What Competencies Should Undergraduate Engineering Programs Emphasize?
A Dilemma of Curricular Design that Practitioners' Opinions Can Inform

by

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CHAPTER 1. THE PROBLEM IN CONTEXT

Designing a curriculum is a multifaceted challenge. In each academic program, issues concerning implementation of the curriculum plan must be considered simultaneously with questions about *what competencies students should have upon graduation* and *what the relative emphasis should be among those competencies*. In academic programs that prepare students for a profession, such as medicine, law, or engineering, the curriculum will ideally develop some of the competencies that are imperative for professional success. Although faculty often practice professionally in addition to teaching, their experience cannot reflect the full diversity of the environments, or settings, in which their graduates will practice the profession. Thus, faculty who design curricula for any profession can be informed by practitioner opinions about which competencies are important for professional practice and what the relative emphasis should be among them.

In the profession of engineering, undergraduate programs must demonstrate that their graduates have achieved eleven ‘program outcomes’, or competencies, that were first required in 2001-02 by ABET, the U.S. accrediting agency for engineering programs (Appendix A). This focus on outputs (competencies achieved by students) completely replaces ABET’s focus on inputs (such as topics taught) from 1932 to 2000. This is a transformational change of the type that Kuhn (1962) called a “paradigm shift”.

As a result, each engineering program faces questions about relative emphasis among those competencies, such as “How important is the ability to work on a multidisciplinary team relative to the ability to design experiments?” This research informs faculty decisions about relative emphasis among competencies by analyzing the opinions of engineering graduates. These opinions come from over 10,000 engineering graduates who rated the relative importance of various competencies in their work. The patterns of their ratings are explored, including differences by undergraduate major and by type of work after graduation.

This study intends to identify engineering graduates' answers to two questions related to engineering education:

- *Which competencies are important for professional practice?* and
- *What should the relative emphasis be among them?*

It presents data to support decisions by engineering faculty as they design undergraduate curricula, also known as undergraduate programs. The need for such data arose from a paradigm shift in higher education that has been promulgated by quality assurance bodies worldwide, such as accreditation agencies. This study has implications for other professions and disciplines through its contribution to theory in curriculum design.

1.1 The Problem: Greater Demands on Professors

Faculty in higher education, worldwide, are in the midst of a culture change, by Berquist's (1992) definition of culture. They are adapting to a paradigm shift regarding teaching. Today's faculty were educated within one paradigm, the *instruction* paradigm, and are now increasingly required to teach under a new paradigm, the *learning* paradigm.

> A paradigm shift is taking hold in American higher education. In its briefest form, the paradigm that has governed our colleges is this: A college is an institution that exists *to provide instruction*. Subtly, but profoundly we are shifting to a new paradigm: A college is an institution that exists *to produce learning*. This shift changes everything. (Barr & Tagg, 1995, p. 13 [emphasis in the original])

The Association for American Colleges and Universities (2002) discusses the changes:

> Focusing education on learning should not be a radical concept for schools and colleges. But in fact, if taken seriously, the new paradigm implies important and far-reaching changes in the practices of American higher education. It means, first of all, turning upside-down a basic premise: that colleges exist to teach. Colleges would be seen, rather, as providing the opportunities for students to learn. In learning-centered education, the focus becomes the student rather than the professor, with success determined by how well students achieve the desired learning goals. Ironically, increased attention to student learning entails an expanded repertoire of good teaching practices. (p. 21)

The two paradigms imply remarkably different roles for faculty. For example, in the dominant *instruction* paradigm, "there is often little collective work on the curriculum. Rather, courses 'belong' to a professor who exercises exclusive control over their content" (Pazandak, 1989, p. 18). By contrast, the newer *learning* paradigm "revive[s] the responsibility of the faculty *as a whole* for the curriculum *as a whole*" (Association of American Colleges, 1990, p. 8 [authors' emphasis]). Considering this paradigm shift through the lens of Stark and Lattuca's (1997) theory for curriculum design, the shift in engineering accreditation is a shift from stipulating content to stipulating specific purposes, i.e., prescribed outcomes and a competency focus. In other words, the former criteria dictated "how the curriculum should be developed or designed" (Stark & Lowther, 1986a, p. 104). The current criteria dictate "what the curriculum should be" (p. 104), leaving curriculum design to the discretion of the faculty.

