributes new information for understanding interest in the engineering PhD by domestic students. One of the most salient findings of the qualitative grounded theory phase was that by and large, undergraduate engineering students have a lot of misperceptions regarding the engineering PhD. These misperceptions can be grouped by three primary themes: graduate education, economic and personal costs, and nature of work. Because these misperceptions are so prevalent in the environment and engineering programs, in general, do little to correct them, students make their decisions whether to consider the engineering PhD based on faulty or lacking data.

**Recommendations for engineering educators.** In response to research question 3, a number of recommendations for engineering educators were identified to intervene and foster engineers’ interest in the engineering PhD. The strategies have been categorized into those that can be implemented by undergraduate programs and by graduate programs. While engineering faculty serve both programs concurrently, it is important to make special note of the unique role each perspective has to play in addressing the issues.
Recommendations for undergraduate programs. Faculty in undergraduate engineering programs can provide more information on doctoral education in engineering to their students. Exposure to the PhD, through such experiences as graduate school workshops or even lab tours, gives students ideas that they can build upon. Interactions with current PhD students and industry engineers with PhDs show engineering students the breadth of engineering careers available to them with varying levels of education. Promoting engineering role models, especially those who would work with students over the long-term to provide mentoring, are recommended. Engineering professionals should be proactive in seeking out undergraduate students for these interactions. Topics of discussions could include information about their research agenda, the work they do, open invitations for collaborative research, inquiring if they have considered graduate school, how graduate school and work could coexist, sharing their educational pathway story, etc. These interactions could be geared toward an entire class or group of students or could be one-on-one discussions. The outcome of these interactions should be to correct the common misperceptions about the engineering PhD and to engage the students in a way so that they are "not ready to quit this yet."

Encouragement from a faculty member was a consistent theme in the PhD interviews. Having someone notice your potential and take an interest in reaching your potential was a powerful experience for many engineering PhDs. Increasing the circle of students whom receive mentoring and encouragement to pursue a PhD would be a low-cost, low-resource, high-payoff strategy. Engineering educators need to be aware of the workload students face and its impact on feelings of burnout and “just wanting to get the heck out of school” when considering who to encourage to consider the engineering PhD.
Self-confidence and family and financial pressures also play a role in assessing a student’s readiness to have “the talk” about the engineering PhD. Promoting masters education may be less threatening for some students to consider, especially since many employers pay for the master’s degree. The qualitative data clearly identified the master’s degree as a critical experience for many engineering PhDs to begin considering the PhD.

**Recommendations for graduate programs.** Graduate programs also have a role to play in increasing interest in PhD programs among domestic students. Graduate programs need to educate prospective students about the lifestyle of PhD students. Prospective students would also benefit from information about the kinds of projects PhD students are involved in and the kinds of jobs they obtain after graduation. Developing schedules that allow for a work/life balance was suggested by several participants. Developing partnerships with local industries was also suggested as a way to integrate academic research with real-world application in the workplace. These partnerships could also include flexible scheduling options so that PhD students could continue to work full-time (and maintain their standard of living) while pursuing a PhD.

Direct admission to an engineering PhD program may be a more efficient pathway to completing the PhD, but graduate programs need to recognize that most undergraduates have not developed the self confidence to feel they could be successful in a doctoral program. Participating in a master’s degree program is an opportunity for prospective PhD students to experience graduate school, have success with the graduate curriculum and begin to see the PhD as something obtainable. Additionally, graduate programs may need to expand their recruitment efforts beyond the captive audience of current undergraduate students and reach out to recent alumni. A period of work
experience (often described as mundane or boring) was typical for many people who had earned or were pursuing their PhD.

Increasing financial stipends or other incentives for graduate students may have some positive effect on prospective students’ interest in PhD programs, although this was not a strong concern among participants. One faculty member mentioned that his stipend as a graduate student, many years ago, was $1,000 per month – the same amount they pay their current graduate students. Even though it is unlikely that graduate student stipends could be raised to be competitive with salaries of full-time engineers efforts to increase stipends should continue nonetheless.

**Phase II: Instrument Development Summary**

This section provides a summary of the instrument development process. In general, the framework for developing the Exploring Engineering Interest Inventory (EEII) followed the first five of steps for developing measurement scales identified by DeVellis (2003): (1) Determine clearly what you want to measure; (2) Generate an item pool; (3) Determine the format of the measure; (4) Have experts review the initial item pool, (5) Consider the inclusion of validation items. (pp. 61-87).

For step one, the grounded theory model served as a framework for the EEII scale, with some of the factors expanded into two separate sub-scales: (1) misperceptions of economic and personal costs – an assessment of perceptions of and awareness about the costs of doctoral programs; (2) misperceptions of engineering work – an assessment of perceptions of the kind of work engineers do with different levels of education; (3) educational environment – an assessment of experience as an undergraduate engineering student; (4) interpersonal environment – an assessment of relevant support systems; and
(5) personal characteristics – an assessment of key personal factors relevant to the model. In step two, an item generation matrix listing the sub-scales and relevant quotes from participants was used as tool to guide the item generation process. In step three, the core items for the five sub-scales were written using a Likert scale for response options. The instrument was uploaded to SurveyMonkey to facilitate participant use and data accuracy. Step four consisted of a review of the items by the research team, feedback from colleagues in a psychometric graduate program, and iterative feedback interviews conducted with representative undergraduate engineers. Validation items were considered for inclusion with the pilot study in step five, but in order to increase completion rates of participants and to avoid any potential interaction effects caused by the additional items, no validation items were included in this scale.

**Phase III: Quantitative Summary**

Phase III, the quantitative phase included an online survey completed by over 900 undergraduate engineering majors at five institutions across the country. Analysis of the data answered the following research questions:

1. **What is the factor structure of the instrument, as determined from a sub-set of the available cases (n=300)?** Four factors (personal characteristics, engineering work, economic and personal costs, and educational environment) were identified by conducting an exploratory factor analysis.

2. **What are the reliability measures for the factors retained by the EFA?** Which items detract from the reliability of the scores from each factor? All four factors had Cronbach’s Alpha values over .7, and none of the remaining 23
items significantly detracted from the reliability of the scores from each factor.

3. Is the factor structure of the instrument validated and retained by the remaining cases (n=604)? The four factor structure was validated by a confirmatory factor analysis.

4. Which factors retained by the EFA and confirmed by the CFA are significantly related to interest in pursuing a PhD in engineering? All four factors were significantly related to interest in pursuing a PhD in engineering.

5. What additional characteristics and experiences are significantly related to interest in pursuing a PhD in engineering? Participating in a graduate school fair or a graduate school preparation program had a positive significant relationship with interest in the engineering PhD. Participating in a co-op or engineering internship had a negative significant relationship with interest in the engineering PhD. Knowing someone such as a parent or other important figure growing up who had a PhD had a positive significant relationship with interest in the engineering PhD, as did being an underrepresented minority.

6. Does the instrument discriminate between undergraduates (novice) and PhD students/recent PhD alumni (experts)? There was not a large enough sample of “expert” respondents to answer this question.

All four factors were significant predictors of interest in the engineering PhD. The greater the misperceptions of economic and personal costs and the nature of engineering work, the less likely a particular respondent was interested in the engineering PhD. High scores in the personal characteristics and the educational environment factors increased
the likelihood of interest in the engineering PhD. Based on the quantitative results, it would appear that efforts to correct the misperceptions about the engineering PhD and encouragement from faculty would have a positive influence in increasing interest in the engineering PhD among domestic engineering undergraduates.

Attending a graduate school fair or participating in a graduate school preparation program both were significantly related to interest in the engineering PhD. Any causal interpretation of these experiences would be highly suspect as these activities likely occur after a student has established his or her interest in the engineering PhD. However, students who attend graduate school fairs or participate in graduate school preparation programs would benefit from close mentoring and additional encouragement from faculty to support them in pursuing their interest in the engineering PhD.

Participating in a co-op was one of the recommendations from the qualitative phase to increase interest in the engineering PhD, yet this experience had a significantly negative relationship with interest in the engineering PhD in the quantitative phase. This finding has pointed out the need for additional clarification to the recommendation from the qualitative phase. Co-ops where students interact on a regular basis with PhD engineers and receive encouragement from them can have a positive influence on increasing interest in the engineering PhD. However, co-ops where students interact primarily or exclusively with Bachelor’s-level engineers who either passively or actively discourage advanced education can have a negative influence on interest in the engineering PhD. The nature of the co-op experience greatly influences the interest in the engineering PhD in both directions, and therefore engineering educators should work closely with students to identify opportunities that fit their educational and career goals.
A common experience in the qualitative data for engineers who went directly from their undergraduate program into graduate school, straight through the PhD, was having a parent, or other important figure (uncle, neighbor, teacher, etc.) who had a PhD in any field. Growing up familiar with what a PhD is, the kind of work one can do with a PhD, and the lifestyle of people with PhDs seemed to circumvent the misperceptions that many undergraduates have about the PhD. This insider knowledge, likely coupled with higher levels of family encouragement, was also significant in the quantitative data. In particular, knowing someone with a PhD was significant for students who planned to pursue a PhD, but not for determining the likelihood of pursuing a PhD. We know from the qualitative data that it is difficult for undergraduates to plan a pathway to the engineering PhD, however students who have a parent or other significant figure with a PhD seem to be the exception to this particular trend. While PhD engineers may not be willing to raise additional children for the purpose of increasing the number of domestic students interested in the engineering PhD, they can develop relationships with more students and mentor them towards the PhD.

The final significant characteristic in predicting interest in the engineering PhD was status as an underrepresented minority. This finding is consistent with the APPLES project (Atman et al., 2010) which noted that underrepresented minority status was a significant predictor for first year engineering students when planning to attend engineering graduate school. They found only 38% of non-minority first year engineering students expressed an interest in engineering graduate school compared with 65% of underrepresented first year engineering students. Although underrepresented minority status was not a significant predictor for senior engineering students, there was a
substantially larger proportion of URM students planning to attend engineering graduate school in their study. Atman and her colleagues did not speculate as to what might be contributing to the higher level of interest among URM students in engineering graduate school, or why this higher level of interest is not translating into higher enrollment levels. Unfortunately, the findings of this study do not contribute any additional explanation for the increased interest of URM students in advanced engineering degrees. This is clearly a topic for future study.

**Phase IV: Synthesis**

The synthesis phase of the study involved integrating the findings from the qualitative and quantitative phases of the study, reflecting on the lessons learned from the second phase of the study, and planning for the dissemination of the findings to both engineering educators and research methodologists. This phase specifically addressed the following:

1. Does the factor structure of the instrument confirm the qualitative themes?
2. Based on the results from the quantitative phase, how would the recommendations from the qualitative phase be prioritized?
3. How does the instrument that has been designed based on the qualitative data provide a better measure of the phenomenon than other measurement alternatives or development approaches?

**Integration.** Research questions 1 and 2 both are concerned with issues of integrating the qualitative and quantitative phases of the study. The three factors from the grounded theory model (personal characteristics, environment and misperceptions) were expanded into five sub-scales for the EEII. Figure 12 portrays these five sub-scales.
The quantitative study confirmed this expanded grounded theory model with one slight adjustment to the factor structure. The items written for the interpersonal environment factor did not load together. Rather, those items loaded with their relevant environment: faculty loaded with the educational environment; family loaded with personal characteristics; and employers loaded with engineering work. The revised theoretical model, based on the quantitative findings is shown in Figure 13.
Research question 2 provides another opportunity to integrate the qualitative and quantitative phases by prioritizing the recommendations from the qualitative phase based on the quantitative findings. The key finding from both the qualitative and quantitative phases was that misperceptions regarding the engineering PhD are a significant inhibitor of interest in the engineering PhD. The priority, then, for engineering educators, is to integrate correct perceptions about the engineering PhD in both curricular and co-curricular activities. Faculty should take steps to make the engineering PhD more visible to their students and expand the students’ knowledge of career opportunities at different educational levels. The next priority for engineering educators is to take an active role in encouraging undergraduate students who demonstrate curiosity and creativity (and not
necessarily a 4.0) to consider a master’s degree in engineering, and once in a master’s program, to encourage them to continue to the PhD.