The competency focus strongly influences curriculum design.

> An intellectual skills [or competency] approach changes the way we think about the structure of the curriculum, the way we think about teaching and assessing our students, and the way we relate as educators across levels of education….Instead of asking ourselves what subject matter we are going to teach to our students, we would need to ask instead how the unique aspects of our disciplines make them appropriate frameworks to help students develop the knowledge and intellectual skills they need….In addition to expanding the teaching and learning of intellectual skills to all courses in the educational spectrum, a skills emphasis would allow us to conceptualize integration and coherence in the curriculum in new ways. There would be the potential for better vertical integration of beginning-, intermediate-, and advanced-level courses within a discipline….There would also be the possibility of a more meaningful horizontal integration of the various disciplines in higher education for the common purpose of preparing students for personal, occupational, and civic life. (Doherty, Chenevert, Miller, Roth, & Truchan, 1997, p. 176-177)

Consequently, a competency focus "has significant implications for what knowledge and skills faculty need" (Doherty et al., 1997, p. 182). Drawing on my experience in human performance technology, I identified six competencies that faculty need in order to implement the learning paradigm. Specifically, faculty need:

- The ability to envision, collectively articulate, and prioritize the learning outcomes that students should gain from the educational program before they graduate. While doing this, faculty must consider graduates' myriad career paths, many of which go beyond most faculty members' personal experience.
- The ability to collectively design a program of study (design a curriculum) that will facilitate students' development of the intended learning outcomes.
- The ability to facilitate students' development of the learning outcomes (teaching as facilitation of learning rather than coverage of topics) through specific educational experiences, such as courses and internships, and also through interconnections through different aspects of the educational program.

- The ability to design and interpret assessments of student's achievements in each of the intended learning outcomes.
- The ability to use assessment information to assist each individual student in achieving the intended learning outcomes.
- The ability to triangulate assessment information from various sources to evaluate the educational program, to work collectively to improve the program (that is, to increase students' ability to achieve the intended learning outcomes), and to document these efforts convincingly. Quality assurance bodies, such as accreditation agencies, require program improvement based on assessment data.

These six abilities are essential for adopting and implementing the learning paradigm. Yet, few mechanisms are in place to help faculty develop them. This study provides information to support the first faculty competency: the ability to envision, collectively articulate, and prioritize program learning outcomes that will prepare graduates for a myriad of career paths. These results add to the knowledge base on how engineering graduates use their undergraduate learning in life and work, which will support decisions about the purpose of and emphasis in the curriculum.

1.2 The Context: Forces in Higher Education

1.2.1 The Worldwide Context of Quality Assurance

Around the world, higher education's quality assurance bodies – such as accreditation agencies in the U.S. – are changing their requirements from the instruction paradigm to the learning paradigm. Specifically, the quality assurance bodies are requiring programs to state intended learning outcomes for each educational program and demonstrate that students achieve the stated outcomes (e.g., Barrie, 2006; Westerheijden, Brennan, & Maasen, 1994). In short, the trend is toward defining competence and assessing competence. Note that the requirement that competencies must be assessed actually restricts the competencies that can be selected to those that are "assessable".

In the U.S., the requirement to define and assess outcomes has been regulated by the 1988 reauthorization of the Higher Education Act (Committee on Health Education Labor and Pensions -- United States Senate, 2004). In parallel, professions in the U.S. have moved their licensure requirements to assess *continuing competence* rather than aptitude (Houle, 1980; Larson, 1983; Office of the Professions, 2000; Pottinger & Goldsmith, 1979). In higher education, the shift toward assessing student learning is an increase of external control over the design of curriculum (Fagan & Wells, 2000; Selden, 1960; Young, 1983). When accreditation requires assessment of student learning, it moves toward defining what students should learn and, to some extent, how student achievement will be measured. Thus, accreditation that specifies student learning outcomes, as ABET does, is a dominant constraint on curriculum design.

ABET has "moved from a quality assurance process based on evaluating program characteristics relative to minimum standards to one based on evaluating and improving the intellectual skills and capabilities of graduates" (Prados, Peterson, & Lattuca, 2005, p. 169). The former inputs-focused requirements (instruction paradigm) discouraged engineering faculty from developing their curriculum design skills. ABET's shift to outputs-focused criteria (learning paradigm) requires faculty 1) to adopt the learning paradigm, 2) to adopt a new paradigm for the nature of engineering expertise, and 3) to develop new skills to both a) re-design their curriculum to external specifications and b) demonstrate through assessment that graduates achieve those outcomes.

Because ABET has been an international leader for two decades, a growing number of countries have adopted outcomes-based quality assurance for engineering education (e.g., Prados et al., 2005; Washington Accord, 2005). The seven outcomes in the international list are an adapted subset of ABET's Criterion 3a-k. In short, engineering faculty worldwide face similar curricular design challenges, including determining, for their academic program, the ideal emphasis among the eleven intended learning outcomes that ABET prescribes. Thus, ABET's accreditation criteria constrain curriculum design in engineering programs worldwide, in Australia, Canada, Germany, Hong Kong, India, Ireland, Japan, Korea, Malaysia, New Zealand, Russia, Singapore, Sri Lanka, South Africa, Taiwan, the United Kingdom, and the United States (International Engineering Alliance, 2008).

Specifically, engineering programs in many countries are required to 1) adopt ABET's list of specified learning outcomes (or a subset), 2) use the outcomes for establishing curriculum content, and 3) assess student learning in each of the eleven outcomes (Prados et al., 2005). The details of the new criteria are also radically changed. First, they require that graduates demonstrate specific *competencies* in ABET's traditional areas (as opposed to the former "coverage" requirements for assorted bodies of knowledge). Second, they add four entirely new competencies. Third, they require that engineering faculty be responsible for the competencies gained even in humanities and social science courses taught by other departments. (Details are in Appendix A). In other words, the current criteria require faculty to design and implement curricula that help students achieve *prescribed* learning outcomes – what Stark and Lattuca (1997) call 'purpose' – but ABET leaves all other curriculum design decisions to program faculty.

These are fundamental challenges for faculty, challenges that go far beyond what accreditation requires medical educators to do. Medical accreditors require programs to move to the learning paradigm, then "say what you do and do what you say". Medical accreditors leave the choice of competencies to the faculty (Liaison Committee on Medical Education, 2007). In fact, *ABET's requirements embody a paradigm shift in what constitutes engineering expertise*. The shift is from the "theory and general principles" perspective of engineering expertise that dominated from 1950-2000 to a combination of all four of Kennedy's (1987) perspectives on expertise: "theory and general principles", "specialized skills", "critical analysis", and "deliberate action".

1.2.2 The Origins of ABET's Program Outcomes (Criterion 3a-k)

According to George Peterson, executive director of ABET, a confluence of events occurred in the early 1990's (personal communication, May 5, 2005). First, ABET's president, John Prados, became increasingly dissatisfied with ABET's inputs-oriented accreditation paradigm. Second, the engineering deans of 'The Big Ten Plus' protested ABET's minutely detailed (and therefore restrictive) curricular requirements. Third, The Boeing Company set forth a list of skills and attitudes they deemed essential for practicing engineers. These combined events sparked a spirit of innovation and a torrent of national meetings and workshops involving practicing engineers, engineering faculty, and engineering administrators in industry, government, and academia (Prados et al., 2005). Several reports distilled the discussions, for example:

> It is now widely believed that for several decades too much emphasis was placed on engineering science (analysis) at the expense of design (creative synthesis) and other aspects of the practice of engineering. Notwithstanding that students need a solid foundation in basic mathematics and physical science to formulate and solve problems, they also need much more exposure to the practice aspects of engineering. (National Research Council, 1995, p. 21)