**Reflection.** This dissertation was designed as an empirical study with a strong methodological focus. It is appropriate, therefore, to reflect on the mixed methods approaches employed in this study, address the final mixed methods research question, and offer recommendations for future mixed methods instrument development studies.

This study was a sequential exploratory mixed methods project. Qualitative data were collected, analyzed, and developed into quantitative items which were in turn evaluated for their psychometric properties, consistent with an instrument development variant design. The mixing of qualitative and quantitative methods however, was not restricted to simply the point of transition from qualitative data to quantitative items. Within the instrument development phase, qualitative methods were used when evaluating the initial EEII instrument before collecting quantitative data. The iterative feedback interview technique used to solicit suggestions from key informants was an intentionally qualitative alternative to the often quantitative cognitive interview technique used by survey research methodologists. Even the exploratory factor analysis was conducted using a mixed methods framework by incorporating both quantitative statistical data about the items and qualitative, theory-based information when making decisions about factor and item retention.

There remains one final research question to be addressed: How does the instrument that has been designed based on the qualitative data provide a better measure of the phenomenon than other measurement alternatives or development approaches? Although we do not have an alternate measure to compare the EEII with, there are a
variety of reasons why the mixed methods approach used in this study developed a better measure than one that could have been produced using other approaches. In general, a mixed methods approach to instrument development allows the research to capitalize on the strength of each method while minimizing the weaknesses (Creswell & Plano Clark, 2007). The qualitative phase provides an opportunity for instrument developers to understand the phenomenon from the participants’ perspective, and then use language that is most relevant to the target population when developing items.

This particular mixed methods instrument development design incorporated strategies with the specific intent of ensuring the quality of the instrument, and therefore the utility of the findings. A grounded theory approach was selected for the qualitative phase to provide a systematic and iterative process for developing a theoretical model. This approach allowed the research team to develop a thorough understanding of the construct domain and the relationships between factors within that domain. Additionally, the process for combining the qualitative and quantitative approaches respected the value and contribution of each methodology. This strategy involves more than simply capitalizing on the strengths of each method, but elevating the importance of each method. Qualitative data were not converted into quantitative data or analyzed using a quantitative approach. Quantitative data were evaluated using the currently accepted standards, but within the context of the qualitative findings (theoretical model). Finally, each phase, and each stage within each phase, was conceptualized as an iterative process. As the project progressed and new information was discovered or new interpretations were suggested, the research team was able to move fluidly across the phases of the study.
to adjust prior decisions and determinations to reflect the most informed and up-to-date understanding of the phenomenon.

Perhaps the most valuable enhancement provided by a mixed methods approach to developing an instrument is that mixed methods research requires a team of people to conduct a study. It may be possible for a single individual to conduct a mixed methods project, however, the scope of conducting multiple phases would take an extraordinary time commitment for someone to accomplish by themselves. Teamwork, however, is more than just sharing the workload in a mixed methods project. Ideally the research team would have individuals with a variety of expertise; qualitative methods, quantitative methods, content knowledge, etc. These different perspectives provide opportunities for a dialectical approach to challenge assumptions, provide alternative interpretations, and stimulate deeper thinking. In this project, the synergy of the research team (lead researcher, research assistants, advisors, and consultants) contributed to the most important methodological decisions and interpretation of findings. A single perspective could not have generated the depth of understanding that was achieved through this process.

**Recommendations for Mixed Methods Instrument Development Studies.** Based on the methods used in this study to develop the EEII, the following recommendations are forwarded to other researcher who may be considering this approach.

*Be explicit about the rationale for using a mixed methods approach.* In reviewing over 30 empirical mixed methods instrument development studies, very few researchers were explicit about their rationale for selecting this particular design variant. There were two broad categories for rationales identified in the reviewed studies: Participant focused
interest in the engineering PhD and methodological expansion. Each rationale provides a different context for the study, and therefore researchers should be explicit about which approach or combination of approaches is guiding their study. This study articulated both rationales for using a mixed methods approach, although priority was given to methodological expansion.

Clearly describe the process for establishing the construct definition. Previous authors have described the importance of clearly defining the construct of interest of the study (e.g. Campbell & Fiske, 1959; DeVellis, 2003; Fowler, 1995; Worthington & Whittaker, 2006). The reliability and validity of a scale cannot begin to be assessed without a clear understanding of what the scale is intending to measure and what it is not intending to measure. In a mixed methods instrument development study it is equally important to clearly describe the process for arriving at that definition by describing the data analysis process for the qualitative phase. Unfortunately, the majority of the reviewed studies provided only vague information about their qualitative data analysis approach, such as “content analysis” or “thematic extraction.” Providing more details about the data analysis process not only adds credibility to the qualitative phase, but to the study as a whole.

Develop and clearly describe the protocol for generating an item pool. Although studies that involved multiple languages gave detailed descriptions of the translation and back-translation process, the reviewed studies rarely described the item writing process with sufficient detail to clearly articulate the connections from the qualitative results to be helpful to other researchers. One of the primary benefits of conducting a mixed methods instrument development study is that the items emerge from the participants’ experiences, often using their own words. An item generation matrix, such as Table 5, is a particularly
helpful tool in demonstrating that the items cover the breadth of the construct, themes, and categories and illustrating relevant quotes.

*Develop and clearly describe the protocol for reviewing the scale before conducting a pilot study.* Expert review of a new scale has been recommended by previous authors (DeVellis, 2003; Worthington & Whittaker, 2006; Onwuegbuzie et al., 2010). In traditional scale development, this review is generally conducted by individuals who have some type of credential relevant to the focal construct. Often the review consists of a quantitative survey for experts to rate the clarity, ease of use and relevance of the scale. Cognitive interviews are another common method for reviewing a scale before conducting a pilot study. Cognitive interviews are generally highly structured and the data is usually analyzed in a quantitative framework. Mixed methods instrument development studies provide opportunities for other types of scale review procedures. Contributors to the review process may include the research team, identified/credentialed experts, the participants (either from the qualitative phase or from the population for whom the scale is intended) or a combination of tactics. The scale review may be conducted individually or in groups, such as focus groups or research teams. By incorporating a qualitative approach to the scale review, the feedback can be addressed in real-time, with refinements occurring in an iterative process. Clearly describing the scale review process reveals much about the content validity of the scale, the relevance of the topic to the target population, the completeness of measuring the construct domain, and the appropriateness and clarity of the item wording.

*Consult survey research literature for resources regarding scale formatting and maximizing data collection efficacy.* Regardless of the construct being measured, the field
Interest in the Engineering PhD provides a wealth of information regarding data collection modes, visual design, response options, recruitment, incentives, etc. Integrating best practices from survey research can help design a scale that is not only reliable and valid, but eases the demands on participants and increases response rates.

Provide details regarding the pilot study and scale evaluation process. A pilot study provides important information about the validity of a scale and the reliability of the scores collected by the scale. While there are established guidelines for what are considered acceptable values for different statistical tests, it is important to be explicit about the review criteria and decision thresholds for retaining or removing items and factors. Transparency is necessary so that other researchers have a full understanding of the scale development process.

Dissemination. Because this research project was funded by a grant from the National Science Foundation, dissemination of the results beyond this dissertation is an important part of this study. Manuscripts and presentation proposals specific to the qualitative phase and the quantitative phase are being prepared for the engineering education community. Additional manuscripts and presentation proposals are being developed regarding the methodology of this study for the research methodology community.

Limitations

Prior to collecting data, this study was limited by the type of institutions that participated in the study. In particular, no top-tier PhD granting institution or Historically Black College or University elected to participate. Once data collect began, other limitations emerged, particularly in the quantitative phase. Several sites did not follow the
recruitment protocol as recommended; therefore response rates were lower at those sites. Future studies should more strongly encourage following the recommended protocol.

Non-random missing data was also a limitation of this study in the quantitative phase. Due to the structure of the instrument, there was a clear pattern of participants leaving the survey after each page. The validated instrument is much shorter and future versions will have all items randomized on one page, therefore eliminating the non-random missing data. The final limitation of this study was a lack of a clearly defined and clearly measured outcome variable in the quantitative phase of the study. Given the inconsistent response pattern between the two potential outcome measures, “PhDPlan” and “PhDLikely”, additional work is needed to refine how interest in the engineering PhD is being measured. A more reliable and valid measure of interest in the engineering PhD will more clearly illuminate the relationships of the other variables with the focal construct.

**Future Research**

There are several opportunities to extend this dissertation into further studies of understanding the process of developing interest in the engineering PhD. The most likely next step would be to conduct another validation study of the EEII. Additional sites, particularly top-tier doctoral granting engineering programs and engineering programs at HBCUs should be included in this study. Participating sites should be strongly encouraged to follow the recommended recruitment protocol of sending a pre-notification e-mail by a known and trusted individual, such as an engineering Dean, and generating personalized recruitment messages and follow-up reminders, as these strategies had a positive impact on the response rates. The streamlined measurement, with only 23 core
items, should reduce the amount of missing data, and the randomization of the items across all factors should attenuate the non-random missing data pattern of this study.

Additional variations of this study would also extend our understanding of increasing interest in the engineering PhD. One option would be to conduct a larger-scale discriminant study by recruiting PhD students and recent PhD alumni at all participating sites that offer an engineering PhD. Another option would be to conduct a comparison study by including international students in the data collection and evaluating the data for significant differences between domestic and international students. Conducting a longitudinal study and tracking actual PhD program enrollments of students who complete the EEII would provide valuable information about how interest in a PhD translates into enrollment in a PhD program.

The results from this study indirectly support undergraduate research experiences, as research provides an opportunity for students to develop mentoring relationships with faculty, directly observe what graduate school is like, and receive support in pursuing doctoral education. These findings would be enhanced by additional information regarding the efficacy of the National Science Foundation’s Research Experiences for Undergraduates (REU) program. A coordinated, national effort to collect data from all REU participants, would provide valuable information about the students who participate in REUs, their interest in doctoral programs, and the efficacy of the REU in preparing them to apply for PhD programs and for conducting doctoral-level research. Longitudinal data on REU participants should also be collected, so that the long-term investment of resources can be accurately evaluated. Without a more comprehensive assessment of the
REU program, any suggestion of the influence of the program in increasing interest in doctoral programs is merely speculation.

Another potential study that would extend the findings would be to explore the motivational factors for people who have earned their PhD with the goal of identifying critical experiences that facilitated not only their interest in but also enrollment and completion of the engineering PhD. This study identified some of those factors (having a parent with a PhD, dissonance with career choice, love of learning, teaching and/or research, “the talk” from a respected mentor encouraging graduate school, etc.). There would be value in studying these experiences specifically as systematic study provides stronger support for planned interventions.

A response-to-intervention study would be an important follow-up from this project. Although the EEII would benefit from additional validation studies, the combined results from both the qualitative and quantitative phases are compelling enough in their own right to warrant the development of a pilot program that would work to correct the misperceptions that undergraduate students have regarding the economic and personal costs of the engineering PhD and the nature of work. Graduate school workshops, class discussions, guest lecturers from industry PhDs are but a few of the many programs that could be implemented to raise awareness of the engineering PhD and provide accurate information to undergraduate engineering students about PhD career paths. The pilot program should also include an element of faculty training to assist them in maximizing their role in encouraging students to pursue an engineering PhD. The EEII could be used as a pre- and post-test to measure how students’ responses change after
exposure to higher levels of information and encouragement regarding the engineering PhD.

**Conclusion**

In conclusion, the qualitative grounded theory phase of this study found three factors that influenced interest in the engineering PhD: Misperceptions (engineering work and economic and personal costs), Environment (undergraduate educational environment and interpersonal environment), and Personal Characteristics (belief in self and interests and skills). These factors combine to form the pathways to the engineering PhD. The Exploring Engineering Interest Inventory (EEII) was developed to measure the influence of these factors and other relevant engineering experiences on interest in the engineering PhD. Four factors were found to be significant predictors of interest in the engineering PhD: Engineering work misperceptions, economic and personal costs misperceptions, educational environment, and personal characteristics.