Following the workshops, an *ad hoc* ABET committee drafted new criteria, drawing heavily from three key source documents. Personal communications with John McMasters (March 21, 2006) and John Prados (March 31, 2006) identified the key source documents for the EC2000 criteria: the Boeing List of "Desired Attributes of an Engineer" (McMasters & Komerath, 2005), a list composed by two ASEE committees (American Society for Engineering Education, 1994), and a report by the National Research Council (National Research Council, 1995). ABET's committee attempted to create *measurable outcomes* inspired by the key source lists (personal communication with G. Peterson, May 5, 2005). An additional aim was to allow programs creative freedom in designing curricula, moving away from the homogenization that had been fostered under the previous criteria.

My own comparison of ABET's Criteria 3a-k with the lists in the source documents confirmed the substantial agreement with the source lists. I also identified a number of concepts in the three source lists that are not represented in ABET's criteria: business practices (3 lists), systems perspective (2 lists), incorporation of engineering practice into the curriculum (2 lists), and several ideas present in only one of the lists – types of communication (written, oral, graphic, and listening), history, customer needs, flexibility, leadership, appreciation of different cultures, the concept of engineers as decision makers, integration of knowledge throughout the curriculum, and commitments to quality, to timeliness, and to continuous improvement.

In October 1995, ABET adopted a short set of criteria requiring that engineering programs demonstrate – through assessment – that their graduates achieve the learning outcomes specified in Criterion 3 a-k (Prados et al., 2005). Minor revisions have been made since then. The current criteria appear in Appendix A.

This description of the origins of ABET's program outcomes clearly shows that they express the 1990's influences of engineers in industry, government, and academia. In short, *ABET's program outcomes resulted from sincere effort to voice the collective* *values of the engineering profession*. It appears that the outcomes may still express collective opinion. In mid-2004, a national survey of 1,622 engineers who have evaluated recent engineering graduates for at least seven years asked how important the ABET program outcomes are for new engineering graduates. Seventy percent rated all eleven outcomes as at least moderately important, and sixty percent rated nine of the outcomes as highly important or essential for new hires (Lattuca, Terenzini, & Volkwein, 2006). In a similar manner, results of my study can be used to further explore the enduring importance of ABET's program outcomes.

1.3 Addressing the Problem: Supporting Faculty Decisions

Due to regulation in countries worldwide, engineering faculty face a double paradigm shift. The implications are twofold. Teaching has changed drastically, from the instruction paradigm to the learning paradigm. In addition, quality assurance (or accreditation) requirements embody a paradigm shift in what constitutes engineering expertise, which also has profound implications for curriculum design.

Unfortunately, neither tradition nor training has prepared engineering faculty to design curricula, especially curricula that include new competencies. Engineering faculty need training in curriculum design *and* information to support their curricular design decisions. With such skills and knowledge, engineering faculty may be able to apply their design proficiency – honed in the engineering context – to designing curriculum in the educational context. This study provides information to support faculty decisions about the purposes of the curriculum and the relative emphasis among various purposes, information about 10,000 engineering graduates' answers to the questions: *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?*

CHAPTER 2. THEORY AND LITERATURE

Designing a curriculum is a multifaceted challenge. In addition to issues of implementation and assessment of programmatic outcomes, curriculum designers consider questions of purpose for their academic program, such as "what competencies should students have at graduation?" and "what should the relative emphasis be among those competencies?" These are the research questions in this study.

Theoretical and empirical literature undergird this study. For two reasons, I have restricted the scope of my empirical review to studies published since 1990. First, "by 1990, it was widely recognized that students … [in science, mathematics, and engineering programs] required broader training than they were receiving" (Meier, Williams, & Humphreys, 2000, p. 377). Pertinent evidence of this recognition is ABET's widely supported effort to transform their accreditation requirements starting around 1990.   Second, engineers' professional roles have changed. Since around 1990, the role of cold-war defense-related engineering has declined and the role of engineering in a global economy has increased (e.g., Coles & Vest, 1995; Lang, Cruse, McVey, & McMasters, 1999). With this change in roles, the competencies required of engineers have changed dramatically. Thus, *apparently* related studies published before 1990 (e.g., Bakos, 1986; Chrisman, 1987; Grubbs, 1986; Kimmel & Monsees, 1979; Mailloux, 1989) are not considered truly related because of changes in context.

An exhaustive review of theoretical and empirical literature led to four points: 1) importance ratings among competencies depend on practice setting, 2) there are important competencies for engineering graduates beyond ABET's list, 3) engineering faculty's ratings differ from practicing engineers' ratings, and 4) importance ratings depend on survey wording. This chapter interweaves sources to make these points. At the end, I frame the research questions: *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?*

2.1 Defining “Competency” and “Expertise”

Competency has been defined differently by different communities. Some have defined it narrowly in the context of a specific job either as task skills (National Institute of Adult Continuing Education, 1989) or as underlying characteristics that result in effective performance (Klemp, 1980). A holistic definition was developed at Alverno College, well known for its competency-based liberal arts curriculum (Hutcheson, 1997). Alverno’s definition includes knowledge, skills, abilities, attitudes, values, motivations, strategies and other characteristics that enable effective performance (Mentkowski & Associates, 2000). They define the performance context as work, personal, and civic life, implying – but not stating – the complexity of those situations. Their definition echoes elements of “competency” that are discussed by other scholars (e.g., Bemis, Belenky, & Soder, 1983; Ghorpade, 1988; Heywood, 2005; Whetzel, Steighner, & Patsfall, 2000).

In my opinion, Alverno’s definition is a solid foundation, needing three changes. First, their implied complexity of performance situations needs to be explicit. Second, Alverno implies that performance cannot be assessed solely on the basis of pencil-and-paper tests, and this should be explicit. Critics of the competency concept often cite professional licensure exams as a contrived and oversimplified context for demonstrating performance (e.g., Curry & Wergin, 1997). Third, performance is insufficiently defined, though Alverno’s discussion clearly encompasses effective action and discretion as do thinkers in professional education (e.g., Curry & Wergin, 1997; Kennedy, 1987). My definition, based on Alverno’s, incorporates these three enhancements.

By *competencies*, I mean *the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action), in complex and uncertain situations such as professional work, civic engagement, and personal life*.[1] Using this definition, knowledge includes all the types of knowledge defined by Anderson, et al.’s (2001) taxonomy: *factual knowledge* (terminology and details), *conceptual knowledge* (classifications, principles, theories, and

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[1] My definition draws on the scholarly description of competency and performance by the faculty of Alverno College (Marcia Mentkowski and Associates, 2000) and other international leaders in the field of competency-based (also called ability-based) higher education (e.g., Heywood, 2005; Hutcheson, 1997). My definition includes language from the field of industrial psychology (e.g., Bemis et al., 1983; Ghorpade, 1988; Whetzel et al., 2000) and higher education for the professions (Curry & Wergin, 1997).

models), *procedural knowledge* (knowing both how and when to use specific skills and methods), and *meta-cognitive knowledge* (self-knowledge and both how and when to use cognitive strategies for learning and problem-solving).

In my study, competencies, and the related term "learning outcomes", are actual skills and abilities that graduates demonstrate at the end of their undergraduate program. Competencies are entirely different from what subjects are taught and the amount of class time spent on each subject, which have also been studied for the practical purpose of improving curricula (e.g., Keenan, 1993). I make the assumption that competencies, as opposed to educational credentials alone, are the foundation of successful professional practice throughout a career, an assumption shared with agencies that grant licenses for individuals to practice professions (e.g., Continuing Professional Education Development Project (University of Pennsylvania), 1981; Houle, 1980; Larson, 1983; Office of the Professions, 2000; Pottinger & Goldsmith, 1979).