Engineering programs have an opportunity to increase interest in the engineering PhD by working to correct many of the misperceptions that undergraduate engineering students have about this particular career path. Including messages about doctoral opportunities in existing courses, offering workshops about doctoral programs and exposing undergraduates to PhD engineers in industry all have the potential to positively impact interest levels. Additionally, one of the most significant experiences for students who plan on pursuing the engineering PhD was encouragement from an engineering faculty member. Increasing the numbers of students that faculty have “the talk” with would most certainly lead to an increased interest in the engineering PhD.

Another important finding of this study was that for engineering majors, an element of time seems a necessary component for developing interest in the engineering
PhD. Many of the PhD engineers pursued traditional engineering employment upon completing their bachelor’s degree, only to become bored with the work that they were doing. They realized that they were more interested in doing a different kind of engineering work: one that was more on the cutting edge and blazing new trails; one that required deeper thinking about problems that may only just be emerging; one that would require a PhD in engineering.

By having an empirically derived theory and a tested measure of that theory, engineering programs are now in a position to consider strategies to more effectively and efficiently increase interest in the engineering PhD.
Appendix A: Phase I Recruitment Messages

Site Recruitment
We are writing to invite you to participate in a study, “Understanding Perceived Barriers to Ph.D. Programs in Engineering for Domestic Students,” funded by NSF’s Innovations in Engineering Education, Curriculum, and Infrastructure Program. The purpose of the study is to create a systematic understanding of the methods that engineering schools can increase the number of domestic Ph.D. students. We have enclosed a copy of our project summary.

If you agree to participate and allow us to spend a few days on your campus, we will only ask for a small amount of assistance:

- Provide a list of potential undergraduate participants for on-campus interviews;
- Provide space to conduct focus groups (e.g., conference room, class room); and
- Arrange for a meeting with your admissions office or college advisor for a brief overview of your academic programs.

In return, we will:

- Provide you with personalized consultation about the study’s results for your campus.
- Acknowledge your assistance in all papers and presentations.

Thanks very much for considering our request. We will call you soon to discuss your willingness to participate as a data collection site.
Undergraduate Student Focus Group
You have been selected to participate in a study at UNL that is aimed at better understand the experiences of undergraduate students in the field of Engineering.

We are interested in your experience and would like to invite you to join a focus group on DATE, at TIME pm. The discussion group will last approximately 60 minutes and will be held ROOM LOCATION. To compensate for your time, you will receive:

- Free pizza dinner
- $25 gift card to the University Bookstore

Please RSVP so that I will be able to save a spot for you!

Attached is a copy of the Informed Consent form to provide you with more details about the study and the interview protocol. Feel free to review it before you respond.

Looking forward to meeting you soon!

Faculty Individual Interview
I am a doctoral student at the University of Nebraska-Lincoln in the Educational Psychology department. For my dissertation, I am conducting a study funded by the National Science Foundation, “Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study.”

I will be visiting your campus next week on DATE to conduct focus groups with domestic undergraduate engineering majors, as arranged with PERSON, TITLE.

I would also like to interview current engineering faculty about their perceptions of engineering education in general and the engineering Ph.D. in particular.

If you would be willing to share your perceptions with me, please reply to this e-mail and we can schedule your 20 minute interview at a time that is convenient for you.

I look forward to meeting you soon!
PhD Student Individual Site Interview
I am a doctoral student at the University of Nebraska-Lincoln in the Educational Psychology department. For my dissertation, I am conducting a study funded by the National Science Foundation, “Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study.”

I will be visiting your campus next week on DATE to conduct focus groups with domestic undergraduate engineering majors, as arranged with PERSON, TITLE.

I would also like to interview US citizens who are pursuing a PhD in engineering. The interview will take approximately 20 – 30 minutes and will include questions about your perceptions of engineering education in general and the engineering PhD in particular.

I have attached a copy of the Informed Consent form that has more details about the study so that you may review it before you make your decision. To compensate you for your time, you will receive a $25 gift card to your university’s book store.

If you would be willing to share your perceptions with me, please reply to this e-mail and we can schedule your interview at a time that is convenient for you.

I look forward to meeting you soon!

PhD Student Individual Phone Interview
I am a doctoral student at the University of Nebraska-Lincoln in the Educational Psychology department. I am currently working on a study funded by the National Science Foundation, “Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study.”

I have found your name and e-mail address on your university’s Web site and think you may meet my study criteria.

I would like to interview US citizens who are pursuing a PhD in engineering. The interview will take approximately 20 – 30 minutes and will include questions about your perceptions of engineering education in general and the engineering PhD in particular.

I have attached a copy of the Informed Consent form that has more details about the study so that you may review it before you make your decision. To compensate you for your time, you will receive a $25 gift card to Amazon.com.

If you would be willing to share your perceptions with me, please reply to this e-mail and we can schedule your phone interview at a time that is convenient for you.

I look forward to talking to you soon!

Industry PhD Individual Phone Interview
I am a doctoral student at the University of Nebraska-Lincoln in the Educational Psychology department. I am currently working on a study funded by the National Science Foundation, “Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study.”

NAME has given me your name and e-mail address as someone who may meet my study criteria. [I have found your name and e-mail address on UNIVERSITY Web site and think you may meet my study criteria.]

I would like to interview US citizens who have earned a PhD in engineering and are working in non-academic/industrial settings. The interview will take approximately 20 – 30 minutes and will include questions about your perceptions of engineering education in general and the engineering PhD in particular.

I have attached a copy of the Informed Consent form that has more details about the study so that you may review it before you make your decision.

If you would be willing to share your perceptions with me, please reply to this e-mail and we can schedule your phone interview at a time that is convenient for you.

I look forward to talking to you soon!
Appendix B: Phase I Interview Protocols

Undergraduate Focus Groups
1. Let’s start with having each person introduce themselves by telling us your first name, major, and about how you first got interested in engineering.
2. What is it like to be an engineering undergraduate student?
3. What are your career plans after graduating?
   a. Probe about plans for 5 years later
   b. Probe about plans for 10 years later
4. What do you typically think about people who choose to pursue PhDs in engineering?
   a. Probe about their perceptions: who they imagine these people are, what they are like, etc.
   b. Follow-up with how engineers with PhDs differ from/similar to other engineers (in the industry)
5. Why would/wouldn’t you pursue a PhD in Engineering? (Derive a list)
6. What do you think it takes to be a PhD in Engineering?
7. What kinds of changes do you think would cause you (or other people) to more seriously consider getting a Ph.D. in engineering?
8. What other ideas do you have about engineering PhD programs that you’d like to share?

PhD Student Individual Interviews
1. I thought we could start by having you tell me about how you first got interested in engineering.
2. What perceptions did you have of Engineering PhD programs when you were an undergraduate student?
3. How did you decide to go to graduate school in Engineering?
   a. Probe about other career options
4. Probe about choice of program and why it was selected
5. If applicable – tell me more about “the talk.”
6. What are your career plans after graduating?
7. Why is an engineering PhD important?
8. What changes might encourage more domestic students to pursue Engineering PhDs?
9. What else can you tell me to help me understand engineering PhD programs?

PhD Students Individual PHONE Interviews
1. I thought we would start with having you tell me a little bit about yourself and how you decided to pursue a PhD in engineering.
2. What were your perceptions about engineering Ph.D. programs before you started? How have your experiences matched (or not) your expectations?
3. What do you like about being an engineering grad student? What do you NOT like about being an engineering grad student?
4. What kind of career do you envision for yourself? How do you see your background in engineering facilitating your career path?
5. What kinds of changes would you like to see that would cause domestic students to more seriously consider getting a Ph.D. in engineering?
6. Are there any other thoughts you have about engineering Ph.D. programs that you’d like to share?

**Faculty Individual Interviews**

1. How did you decide to go to graduate school in Engineering?
   a. Probe about other career options
   b. Probe about choice of program and why it was selected
2. If applicable – tell me more about “the talk.”
3. What factors helped you to become a faculty member?
   a. Listen for background (especially undergraduate experience)
4. Why is an engineering PhD important?
5. How do you convey that to undergraduate students?
6. Can you think of some PhD students who are successful in your program. What characteristics would you use to describe them?
   a. Probe for what the students are like as people, such as their attributes, work-ethic, way of looking at the world, etc.
7. What characteristics do you think helped you succeed in getting your PhD?
8. What changes might encourage more domestic students to pursue Engineering PhDs?
   a. Follow-up with asking whether Engineering programs are ready to make these kinds of changes.
9. What else can you tell me about domestic students pursuing engineering PhD programs?

**Industry PhDs Individual PHONE Interviews**

1. I thought we would start with having you tell me a little bit about yourself and how you decided to pursue a PhD in engineering.
2. Now I’d like to talk about your role as an as a PhD working in industry. What do you like about being a PhD engineer? What did you NOT like about being a PhD engineer?
3. One of the themes from the undergraduate focus groups was that they felt they could do the same kind of work with a BS that someone would do with a PhD. I’d like to know more about the nature of the work you do in industry and how that might be different from what you would have been able to do with only a BS.
4. Another theme from the focus groups was that they felt earning a PhD in engineering would limit their career options. What are your thoughts on their perceptions?
5. What kinds of changes do you think would cause domestic students to more seriously consider getting a Ph.D. in engineering?
6. Are there any other thoughts you have about engineering Ph.D. programs that you’d like to share?
## Appendix C: Phase I Code List

<table>
<thead>
<tr>
<th>Code</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EDUCATIONAL ENVIRONMENT</strong></td>
<td></td>
</tr>
<tr>
<td>Institutional specific programs/services</td>
<td>60</td>
</tr>
<tr>
<td>Research experiences/REU</td>
<td>52</td>
</tr>
<tr>
<td>Work load</td>
<td>75</td>
</tr>
<tr>
<td>Curriculum and pedagogy</td>
<td>90</td>
</tr>
<tr>
<td>Grad school knowledge</td>
<td>40</td>
</tr>
<tr>
<td>PhD</td>
<td>149</td>
</tr>
<tr>
<td><strong>ENGINEERING WORK</strong></td>
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</tr>
<tr>
<td>Hire-ability</td>
<td>110</td>
</tr>
<tr>
<td>Salary</td>
<td>46</td>
</tr>
<tr>
<td>Non-PhD level work</td>
<td>38</td>
</tr>
<tr>
<td>PhD level work</td>
<td>70</td>
</tr>
<tr>
<td>Impact of work</td>
<td>26</td>
</tr>
<tr>
<td><strong>INTERPERSONAL ENVIRONMENT</strong></td>
<td></td>
</tr>
<tr>
<td>Professor/Mentor Access/Engagement</td>
<td>105</td>
</tr>
<tr>
<td>Family influences</td>
<td>103</td>
</tr>
<tr>
<td>Industry (co-worker, etc.)</td>
<td>56</td>
</tr>
<tr>
<td>Peers</td>
<td>32</td>
</tr>
<tr>
<td>Societies, student organizations, conferences, special programs</td>
<td>13</td>
</tr>
<tr>
<td><strong>PERSONAL CHARACTERISTICS</strong></td>
<td></td>
</tr>
<tr>
<td>Developmental psychology</td>
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<tr>
<td>Passion</td>
<td>13</td>
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<tr>
<td>Interest in research and/or teaching</td>
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<tr>
<td>Motivation, Drive, Initiative, Self-starter</td>
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<tr>
<td>Work experience</td>
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<tr>
<td>Bored/Burned out</td>
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<tr>
<td>Confidence/Self efficacy</td>
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<td>Problem solving</td>
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<td>Initial interest in engineering</td>
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<tr>
<td>Love of learning/Lifelong learning/Curiosity</td>
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<tr>
<td><strong>ECONOMIC AND PERSONAL COSTS</strong></td>
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<tr>
<td>Financial issues</td>
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<td>Flexibility/Time</td>
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<td>Economic climate</td>
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<td>Public/Society view</td>
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<td>Quality of life</td>
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<tr>
<td><strong>PATHWAY TO THE PHD</strong></td>
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<td>Trigger event/Happenstance</td>
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<td><strong>BUCKET CODES</strong></td>
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<td>Quotes</td>
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<td>Recommendations</td>
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<td>MBA</td>
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<tr>
<td>Diversity issues</td>
<td>54</td>
</tr>
</tbody>
</table>
Appendix D: Phase I Informed Consent

(Focus groups: undergrad students)

INFORMED CONSENT FORM
IRB# 20090610005 EX, 10005

Title: Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study

Purpose of the Research:
The goal of the proposed study, funded by the National Science Foundation, is to understand the factors that facilitate or inhibit domestic student enrollment in engineering Ph.D. programs, and to identify strategies for reinforcing positive factors or removing barriers. The overarching goal of the project is to identify actionable strategies to increase domestic student enrollments.

Procedures:
Participation in this study will require approximately 60-90 minutes of your time and will consist of a group interview regarding your experience as an engineering student. The interview will be audio taped with your permission. The interview will take place on campus either at an office or conference room in your building, or at another convenient campus location.

Risks and/or Discomforts:
There are no known risks or discomforts associated with this research.

Benefits:
In order to attract more domestic students, universities need an empirical understanding of the factors that underlie the decision to pursue or forego an engineering PhD. They also need a new set of strategies for increasing domestic PhD enrollments. The proposed study is designed to address both of these critical needs.

The findings of this research study will have broad application in the field of engineering doctoral education. The results will be used to generate specific strategies that universities can implement to increase domestic student enrollment in engineering PhD programs.

Confidentiality:
Any information obtained during this study which could identify you will be kept strictly confidential. The data will be stored in a locked cabinet in the investigator’s home office and will only be seen by the investigator and transcriber during the study and for three years after the study is complete. The audiotapes will be erased after transcription. The information obtained in this study may be published in scientific journals or presented at scientific meetings but the data will be reported using a pseudonym of your choosing.
Compensation:
You will receive a $25 gift card to the campus bookstore for participating in this study.
Dinner will be provided during the focus group.

Opportunity to Ask Questions:
You may ask any questions concerning this research and have those questions answered
before agreeing to participate in or during the study. Or you may contact the investigator
via phone or email at any time. If you have questions concerning your rights as a research
subject that have not been answered by the investigator or to report any concerns about
the study, you may contact the University of Nebraska-Lincoln Institutional Review
Board, telephone (402) 472-6965.

Freedom to Withdraw:
You are free to decide not to participate in this study or to withdraw at any time without
adversely affecting your relationship with the investigators or the University of Nebraska.
Your decision will not result in any loss or benefits to which you are otherwise entitled.

Consent, Right to Receive a Copy:
You are voluntarily making a decision whether or not to participate in this research study.
Your signature certifies that you have decided to participate having read and understood
the information presented. You will be given a copy of this consent form to keep.

_________________________________________    ____________
Signature of Research Participant                        Date

Principal Investigator:
Michelle Howell Smith, mhowell2@unl.edu, (402) 472-4458 Office, (402) 432-3639 Cell

Advisor:
Dr. Ellen Weissinger, eweissinger1@unl.edu, (402) 472-2878 Office
Title: Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study

Purpose of the Research:
The goal of the proposed study, funded by the National Science Foundation, is to understand the factors that facilitate or inhibit domestic student enrollment in engineering Ph.D. programs, and to identify strategies for reinforcing positive factors or removing barriers. The overarching goal of the project is to identify actionable strategies to increase domestic student enrollments.

Procedures:
Participation in this study will require approximately 30 minutes of your time and will consist of a semi-structured interview regarding your experience as an engineering student. The interview will be audio taped with your permission. The interview will take place on campus either at an office or conference room in your building, or at another convenient campus location.

Risks and/or Discomforts:
There are no known risks or discomforts associated with this research.

Benefits:
In order to attract more domestic students, universities need an empirical understanding of the factors that underlie the decision to pursue or forego an engineering PhD. They also need a new set of strategies for increasing domestic PhD enrollments. The proposed study is designed to address both of these critical needs.

The findings of this research study will have broad application in the field of engineering doctoral education. The results will be used to generate specific strategies that universities can implement to increase domestic student enrollment in engineering PhD programs.

Confidentiality:
Any information obtained during this study which could identify you will be kept strictly confidential. The data will be stored in a locked cabinet in the investigator’s home office and will only be seen by the investigator and transcriber during the study and for three years after the study is complete. The audiotapes will be erased after transcription. The information obtained in this study may be published in scientific journals or presented at scientific meetings but the data will be reported using a pseudonym of your choosing.

Compensation:
You will receive a $25 gift card to the campus bookstore for participating in this study.
Opportunity to Ask Questions:
You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. Or you may contact the investigator via phone or email at any time. If you have questions concerning your rights as a research subject that have not been answered by the investigator or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Freedom to Withdraw:
You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or the University of Nebraska. Your decision will not result in any loss or benefits to which you are otherwise entitled.

Consent, Right to Receive a Copy:
You are voluntarily making a decision whether or not to participate in this research study. Your signature certifies that you have decided to participate having read and understood the information presented. You will be given a copy of this consent form to keep.

________________________________________  
Signature of Research Participant  
________________________________________  
Date

Principal Investigator:  
Michelle Howell Smith, mhowell2@unl.edu, (402) 472-4458 Office, (402) 432-3639 Cell

Advisor:  
Dr. Ellen Weissinger, eweissinger1@unl.edu, (402) 472-2878 Office
Interest in the Engineering PhD

(Individual interview: faculty)

INFORMED CONSENT FORM
IRB# 20090610005 EX, 10005
Title: Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study

Purpose of the Research:
The goal of the proposed study, funded by the National Science Foundation, is to understand the factors that facilitate or inhibit domestic student enrollment in engineering Ph.D. programs, and to identify strategies for reinforcing positive factors or removing barriers. The overarching goal of the project is to identify actionable strategies to increase domestic student enrollments.

Procedures:
Participation in this study will require approximately 30 minutes of your time and will consist of a semi-structured interview regarding your experience as an engineering faculty member. The interview will be audio taped with your permission. The interview will take place on campus either at an office or conference room in your building, or at another convenient campus location.

Risks and/or Discomforts:
There are no known risks or discomforts associated with this research.

Benefits:
In order to attract more domestic students, universities need an empirical understanding of the factors that underlie the decision to pursue or forego an engineering PhD. They also need a new set of strategies for increasing domestic PhD enrollments. The proposed study is designed to address both of these critical needs.

The findings of this research study will have broad application in the field of engineering doctoral education. The results will be used to generate specific strategies that universities can implement to increase domestic student enrollment in engineering PhD programs.

Confidentiality:
Any information obtained during this study which could identify you will be kept strictly confidential. The data will be stored in a locked cabinet in the investigator’s home office and will only be seen by the investigator and transcriber during the study and for three years after the study is complete. The audiotapes will be erased after transcription. The information obtained in this study may be published in scientific journals or presented at scientific meetings but the data will be reported using a pseudonym of your choosing.

Compensation:
There is no compensation for participating in this study.
Opportunity to Ask Questions:
You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. Or you may contact the investigator via phone or email at any time. If you have questions concerning your rights as a research subject that have not been answered by the investigator or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Freedom to Withdraw:
You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or the University of Nebraska. Your decision will not result in any loss or benefits to which you are otherwise entitled.

Consent, Right to Receive a Copy:
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_________________________________________  ______________
Signature of Research Participant              Date

Principal Investigator:
Michelle Howell Smith, mhowell2@unl.edu, (402) 472-4458 Office, (402) 432-3639 Cell

Advisor:
Dr. Ellen Weissinger, ewessinger1@unl.edu, (402) 472-2878 Office
(individual phone interview: PhD students)

INFORMED CONSENT FORM
IRB#  20090610005 EX, 10005
Title: Factors that facilitate or inhibit enrollment of domestic engineering PhD students:
A mixed methods study

Purpose of the Research:
The goal of the proposed study, funded by the National Science Foundation, is to
understand the factors that facilitate or inhibit domestic student enrollment in engineering
Ph.D. programs, and to identify strategies for reinforcing positive factors or removing
barriers. The overarching goal of the project is to identify actionable strategies to
increase domestic student enrollments.

Procedures:
Participation in this study will require approximately 30 minutes of your time and will
consist of a semi-structured phone interview regarding your experience as an engineering
student. The interview will be audio taped with your permission.

Risks and/or Discomforts:
There are no known risks or discomforts associated with this research.

Benefits:
In order to attract more domestic students, universities need an empirical understanding
of the factors that underlie the decision to pursue or forego an engineering PhD. They
also need a new set of strategies for increasing domestic PhD enrollments. The proposed
study is designed to address both of these critical needs.

The findings of this research study will have broad application in the field of engineering
doctoral education. The results will be used to generate specific strategies that
universities can implement to increase domestic student enrollment in engineering PhD
programs.

Confidentiality:
Any information obtained during this study which could identify you will be kept strictly
confidential. The data will be stored in a locked cabinet in the investigator’s home office
and will only be seen by the investigator and transcriber during the study and for three
years after the study is complete. The audiotapes will be erased after transcription. The
information obtained in this study may be published in scientific journals or presented at
scientific meetings but the data will be reported using a pseudonym of your choosing.

Compensation:
You will receive a $25 gift card from Amazon.com for participating in this study.
Interest in the Engineering PhD 189

Opportunity to Ask Questions:
You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. Or you may contact the investigator via phone or email at any time. If you have questions concerning your rights as a research subject that have not been answered by the investigator or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Freedom to Withdraw:
You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or the University of Nebraska. Your decision will not result in any loss or benefits to which you are otherwise entitled.

Consent, Right to Receive a Copy:
You are voluntarily making a decision whether or not to participate in this research study. Your indication of your agreement to participate in the reply e-mail certifies that you have decided to participate having read and understood the information presented.

Principal Investigator:
Michelle Howell Smith, mhowell2@unl.edu, (402) 472-4458 Office, (402) 432-3639 Cell

Advisor:
Dr. Ellen Weissinger, eweissinger1@unl.edu, (402) 472-4929 Office
(individual phone interview: industry PhDs)

INFORMED CONSENT FORM
IRB#  20090610005 EX, 10005
Title: Factors that facilitate or inhibit enrollment of domestic engineering PhD students: A mixed methods study

Purpose of the Research:
The goal of the proposed study, funded by the National Science Foundation, is to understand the factors that facilitate or inhibit domestic student enrollment in engineering Ph.D. programs, and to identify strategies for reinforcing positive factors or removing barriers. The overarching goal of the project is to identify actionable strategies to increase domestic student enrollments.

Procedures:
Participation in this study will require approximately 30 minutes of your time and will consist of a semi-structured phone interview regarding your experience as someone who has earned a PhD in engineering and is working in a non-academic/industrial setting. The interview will be audio taped with your permission.

Risks and/or Discomforts:
There are no known risks or discomforts associated with this research.

Benefits:
In order to attract more domestic students, universities need an empirical understanding of the factors that underlie the decision to pursue or forego an engineering PhD. They also need a new set of strategies for increasing domestic PhD enrollments. The proposed study is designed to address both of these critical needs.

The findings of this research study will have broad application in the field of engineering doctoral education. The results will be used to generate specific strategies that universities can implement to increase domestic student enrollment in engineering PhD programs.

Confidentiality:
Any information obtained during this study which could identify you will be kept strictly confidential. The data will be stored in a locked cabinet in the investigator’s home office and will only be seen by the investigator and transcriber during the study and for three years after the study is complete. The audiotapes will be erased after transcription. The information obtained in this study may be published in scientific journals or presented at scientific meetings but the data will be reported using a pseudonym of your choosing.