By *expertise*, I mean *the proficient coordination of multiple competencies that leads to consistently effective performance in a variety of unique, complex, and uncertain situations*. This definition draws on cognitive science (e.g., Ericsson & Smith, 1991) and is echoed in literature on expertise in the professions (e.g., Curry & Wergin, 1997; Kennedy, 1987). In my study, expertise is the holistic combination of assorted competencies and is an ultimate goal of professional education and lifelong learning.

2.2 Importance Ratings Depend on Practice Setting

A dominant idea in theory and literature is that the importance of various competencies depends strongly on the practice setting. That is, different academic disciplines and work environments require different competencies and different emphasis among them.

2.2.1 Holland's Theory

According to Holland's (1997) theory a person is most likely to flourish in an environment that matches their personality, which is called person-environment fit or the *person-environment congruence* assumption. A person in a congruent environment will have the opportunity to engage in roles and tasks where they can use their strongest competencies and engage in activities they value. At the same time, a congruent environment allows a person to "avoid…activities they dislike, …demands for competencies they lack, …tasks and self-images they do not value, and…situations in which their personality types are not encouraged" (Holland, 1997, p. 56). This assumption of person-environment fit, or congruence, is based on the idea that people's personalities can be classified by distinctive patterns of competencies, values, and interests. Similarly, a work or school environment can be classified by its distinctive pattern of the activities that are preferred, the competencies that are developed, the self-perceptions that are encouraged, the values and personal styles that are cultivated, and the behaviors that are rewarded. In short, an environment can be classified by the competencies, values, and interests that it requires, reinforces, and rewards. Holland's environments are very specific: His dictionary includes over 15,000 occupations (Gottfredson & Holland, 1996). For example, there are six entries under "Sales engineer" having a total of three different occupational codes.

The congruence assumption has two consequences: 1) that people who are congruent with their environment are more likely to experience vocational or educational stability, satisfaction, and achievement or success; and 2) that people who are not congruent with their environment are more likely to experience vocational or educational instability, dissatisfaction, and low performance (Smart, Feldman, & Ethington, 2000).

In addition to *congruence*, Holland's theory makes two other assumptions: *self-selection* and *socialization*. The self-selection assumption states that individual people search for and select school and work environments that are congruent with their personality characteristics, such as their competencies and values. The socialization assumption states that an environment requires, reinforces, and rewards the personality characteristics (e.g., competencies and values) of the people who dominate it. Specifically, the members of the environment bring about socialization by 1) stimulating individuals to engage in activities that are valued in the environment, 2) fostering the distinctive competencies that are required in the environment, and 3) reinforcing the environment's preferred values by a) encouraging perspectives and self-images consistent with the values and b) rewarding the display of the preferred values (Smart et al., 2000).

Holland's theory was developed to predict and explain vocational behavior. Hundreds of studies have tested the theory, and the pooled findings have been examined in meta-analyses and review articles (Assouline & Meir, 1987; Holland, 1985, 1997; Spokane, 1985; Spokane, Meir, & Catalano, 2000; Tranberg, Slane, & Ekeberg, 1993; Walsh & Holland, 1992). A longitudinal study of 2,309 college students at over 300 colleges and universities supports the validity of all three assumptions in Holland's theory – congruence, self-selection, and socialization – in higher education environments (Smart et al., 2000). Evidence for the socialization assumption is as follows. Each environment (academic major) had students with congruent personalities and students with incongruent personalities. All students graduating with an academic major, regardless of congruence or incongruence, grew by equal amounts with respect to the competencies and values characteristic of the major. Also, incongruent students grew *only* in the competencies and values of their major, *not* in their original personality type. In short, the environment (major) socialized students equally whether or not their original personality was congruent. *The study's central finding was that students in a major learn the distinctive pattern of competencies, values, attitudes, interests, and self-perceptions that are reinforced by their major, regardless of their congruence or fit with the environment (major).*