Compensation:
There is no compensation for participating in this study.
Opportunity to Ask Questions:
You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. Or you may contact the investigator via phone or email at any time. If you have questions concerning your rights as a research subject that have not been answered by the investigator or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Freedom to Withdraw:
You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or the University of Nebraska. Your decision will not result in any loss or benefits to which you are otherwise entitled.

Consent, Right to Receive a Copy:
You are voluntarily making a decision whether or not to participate in this research study. Your indication of your agreement to participate in the reply e-mail certifies that you have decided to participate having read and understood the information presented.

Principal Investigator:
Michelle Howell Smith, mhowell2@unl.edu, (402) 472-4458 Office, (402) 432-3639 Cell

Advisor:
Dr. Ellen Weissinger, eweissinger1@unl.edu, (402) 472-4929 Office
Appendix E: Phase II Recruitment Flyer

Earn $25

Share your opinions about an engineering education survey

Only 30 minutes of your time

gift card to the University Bookstore

Eligible students must be:
- US Citizen
- Junior or Senior
- Engineering Major

Email us to schedule your feedback session

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey

$25 Engineering Survey
Appendix F: Phase II Iterative Feedback Interview Protocol

Thank you for participating in our survey review. Your participation in the review is a crucial part of our research project. We are developing a survey for undergraduate engineering students, but since we are not engineers, we need to rely on you to give us feedback on the survey. You are representing the thousands of students across the country who will be taking the survey, so if you have questions or comments, we’d like to correct them at this stage before we launch the survey. We appreciate your expert opinion!

We would like you to take the survey and answer the items in a natural way. Your responses are not being collected, but we want to know what it is like for you to take the survey.

As you are taking the survey, we would like you to think out loud and tell us any thoughts you have about the items:
- Did you have to think too long or too hard about an item?
- Did an item irritate you?
- Embarrass you?
- Confuse you?
- Is the wording on the items clear?
- Did you understand the item?
- Are there words in the items that you don’t understand?
- Are there questions you just wanted to skip?
- Are there items you would just delete?
- Are there items you would re-write to make clearer?

After you complete the survey we will have some general questions for you to respond to about the survey.

---

1. What do you think the survey is about?
2. How is this survey relevant to your experience as an undergraduate engineer?
3. Were the answer choices appropriate for your response to the questions or did you want another choice for your response? Did you use a variety of response options?
4. Was the survey organized in a way that made sense to you?
5. Did you feel comfortable answering all of the questions?
6. Did you feel like you could answer the questions honestly, or did you want to answer in a way that you think would make you look “better”?
7. What are your thoughts on the length of the survey?
8. Have any other important issues been overlooked?
9. Any other advice on how we could improve the survey?
Appendix G: Initial Exploring Engineering Interest Inventory

Are you a US Citizen, Permanent Resident or National?
   Yes
   No

What year are you?
   Junior
   Senior
   Super Senior (5+ years)
   None of the above

What is your major?
Aerospace Engineering
Agricultural Engineering
Architectural Engineering
Bioengineering
Biological Systems Engineering
Biomedical Engineering
Chemical Engineering
Civil Engineering
Computer Engineering
Construction Engineering
Electrical Engineering

Engineering Mechanics
Environmental Engineering
Industrial Engineering
Manufacturing Engineering
Materials Engineering
Mechanical Engineering
Nuclear Engineering
Software Engineering
Telecommunications Engineering
Not Engineering
Other Engineering

In what year do you plan to receive your bachelor’s degree?
   2011
   2012
   2013
   2014
   2015 and beyond

Item Response Options: Strongly Agree, Agree, Disagree, Strongly Disagree

Personal Characteristics Items

Confidence and self efficacy
1. I am intimidated by the thought of writing a dissertation.
2. I am not sure if I am smart enough to complete a PhD.
3. I think my GPA is good enough to get admitted to a PhD program.
4. I feel confident in my academic abilities.

Curiosity and love of learning
5. I am a naturally curious person.
6. I love to learn new things.
7. I enjoy helping others learn.
Interest in the Engineering PhD 195

Motivation and initiative
8. I know how to motivate myself.
9. I can take the initiative to get things done.

Problem solving
10. I consider myself a good problem solver.
11. Solving problems on a deeper level is satisfying for me.

Developmental maturity
12. I have clear career goals.
13. I know what kind of work I enjoy doing.
14. I feel I have had enough life experience to know what kind of work I want to do.
15. I don’t think my career interests will change.

Educational Environment Items
Work load
16. I think earning a PhD is even harder than earning a bachelor’s degree in engineering.
17. I feel burned out by the amount of work required by the undergraduate engineering curriculum.
18. I think the amount of time I would have to put into graduate school work would be overwhelming.
19. I think graduate school classes are just like undergraduate classes, only a lot more work.

Curriculum and pedagogy
20. My classes have helped me to develop my critical thinking skills.
21. I have had a lot of experience with problem solving in my engineering classes.
22. I feel engineering courses provide a lot of “hands on” experience.
23. I think there is really not much difference in the classes between undergraduate and graduate.
24. I feel the undergraduate engineering curriculum encourages students to pursue advanced engineering degrees.
25. I have had opportunities to conduct research in my undergraduate program.

Institutional programs and services
26. As an undergraduate engineering student, I have interacted with graduate students.
27. Engineering organizations/clubs are a valuable source of career information for me as an undergraduate student.
28. There are seminars/workshops about graduate school at my undergraduate program.
29. I have a good idea of what it would take to get in to graduate school.
30. My undergraduate program focused on getting a good job after graduation.
31. Resources and support in finding an internship/co-op were readily available at my undergraduate program.
Interest in the Engineering PhD

32. No one at my undergraduate program ever talked about graduate school as a possibility.
33. I participated in workshops/seminars about graduate school at my undergraduate program.
34. I participated in an in-depth program to prepare me for graduate school, such as McNair, LSAMP, REU or others.
35. I have attended a graduate school fair to meet recruiters or faculty from graduate programs.

Balance work, school and family life
36. I think graduate programs in engineering support a balance between school, work, and family responsibilities.
37. I feel earning a PhD in engineering seems to be a flexible process.
38. I can have a family while earning a PhD in engineering.
39. I can work full-time while earning a PhD part-time.

Interpersonal Environment Questions
Family
40. My family encouraged me to pursue a bachelor’s degree in engineering.
41. Family responsibilities would make it difficult for me to pursue a PhD in engineering.
42. My family would support me pursuing a PhD in engineering.

Peers
43. I know someone personally who is pursuing a PhD in engineering.
44. My peers are more interested in getting a good job than earning a PhD.
45. Not very many of my friends are thinking about earning a PhD.
46. I have talked to my friends about going to graduate school.

Industry
47. I have worked in a workplace (intern, co-op experience, career) where many individuals had a PhD in engineering.
48. An industry professional encouraged me to consider earning a PhD in engineering.
49. An industry professional discouraged me from considering a PhD in engineering.
50. Based on the messages from my colleagues in the workplace, on the job training is more important for me than a PhD in terms of career opportunities.
51. PhD engineers are invisible in society in the workplace.

Professors and Mentors
52. A faculty member discussed graduate school as an option in one or more of my classes.
53. A faculty member shared his/her career path with me.
54. A faculty member described the importance of the PhD in the engineering field.
55. A faculty member presented a seminar or workshop explaining the important
elements about graduate school (coursework, funding opportunities, potential
careers, etc.).
56. A faculty member has spoken to me about my future plans and/or career
aspirations.
57. A faculty member has taken interest in me and my future plans.
58. A faculty member talked with me about my abilities/academic talent.
59. A faculty member has given me confidence to pursue a PhD in engineering.
60. Faculty in my undergraduate program encouraged me to consider pursuing a PhD
in engineering.
61. I have worked closely with a faculty member on a research project.

Societal Views
62. I feel engineering is an important career for our society.
63. I believe PhD engineers are essential for the future of our society.
64. I think engineering is a prestigious career regardless of the educational level.
65. I don’t believe I would be viewed as an adult if I continued my education.

Nature of Work Questions
PhD level engineering work
66. I think PhD engineers mainly do theoretical research and development.
67. For me, people with PhDs in engineering are not “real” engineers.
68. I think the only thing you can do with a PhD in engineering is become a faculty
member.
69. I believe PhD engineers are innovative thinkers.
70. I think people with a PhD in engineering are overqualified for most engineering
jobs.
71. PhD level engineering work is interesting and stimulating.
72. PhD level engineers have more freedom to choose the projects they work on.

Employment opportunities for engineers with different levels of education
73. I can do the same kind of work that a PhD engineer can do with a bachelor’s
degree.
74. Earning a PhD in engineering would limit my employment opportunities.
75. Earning a PhD in engineering would pigeonhole me into doing only one thing.
76. In my career, I can do anything I want with a bachelor’s degree in engineering.
77. I don’t think there is any reason for a company to pay for a PhD employee over a
bachelor’s degree employee if they both can do the work.
78. A PhD may be the only way for a person to obtain the specific career he/she
desires.
79. I understand the kind of work that PhD-level engineers do.
80. In order to get a good job I need to continue my education.
81. A bachelor’s degree in engineering is all that I need to obtain a great job.
82. I can get any job I want with a bachelor’s degree in engineering.
83. PhD engineers may be highly sought after for their skills in certain niche markets.
Bachelors or masters level engineering work
84. I know bachelors-level engineering work is hands-on.
85. I feel on the job training is more important than earning a PhD in engineering.
86. I believe that the education I get from my employer will help me advance in my career.

Economic and Personal Costs Questions
Education cost
87. I think graduate school is expensive.
88. I would probably need to take out loans to pay for graduate school.
89. I believe PhD students get free tuition.
90. I think PhD students get paid to go to graduate school.
91. The debt I have incurred for my bachelor’s degree is a consideration in whether I would go to graduate school.
92. I would be worried I wouldn’t be paying my student loan debt if I went to graduate school.

Opportunity cost of advanced education
93. I do not think PhD students are able to work full-time while going to graduate school.
94. I would consider graduate school if my company paid for it.
95. I would give up a good job in order to get the education necessary for the career I want.
96. I would delay taking a good job in order to get the education necessary for the career I want.
97. I would be willing to make less money in the short term in order to work in a career I find rewarding.
98. I think there is a big difference in the salary for a bachelor’s-level job and what a graduate student would get paid while going to school.
99. A PhD in engineering seems like a needless investment to me.

Personal financial influences
100. I would have to put my life on hold if I went to graduate school.
101. I do not think PhD students can afford to buy the nicer things in life.
102. I think it is financially difficult to start a family while working towards a PhD.
103. I think PhD programs are not designed for people who want to have a life.
104. There would not be enough time for my family if I pursue a PhD.
105. I would have to give up having fun and having a social life if I worked towards a PhD.
106. I would not be able to make a major purchase (such as a car or house) on a graduate assistant salary.

DEMOGRAPHIC INFORMATION
What is the highest level of education you plan to complete?
  o Bachelor’s degree in engineering field
  o Master’s degree in engineering field
Interest in the Engineering PhD

- MBA
- Master’s degree in other field (not engineering or business)
- Doctorate or PhD in engineering field
- Doctorate or PhD in other field

Have you considered getting a PhD in engineering?
- Yes, I have seriously considered it
- Yes, I have considered it, but not seriously
- No, I’ve never really thought about getting a PhD (skip next item)

What are your plans concerning the PhD in engineering?
- I’m definitely planning on earning an engineering PhD
- I’m learning towards getting a PhD in engineering, but not 100% committed to it yet
- I’m somewhat interested in getting a PhD in engineering, but need more information
- I’m completely undecided about pursuing an engineering PhD
- I’m definitely not going to pursue a PhD in engineering

What is the highest level of education completed by someone in your family?
- Some high school
- High school graduate
- Some college, but did not finish
- Two-year college degree
- Four-year college degree
- Some graduate or professional school
- Graduate or professional degree
- Doctorate or PhD

Yes  No  I have participated in Undergraduate Research
Yes  No  I have participated in an engineering internship or co-op
Yes  No  I have experience as an undergraduate teaching others in formal or informal settings such as serving as a teaching assistant, tutoring, leading study groups or grading

Employment status:
- Full-time
- Part-time
- Unemployed
- Retired

Student status:
- Full-time student
- Part-time student
What is your gender?
   o Male
   o Female
   o Transgender

Are you Hispanic/Latino (choose only one)?
   o No, not Hispanic/Latino
   o Yes, Hispanic/Latino

Race (choose one or more, regardless of ethnicity status selected above)
   o American Indian or Alaska Native
   o Asian
   o Black or African American
   o Native Hawaiian or Other Pacific Islander
   o White
Appendix H: Pilot Exploring Engineering Interest Inventory

Page 1: Background Information
Thank you for agreeing to share your opinions about engineering education program

Please honestly answer the questions based on your beliefs and experience. We realize you may not have thought about these topics or had all of these experiences and that is ok – we are trying to understand the range of experiences and impressions engineering students have had regarding these issues.

Are you a US Citizen or Permanent Resident? (*REQUIRED RESPONSE)
Yes
No

What year are you?
Junior
Senior
Super Senior/5th Year Senior
None of the above

What is your major?
- Aerospace Engineering
- Agricultural Engineering
- Architectural Engineering
- Bioengineering
- Biological Systems Engineering
- Biomedical Engineering
- Chemical Engineering
- Civil Engineering
- Computer Engineering
- Construction Engineering
- Electrical Engineering
- Engineering Mechanics
- Environmental Engineering
- Industrial Engineering
- Manufacturing Engineering
- Materials Engineering
- Mechanical Engineering
- Nuclear Engineering
- Software Engineering
- Telecommunications Engineering
- Not Engineering
- Other Engineering

In what year do you plan to receive your bachelor’s degree?
2011
2012
2013
2014
2015 or beyond
Interest in the Engineering PhD 202

(Scale: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, Strongly Disagree)

Page #2 Personal Characteristics
73. I am a naturally curious person.
74. I am intimidated by the thought of writing a dissertation.
75. I consider myself a good problem solver.
76. I am smart enough to complete a PhD.
77. I love to learn new things.
78. My GPA is good enough to get admitted to a PhD program.
79. I know how to motivate myself to get things done.
80. I have clear career goals.
81. I feel confident in my academic abilities.
82. I have had enough experience to know what kind of work I want to do.

Page #3 Educational Environment
83. I feel burned out by the amount of work required by the undergraduate engineering curriculum.
84. I have had a lot of experience with problem solving in my engineering classes.
85. Engineering clubs/organizations are helpful in finding career information.
86. My undergraduate program is geared towards helping me get a good job after graduation.
87. Graduate school classes focus more on specific topics than undergraduate classes.
88. I think earning a PhD is even harder than earning a bachelor’s degree in engineering.
89. My classes have helped me to develop my critical thinking skills.
90. There are opportunities to conduct research in my undergraduate program.
91. I know what it would take to get admitted to a PhD program.
92. No one at my undergraduate program ever talked about earning a PhD as a possibility.
93. The amount of time I would have to put into a PhD would be overwhelming for me.
94. In general, engineering courses provide a lot of “hands on” experience.
95. My undergraduate program includes seminars/workshops about graduate school.
96. Resources and support in finding an internship/co-op are readily available at my undergraduate program.
97. Graduate school classes are just like undergraduate classes, only a lot more work.

Page #4 Interpersonal Environment
98. My family would support me pursuing a PhD in engineering.
99. I believe engineers with PhDs are essential for the future of our society.
100. My family encouraged me to pursue a bachelor’s degree in engineering.
101. My peers are more interested in getting a good job than earning a PhD.
102. I know people who are pursuing or have a PhD in engineering.
103. Family responsibilities would make it difficult for me to pursue a PhD in engineering.
104. Not many of my friends are thinking about earning a PhD.
105. I think engineering is a prestigious career regardless of the educational level.
106. I have worked closely with a professor on a research project.
107. Professors have described the importance of the PhD in the engineering field.
108. In general, engineers in industry encourage earning a PhD in engineering.
109. A Professional Engineering license is more valued by industry than a PhD.
110. Professors have discussed earning a PhD as an option in one or more of my classes.
111. On the job training is more important than a PhD in terms of career opportunities.
112. A professor has taken interest in my future plans or career aspirations.
113. A professor has shared his/her career path with me.
114. There are few engineers who have earned a PhD working in industry.
115. Professors in my undergraduate program encouraged me to pursue a PhD in engineering.

Page #5 Engineering Work
116. The only thing you can do with a PhD in engineering is become a professor.
117. Earning a PhD in engineering would reduce my employment opportunities.
118. I understand the kind of work that engineers with PhDs do.
119. For me, engineers with PhDs do not do “real” engineering work.
120. In order to get a good job I need to continue my education beyond a bachelor’s degree.
121. I think engineers with a PhD mainly do theoretical research and development.
122. A bachelor’s degree in engineering is all that I need to get any job I want.
123. I believe engineers with a PhD are innovative thinkers.
124. A PhD may be the only way for a person to obtain the specific career he/she desires.
125. Engineers with a PhD have more freedom to choose the projects they work on.
126. I think people with a PhD in engineering are overqualified for most engineering jobs.
127. Engineers with a PhD are highly sought after for their skills in certain specialized fields.
128. PhD level engineering work is interesting and stimulating.
129. I can do the same kind of work with a bachelor’s degree that an engineer with a PhD can do.
130. Earning a PhD in engineering would limit my career possibilities to a few specialized positions.

Page #6 Economic and Personal Costs
131. I would need to take out loans to pay for a PhD.
132. I would be willing to make less money in the short term in order to work in a career I find rewarding.
133. I am aware of the funding opportunities such as fellowships and assistantships that pay for PhD programs.
134. Balancing school, work and family time would be a factor in considering a PhD.
135. I think PhD programs are expensive.
136. I would delay taking a good job in order to get the education necessary for the career I want.
137. I think it would be financially difficult to start a family while working towards a PhD.
138. I would be unable to make a major purchase (such as a car or house) if I were a full-time graduate student.
139. The debt I have incurred for my bachelor’s degree is a consideration in whether I would pursue a PhD.
140. A PhD in engineering seems like a needless investment to me.
141. I would consider graduate school if my employer paid for it.
142. I could work full-time while earning a PhD part-time.
143. I would have to continue to put my life on hold if I pursued a PhD.
144. I would have to give up having fun and having a social life if I worked towards a PhD.

Page #7 Engineering Experience
(Scale: Yes, No)
I have attended a graduate school workshop.
I have participated in a graduate school preparation program, such as McNair, LSAMP, REU or others.
I have participated in undergraduate research.
I have participated in an engineering internship or co-op.
I have worked as an undergraduate teaching assistant.
I have lead study groups.
I have tutored others formally or informally.
I have assisted with grading.
I have attended a graduate school fair to meet recruiters or professors from graduate programs.
I have interacted with engineering graduate students.
Page 8: Engineering Interest
What degrees have you CONSIDERED or thought about pursuing? (*REQUIRED RESPONSE)
Master’s degree in engineering field
Doctorate or PhD in engineering field
MBA
Master’s degree in other field (not engineering or business)
Doctorate or PhD in other field
Other advanced degree (law, medicine, etc.)
None of the above

What degree(s) do you PLAN to pursue/complete?
Master’s degree in engineering field
Doctorate or PhD in engineering field
MBA
Master’s degree in other field (not engineering or business)
Doctorate or PhD in other field
Other advanced degree (law, medicine, etc.)
None of the above

How likely are you to pursue a MASTER’S DEGREE in engineering?
Very likely
Somewhat likely
Somewhat unlikely
Very unlikely

How likely are you to pursue a PhD in engineering?
Very likely
Somewhat likely
Somewhat unlikely
Very unlikely

Page #9: Demographic Information
What is the highest level of education completed by your parents or guardians?
Some high school
High school graduate
Some college
Two-year college degree
Four-year college degree
Some graduate or professional school
Graduate or professional degree
Doctorate or PhD

Growing up, was there anyone important to you who had earned a PhD in any field?
Yes
No
What is your gender?
Male
Female
Transgender

Are you Hispanic/Latino?
No, not Hispanic/Latino
Yes, Hispanic/Latino

Race (choose one or more, regardless of ethnicity status selected above)
American Indian or Alaska Native
Asian
Black or African American
Native Hawaiian or Other Pacific Islander
White

Have you ever been eligible for a federal Pell Grant?
Yes
No
Don’t Know

Page #10 Survey End and Thank You
Thank you for being willing to share your perceptions about engineering education. If you have any questions about this study or have additional feedback, you may contact us at NSFEngineeringStudy@gmail.com.

Please click on the "Done" button below to submit your responses and end the survey. Thank you.
Appendix I: Phase III Recruitment Messages and Informed Consent

Invitation/Informed Consent
Subject: NSF Engineering Interest Survey
Dear [FirstName]:

You have been selected to participate in a study on engineering education funded by the National Science Foundation. You are invited to share your views because you are an engineering student. [or “an engineering PhD student” or a “recent graduate of an engineering PhD program” – as appropriate for survey]

The online survey will take approximately 15-20 minutes. The survey will include questions about your interest and skills in engineering as well as your experiences and beliefs about engineering education (undergraduate through PhD).

Please help us improve your engineering education program by completing this survey.

Here is a link to the survey: [SurveyLink]

This link is uniquely tied to this survey and your email address. Please do not forward this message.

Thanks for your participation!

This project has been approved by the University of Nebraska Institutional Review Board #20110111495EX

Purpose of the Research: The goal of the proposed study, funded by the National Science Foundation, is to identify actionable strategies to increase domestic student enrollments in engineering PhD programs.

Procedures: Participation in this study will require approximately 15-20 minutes of your time and will consist of completing a web-based survey. You must be at least 19 years of age to participate.

Risks, Benefits, and/or Compensation: There are no known risks or discomforts associated with this research. The benefits of participating will include being able to provide information about your perception of the engineering PhD. There will be no compensation for participating in this research.

Confidentiality: Any information obtained during this study which could identify you will be kept strictly confidential. The data will be stored in a locked cabinet in the investigator’s home office and will only be seen by the investigator and authorized research team members during the study and for three years after the study is complete. The data will be stripped of any identifying information when the data are transferred into an analysis software package. The de-identified data will be analyzed and reported in
aggregate form. The information obtained in this study may be published in scientific journals or presented at scientific meetings.

Opportunity to Ask Questions: You may ask any questions concerning this research and have those questions answered before agreeing to participate in or during the study. Or you may contact the investigator via phone or email at any time. If you have questions concerning your rights as a research subject that have not been answered by the investigator or to report any concerns about the study, you may contact the University of Nebraska-Lincoln Institutional Review Board, telephone (402) 472-6965.

Freedom to Withdraw: You are free to decide not to participate in this study or to withdraw at any time without adversely affecting your relationship with the investigators or the University of Nebraska. Your decision will not result in any loss or benefits to which you are otherwise entitled.

Consent, Right to Receive a Copy: You are voluntarily making a decision whether or not to participate in this research study. By completing the survey, your consent to participate is implied. You may wish to print a copy of this form for your records.

Please note: If you do not wish to receive further emails from us, please click this link and you will be automatically removed from our mailing list: [RemoveLink]

Here is another link to begin the survey: [SurveyLink]

Reminder 1
Subject: Your opinions needed to improve engineering education
Dear [FirstName]:

It is not too late to complete the survey funded by the National Science Foundation to help us improve your engineering education program.

Here is a link to the survey: [SurveyLink]

This link is uniquely tied to this survey and your email address. Please do not forward this message.

Thanks for your participation!

Please note: If you do not wish to receive further emails from us, please click this link and you will be automatically removed from our mailing list: [RemoveLink]
Reminder 2
Subject: It is not too late to help improve engineering education
Dear [FirstName]:

There is still time to participate in the study funded by the National Science Foundation to help us improve your engineering education program.