The implication of Holland's theory for my analysis is that each environment, whether that is a work environment or an academic discipline, has a distinctive pattern of competencies, values, attitudes, interests, and self-perceptions. These distinct patterns are maintained and transmitted through self-selection for the congruent individuals and socialization for all individuals regardless of congruence. In short, a person's undergraduate major and their post-graduate work environment will each strongly influence their competencies and values. Thus, *Holland's theory predicts differences in the pattern of importance ratings of competencies based on undergraduate major and post-graduate work environment.*

2.2.2 Models for Superior Performance in Work Settings

Spencer, McClelland, and Spencer (1994) created "models for superior performance", which defines twenty competencies that distinguish superior performers from average performers in professional and managerial jobs. The models state that job success can be predicted by the congruence between the competencies required to perform a job and the competencies of the employee, which is similar to Holland's theory. The framework synthesizes 286 studies of entrepreneurial, technical, professional, sales, human service, and managerial jobs gathered during 20 years of research using the McClelland/McBer job competence assessment method. This approach does not analyze the elements of the job, but the characteristics of the people who do the job well. The competency models were combined into generic models. Two central findings are 1) that there is a different overall pattern of importance among the competencies for different jobs and 2) that the generic models will not fit any specific job perfectly because there is such variation in the competencies required in different jobs (Spencer et al., 1994; Spencer & Spencer, 1993). Thus, *Spencer & Spencer's "Models for superior performance" predict differences in the pattern of importance ratings of competencies based on work environment.*

2.2.3 A Framework for Outcomes of Professional Programs

Stark, Lowther, and Hagerty (1986) conducted a multi-year, multi-phase study to develop and test a generic set of curricular outcomes for professional education. The first phase identified generic outcomes, that is the intended outcomes shared among faculty across eleven professions: *helping* (dentistry, medicine, nursing, pharmacy, and social work), *enterprising* (architecture, business, engineering, law), and *informing* (education, journalism, library science). A second phase surveyed faculty views about relative emphasis among the generic outcomes.

The study had 2,217 responses from 732 programs in 346 different institutions. A central overarching finding was that faculty in all fields rated each professional outcome as important (Stark & Lowther, 1986b). In fact, the research team noted that questions about ideal emphasis on outcomes had the most restricted variance on their survey (Stark, Lowther, & Hagerty, 1987). They also found that the pattern of emphasis among competencies was "distinctive for each field" (Stark & Lowther, 1986b, p. 13). Not one of the 10 professions exhibited the same overall pattern of importance among competencies as the means for all the professions combined.