Here is a link to the survey: [SurveyLink]

This link is uniquely tied to this survey and your email address. Please do not forward this message.

Thanks for your participation!

Please note: If you do not wish to receive further emails from us, please click this link and you will be automatically removed from our mailing list: [RemoveLink]
### Appendix J: 5-factor EFA solution with all 72 items

<table>
<thead>
<tr>
<th>Item</th>
<th>Cumulative variance explained: 30.427</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
<th>Factor 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>EW15</td>
<td>Earning a PhD in engineering would limit my career possibilities to a few specialized positions.</td>
<td>.722</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW2</td>
<td>Earning a PhD in engineering would reduce my employment opportunities.</td>
<td>.696</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW11</td>
<td>I think people with a PhD in engineering are overqualified for most engineering jobs.</td>
<td>.599</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC13</td>
<td>I would have to continue to put my life on hold if I pursued a PhD.</td>
<td>.562</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW1</td>
<td>The only thing you can do with a PhD in engineering is become a professor.</td>
<td>.555</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW4</td>
<td>For me, engineers with PhDs do not do “real” engineering work.</td>
<td>.549</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC14</td>
<td>I would have to give up having fun and having a social life if I worked towards a PhD.</td>
<td>.542</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW6</td>
<td>I think engineers with a PhD mainly do theoretical research and development.</td>
<td>.530</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE17</td>
<td>There are few engineers who have earned a PhD working in industry.</td>
<td>.414</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE14</td>
<td>On the job training is more important than a PhD in terms of career opportunities.</td>
<td>.373</td>
<td>-.322</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE11</td>
<td>In general, engineers in industry encourage earning a PhD in engineering.</td>
<td>-.340</td>
<td></td>
<td>.326</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE12</td>
<td>A Professional Engineering license is more valued by industry than a PhD.</td>
<td>.337</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE6</td>
<td>Family responsibilities would make it difficult for me to pursue a PhD in engineering.</td>
<td>.320</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC7</td>
<td>I think it would be financially difficult to start a family while working towards a PhD.</td>
<td>.311</td>
<td>-.308</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EE6</td>
<td>I think earning a PhD is even harder than earning a bachelor’s degree in engineering.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EE15</td>
<td>Graduate school classes are just like undergraduate classes, only a lot more work.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE18</td>
<td>Professors in my undergraduate program encouraged me to pursue a PhD in engineering.</td>
<td>.591</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE13</td>
<td>Professors have discussed earning a PhD as an option in one or more of my classes.</td>
<td>.578</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE9</td>
<td>I have worked closely with a professor on a research project.</td>
<td>.554</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE15</td>
<td>A professor has taken interest in my future plans or career aspirations.</td>
<td>.545</td>
<td>.316</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC5</td>
<td>I think PhD programs are expensive.</td>
<td>- .538</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE5</td>
<td>I know people who are pursuing or have a PhD in engineering.</td>
<td>.524</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IE10</td>
<td>Professors have described the importance of the PhD in the engineering field.</td>
<td>.516</td>
<td>.327</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EW3</td>
<td>I understand the kind of work that engineers with PhDs do.</td>
<td>.511</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EE9</td>
<td>I know what it would take to get admitted to a PhD program.</td>
<td>.495</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC3</td>
<td>I am aware of the funding opportunities such as fellowships and assistantships that pay for PhD programs.</td>
<td>.438</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EPC1</td>
<td>I would need to take out loans to pay for a PhD.</td>
<td>-.425</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Interest in the Engineering PhD

EPC8: I would be unable to make a major purchase (such as a car or house) if I were a full-time graduate student. .349 -.396
IE7: Not many of my friends are thinking about earning a PhD. -.376
IE16: A professor has shared his/her career path with me. .366
IE4: My peers are more interested in getting a good job than earning a PhD. .315 -.364
EE10: No one at my undergraduate program ever talked about earning a PhD as a possibility. .327 -.331
EPC11: I would consider graduate school if my employer paid for it. -.322 .310
EPC4: Balancing school, work and family time would be a factor in considering a PhD. -.319
EPC9: The debt I have incurred for my bachelor's degree is a consideration in whether I would pursue a PhD. -.313
EPC12: I could work full-time while earning a PhD part-time.

EE7: My classes have helped me to develop my critical thinking skills. .633
EE12: In general, engineering courses provide a lot of “hands on” experience. .564
EE2: I have had a lot of experience with problem solving in my engineering classes. .512
EE3: Engineering clubs/organizations are helpful in finding career information. .500
EE14: Resources and support in finding an internship/co-op are readily available at my undergraduate program. .437
EE4: My undergraduate program is geared towards helping me get a good job after graduation. .426
EE13: My undergraduate program includes seminars/workshops about graduate school. .390
IE8: I think engineering is a prestigious career regardless of the educational level. .387
PC8: I have clear career goals. .326 .314
IE3: My family encouraged me to pursue a bachelor’s degree in engineering.
EE8: There are opportunities to conduct research in my undergraduate program.
PC10: I have had enough experience to know what kind of work I want to do.
PC3: I consider myself a good problem solver. .651
PC9: I feel confident in my academic abilities. .648
PC4: I am smart enough to complete a PhD. .623
PC6: My GPA is good enough to get admitted to a PhD program. .522
PC5: I love to learn new things. .479
PC7: I know how to motivate myself to get things done. .470
PC1: I am a naturally curious person. .437
EE11: The amount of time I would have to put into a PhD would be overwhelming for me. .352 -.431
PC2: I am intimidated by the thought of writing a dissertation. -.414
<table>
<thead>
<tr>
<th>Statement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE1: I feel burned out by the amount of work required by the undergraduate engineering curriculum.</td>
<td>-.304</td>
</tr>
<tr>
<td>EE5: Graduate school classes focus more on specific topics than undergraduate classes.</td>
<td></td>
</tr>
<tr>
<td>IE2: I believe engineers with PhDs are essential for the future of our society.</td>
<td>.632</td>
</tr>
<tr>
<td>EW13: PhD level engineering work is interesting and stimulating.</td>
<td>.572</td>
</tr>
<tr>
<td>EPC10: A PhD in engineering seems like a needless investment to me.</td>
<td>.499</td>
</tr>
<tr>
<td>EW8: I believe engineers with a PhD are innovative thinkers.</td>
<td>.518</td>
</tr>
<tr>
<td>EW10: Engineers with a PhD have more freedom to choose the projects they work on.</td>
<td>.458</td>
</tr>
<tr>
<td>EW7: A bachelor’s degree in engineering is all that I need to get any job I want.</td>
<td>-.443</td>
</tr>
<tr>
<td>EPC6: I would delay taking a good job in order to get the education necessary for the career I want.</td>
<td>.417</td>
</tr>
<tr>
<td>EW12: Engineers with a PhD are highly sought after for their skills in certain specialized fields.</td>
<td>.379</td>
</tr>
<tr>
<td>EW5: In order to get a good job I need to continue my education beyond a bachelor’s degree.</td>
<td>.379</td>
</tr>
<tr>
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<td>.367</td>
</tr>
<tr>
<td>EW9: A PhD may be the only way for a person to obtain the specific career he/she desires.</td>
<td>.364</td>
</tr>
<tr>
<td>EPC2: I would be willing to make less money in the short term in order to work in a career I find rewarding.</td>
<td>.305</td>
</tr>
<tr>
<td>EW14: I can do the same kind of work with a bachelor’s degree that an engineer with a PhD can do.</td>
<td>-.301</td>
</tr>
</tbody>
</table>

Extraction Method: Principal Axis Factoring.
Rotation Method: Varimax with Kaiser Normalization.
Appendix K: 4-factor EFA solution with all 72 items

<table>
<thead>
<tr>
<th>Cumulative variance explained: 27.275</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
</tr>
<tr>
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</tr>
<tr>
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</tr>
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</tr>
<tr>
<td>IE9: I have worked closely with a professor on a research project.</td>
</tr>
</tbody>
</table>
Interest in the Engineering PhD 214

EE9: I know what it would take to get admitted to a PhD program. -.414 .367
EPC9: The debt I have incurred for my bachelor's degree is a consideration in whether I would pursue a PhD. .397
IE5: I know people who are pursuing or have a PhD in engineering. -.391 .373
EW3: I understand the kind of work that engineers with PhDs do. -.378 .371
IE4: My peers are more interested in getting a good job than earning a PhD. .353 .317
PC2: I am intimidated by the thought of writing a dissertation. .352
IE7: Not many of my friends are thinking about earning a PhD. .345
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EE7: My classes have helped me to develop my critical thinking skills. .565
IE15: A professor has taken interest in my future plans or career aspirations. -.329 .562
IE13: Professors have discussed earning a PhD as an option in one or more of my classes. -.313 .557
IE10: Professors have described the importance of the PhD in the engineering field. .544
IE18: Professors in my undergraduate program encouraged me to pursue a PhD in engineering. -.367 .523
EE12: In general, engineering courses provide a lot of "hands on" experience. .509
EE2: I have had a lot of experience with problem solving in my engineering classes. .479
EE3: Engineering clubs/organizations are helpful in finding career information. .456
EE13: My undergraduate program includes seminars/workshops about graduate school. .453
IE16: A professor has shared his/her career path with me. .420
EE14: Resources and support in finding an internship/co-op are readily available at my undergraduate program. .378
EE8: There are opportunities to conduct research in my undergraduate program. .367
PC8: I have clear career goals. .341
PC10: I have had enough experience to know what kind of work I want to do. .320
EE4: My undergraduate program is geared towards helping me get a good job after graduation. .309
IE8: I think engineering is a prestigious career regardless of the educational level. .303
IE3: My family encouraged me to pursue a bachelor’s degree in engineering.
EPC12: I could work full-time while earning a PhD part-time.
PC3: I consider myself a good problem solver. .609
PC9: I feel confident in my academic abilities. .309 .592
PC4: I am smart enough to complete a PhD. .564
PC5: I love to learn new things. .527
PC1: I am a naturally curious person. .516
PC6: My GPA is good enough to get admitted to a PhD program. .494
PC7: I know how to motivate myself to get things done. .419
IE1: My family would support me pursuing a PhD in engineering. .373
EPC6: I would delay taking a good job in order to get the education necessary for the career I want. .365
EPC11: I would consider graduate school if my employer paid for it. .334 .351
EE5: Graduate school classes focus more on specific topics than undergraduate classes. .331
EW5: In order to get a good job I need to continue my education beyond a bachelor’s degree.

Extraction Method: Principal Axis Factoring.
Rotation Method: Varimax with Kaiser Normalization.
## Appendix L: Rationales for Deleting Items

<table>
<thead>
<tr>
<th>Item</th>
<th>Rnd</th>
<th>Statistical reason</th>
<th>Theoretical Reason</th>
</tr>
</thead>
<tbody>
<tr>
<td>EE1: I feel burned out by the amount of work required by the undergraduate engineering curriculum.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE10: No one at my undergraduate program ever talked about earning a PhD as a possibility.</td>
<td>1</td>
<td>low loading</td>
<td>confusing</td>
</tr>
<tr>
<td>EE11: The amount of time I would have to put into a PhD would be overwhelming for me.</td>
<td>1</td>
<td>cross-loadings</td>
<td>pseudo double barreled</td>
</tr>
<tr>
<td>EE14: Resources and support in finding an internship/co-op are readily available at my undergraduate program.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE15: Graduate school classes are just like undergraduate classes, only a lot more work.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE4: My undergraduate program is geared towards helping me get a good job after graduation.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE5: Graduate school classes focus more on specific topics than undergraduate classes.</td>
<td>1</td>
<td>low item</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE6: I think earning a PhD is even harder than earning a bachelor’s degree in engineering.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE9: I know what it would take to get admitted to a PhD program.</td>
<td>1</td>
<td>cross-loadings</td>
<td>confusing</td>
</tr>
<tr>
<td>EW12: Engineers with a PhD are highly sought after for their skills in certain specialized fields.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EW13: PhD level engineering work is interesting and stimulating.</td>
<td>1</td>
<td>cross-loadings</td>
<td>pseudo double barreled</td>
</tr>
<tr>
<td>EW3: I understand the kind of work that engineers with PhDs do.</td>
<td>1</td>
<td>cross-loadings</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EW5: In order to get a good job I need to continue my education beyond a bachelor’s degree.</td>
<td>1</td>
<td>low item</td>
<td>big qual topic</td>
</tr>
<tr>
<td>EW9: A PhD may be the only way for a person to obtain the specific career he/she desires.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EPC10: A PhD in engineering seems like a needless investment to me.</td>
<td>1</td>
<td>cross-loadings</td>
<td>pseudo double barreled</td>
</tr>
<tr>
<td>EPC11: I would consider graduate school if my employer paid for it.</td>
<td>1</td>
<td>cross-loadings</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EPC12: I could work full-time while earning a PhD part-time.</td>
<td>1</td>
<td>low item</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EPC13: I would have to continue to put my life on hold if I pursued a PhD.</td>
<td>1</td>
<td>cross-loadings</td>
<td>big qual topic</td>
</tr>
<tr>
<td>EPC2: I would be willing to make less money in the short term in order to work in a career I find rewarding.</td>
<td>1</td>
<td>low item</td>
<td>speculation</td>
</tr>
<tr>
<td>EPC3: I am aware of the funding opportunities such as fellowships and assistantships that pay for PhD programs.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EPC6: I would delay taking a good job in order to get the education necessary for the career I want.</td>
<td>1</td>
<td>low loading</td>
<td>speculation</td>
</tr>
<tr>
<td>IE1: My family would support me pursuing a PhD in engineering.</td>
<td>1</td>
<td>low loading</td>
<td>pseudo double barreled</td>
</tr>
<tr>
<td>IE3: My family encouraged me to pursue a bachelor’s degree in engineering.</td>
<td>1</td>
<td>low item</td>
<td>not helpful information</td>
</tr>
<tr>
<td>IE4: My peers are more interested in getting a good job than earning a PhD.</td>
<td>1</td>
<td>cross-loadings</td>
<td>not big qual topic</td>
</tr>
<tr>
<td>IE5: I know people who are pursuing or have a PhD in engineering.</td>
<td>1</td>
<td>cross-loadings</td>
<td>wrong section</td>
</tr>
<tr>
<td>Item</td>
<td>Rnd</td>
<td>Statistical reason</td>
<td>Theoretical Reason</td>
</tr>
<tr>
<td>---------------------------------------------------------------------</td>
<td>-----</td>
<td>--------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>IE6: Family responsibilities would make it difficult for me to pursue a PhD in engineering.</td>
<td>1</td>
<td>low loading</td>
<td>not relevant</td>
</tr>
<tr>
<td>IE7: Not many of my friends are thinking about earning a PhD.</td>
<td>1</td>
<td>low loading</td>
<td>not big qual topic</td>
</tr>
<tr>
<td>IE8: I think engineering is a prestigious career regardless of the educational level.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>IE9: I have worked closely with a professor on a research project.</td>
<td>1</td>
<td>cross-loadings</td>
<td>wrong section</td>
</tr>
<tr>
<td>PC10: I have had enough experience to know what kind of work I want to do.</td>
<td>1</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>PC2: I am intimidated by the thought of writing a dissertation.</td>
<td>1</td>
<td>low loading</td>
<td>big qual topic</td>
</tr>
<tr>
<td>PC7: I know how to motivate myself to get things done.</td>
<td>1</td>
<td>low loading</td>
<td>not big qual topic</td>
</tr>
<tr>
<td>PC8: I have clear career goals.</td>
<td>1</td>
<td>low loading</td>
<td>not big qual topic</td>
</tr>
<tr>
<td>EE7: My classes have helped me to develop my critical thinking skills.</td>
<td>2</td>
<td>cross-loadings</td>
<td>pseudo double barreled</td>
</tr>
<tr>
<td>EW10: Engineers with a PhD have more freedom to choose the projects they work on.</td>
<td>2</td>
<td>low loading</td>
<td>not relevant</td>
</tr>
<tr>
<td>EW8: I believe engineers with a PhD are innovative thinkers.</td>
<td>2</td>
<td>cross-loadings</td>
<td>not helpful information</td>
</tr>
<tr>
<td>IE11: In general, engineers in industry encourage earning a PhD in engineering.</td>
<td>2</td>
<td>cross-loadings</td>
<td>pseudo double barreled</td>
</tr>
<tr>
<td>IE2: I believe engineers with PhDs are essential for the future of our society.</td>
<td>2</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE12: In general, engineering courses provide a lot of “hands on” experience.</td>
<td>3</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE2: I have had a lot of experience with problem solving in my engineering classes.</td>
<td>3</td>
<td>low loading</td>
<td>not helpful information</td>
</tr>
<tr>
<td>EE3: Engineering clubs/organizations are helpful in finding career information.</td>
<td>3</td>
<td>low loading</td>
<td>not big qual topic</td>
</tr>
<tr>
<td>EW14: I can do the same kind of work with a bachelor’s degree that an engineer with a PhD can do.</td>
<td>3</td>
<td>low loading</td>
<td>big qual topic</td>
</tr>
<tr>
<td>IE16: A professor has shared his/her career path with me.</td>
<td>3</td>
<td>low loading</td>
<td>not relevant</td>
</tr>
<tr>
<td>EW2: Earning a PhD in engineering would reduce my employment opportunities.</td>
<td>4</td>
<td>mod indicies</td>
<td>w/in factor correlation</td>
</tr>
<tr>
<td>EW7: A bachelor’s degree in engineering is all that I need to get any job I want.</td>
<td>4</td>
<td>low loading</td>
<td>big qual topic</td>
</tr>
<tr>
<td>IE12: A Professional Engineering license is more valued by industry than a PhD.</td>
<td>4</td>
<td>low loading</td>
<td>not big qual topic</td>
</tr>
<tr>
<td>EE8: There are opportunities to conduct research in my undergraduate program.</td>
<td>5</td>
<td>low item</td>
<td>wrong section</td>
</tr>
<tr>
<td>EPC14: I would have to give up having fun and having a social life if I worked towards a PhD.</td>
<td>6</td>
<td>cross-loadings</td>
<td>pseudo double barreled</td>
</tr>
<tr>
<td>PC1: I am a naturally curious person.</td>
<td>6</td>
<td>mod indicies</td>
<td>w/in factor correlation</td>
</tr>
</tbody>
</table>
Appendix M: Validated Exploring Engineering Interest Inventory

Page 1: Background Information
Thank you for agreeing to share your opinions about engineering education program

Please honestly answer the questions based on your beliefs and experience. We realize you may not have thought about these topics or had all of these experiences and that is ok – we are trying to understand the range of experiences and impressions engineering students have had regarding these issues.

Are you a US Citizen or Permanent Resident? (*REQUIRED RESPONSE)
Yes
No

What year are you?
Freshman
Sophomore
Junior
Senior
Super Senior/5th Year Senior

What is your major?
Aerospace Engineering
Agricultural Engineering
Architectural Engineering
Bioengineering
Biological Systems Engineering
Biomedical Engineering
Chemical Engineering
Civil Engineering
Computer Engineering
Construction Engineering
Construction Management
Electrical Engineering
Engineering Mechanics
Engineering Physics
Environmental Engineering
Industrial Engineering
Manufacturing Engineering
Materials Engineering
Mechanical Engineering
Nuclear Engineering
Optical Engineering
Software Engineering
Telecommunications Engineering
Undeclared Engineering
Not Engineering
Other Engineering

In what year do you plan to receive your bachelor’s degree?
2011
2012
2013
2014
2015 or beyond
Interest in the Engineering PhD

Page #2 Engineering Environment
(Scale: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, Strongly Disagree; All items randomized across factors)

Personal Characteristics (PC)
1. I feel confident in my academic abilities.
2. I am smart enough to complete a PhD.
3. I consider myself a good problem solver.
4. My GPA is good enough to get admitted to a PhD program.
5. I love to learn new things.

Educational Environment (EE)
6. Professors have described the importance of the PhD in the engineering field.
7. Professors in my undergraduate program encouraged me to pursue a PhD in engineering.
8. Professors have discussed earning a PhD as an option in one or more of my classes.
9. A professor has taken interest in my future plans or career aspirations.
10. My undergraduate program includes seminars/workshops about graduate school.

Engineering Work (EW)
11. Earning a PhD in engineering would limit my career possibilities to a few specialized positions.
12. For me, engineers with PhDs do not do “real” engineering work.
13. The only thing you can do with a PhD in engineering is become a professor.
14. I think people with a PhD in engineering are overqualified for most engineering jobs.
15. I think engineers with a PhD mainly do theoretical research and development.
16. There are few engineers who have earned a PhD working in industry.
17. On the job training is more important than a PhD in terms of career opportunities.

Economic and Personal Costs (EPC)
18. I would need to take out loans to pay for a PhD.
19. I think PhD programs are expensive.
20. I think it would be financially difficult to start a family while working towards a PhD.
21. I would be unable to make a major purchase (such as a car or house) if I were a full-time graduate student.
22. The debt I have incurred for my bachelor’s degree is a consideration in whether I would pursue a PhD.
23. Balancing school, work and family time would be a factor in considering a PhD.
Page #3 Engineering Experience (EXP)  
(Scale: Yes, No)  
I have attended a graduate school workshop.  
I have participated in a graduate school preparation program, such as McNair, LSAMP, REU or others.  
I have participated in undergraduate research.  
I have participated in an engineering internship or co-op.  
I have worked as an undergraduate teaching assistant.  
I have lead study groups.  
I have tutored others formally or informally.  
I have assisted with grading.  
I have attended a graduate school fair to meet recruiters or professors from graduate programs.  
I have interacted with engineering graduate students.  

Page 4: Engineering Interest  
What degrees have you CONSIDERED or thought about pursuing? (*REQUIRED RESPONSE)  
Master’s degree in engineering field  
Doctorate or PhD in engineering field  
MBA  
Master’s degree in other field (not engineering or business)  
Doctorate or PhD in other field  
Other advanced degree (law, medicine, etc.)  
None of the above  

What degree(s) do you PLAN to pursue/complete?  
Master’s degree in engineering field  
Doctorate or PhD in engineering field  
MBA  
Master’s degree in other field (not engineering or business)  
Doctorate or PhD in other field  
Other advanced degree (law, medicine, etc.)  
None of the above  

How likely are you to pursue a MASTER’S DEGREE in engineering?  
Very likely  
Somewhat likely  
Somewhat unlikely  
Very unlikely  

How likely are you to pursue a PhD in engineering?  
Very likely  
Somewhat likely  
Somewhat unlikely  
Very unlikely
Page #5: Demographic Information
What is the highest level of education completed by your parents or guardians?
- Some high school
- High school graduate
- Some college
- Two-year college degree
- Four-year college degree
- Some graduate or professional school
- Graduate or professional degree
- Doctorate or PhD

Growing up, was there anyone important to you who had earned a PhD in any field?
- Yes
- No

What is your gender?
- Male
- Female
- Transgender

Are you Hispanic/Latino?
- Yes, Hispanic/Latino
- No, not Hispanic/Latino

Race (choose one or more, regardless of ethnicity status selected above)
- American Indian or Alaska Native
- Asian
- Black or African American
- Native Hawaiian or Other Pacific Islander
- White

Have you ever been eligible for a federal Pell Grant?
- Yes
- No
- Don’t Know

Page #6 Survey End and Thank You
Thank you for being willing to share your perceptions about engineering education. If you have any questions about this study or have additional feedback, you may contact us at NSFEngineeringStudy@gmail.com.

Please click on the "Done" button below to submit your responses and end the survey. Thank you.
Interest in the Engineering PhD

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