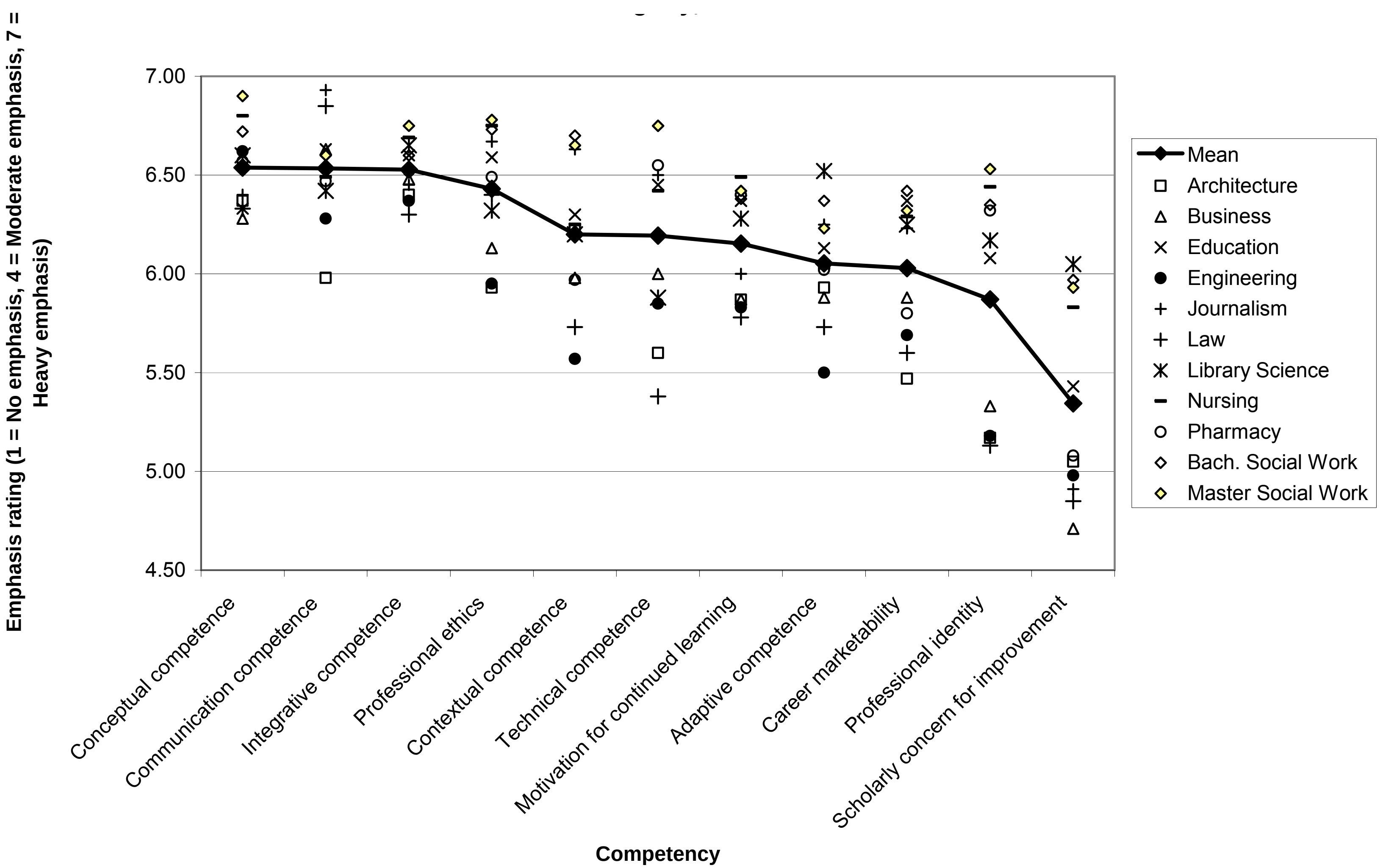
My graph of their published data (Figure 2.1) shows that each profession's importance ratings vary in unique ways from the aggregate ratings. The descending order of importance for the aggregate ratings is: conceptual competence, communication competence, integrative competence, professional ethics, contextual competence, technical competence, motivation for continued learning, adaptive competence, career marketability, professional identity, and scholarly concern for improvement. This sequence differs by profession. For example, 222 engineering faculty (46.6% response rate) responded from 60 programs (61.9% response rate) (Stark et al., 1986, p. 87). Engineering faculty's rank order of importance for emphasis in the curriculum is conceptual competence (heaviest emphasis in the curriculum), integrative competence, communication competence, professional ethics, technical competence, motivation for continued learning, career marketability, contextual competence, adaptive competence, professional identity, and scholarly concern for improvement (least emphasis in the curriculum). Thus, *Stark, Lowther, and Hagerty's framework predicts differences in the pattern of importance ratings of competencies based on professional field.*

2.2.4 Empirical Work in Engineering

Six survey studies validate the theoretical prediction that differences in the pattern of importance ratings of competencies are based on engineering work environment. Four studies of the importance of various competencies in engineering reported their results separately for engineering faculty and engineering practitioners. Results show that *engineering faculty and engineering practitioners rate importance quite differently for some competencies* (ASME, 1995; Bankel et al., 2003; Evans, Beakley, Crouch, & Yamaguchi, 1993; Shea, 1997). Shea's (1997) study also showed that engineers in two practice settings (industrial engineering and manufacturing engineering) differed significantly on their importance ratings for various competencies. The subtle distinction between industrial engineering and manufacturing engineering shows the powerful influence of practice setting on importance ratings.

Two studies by Saunders-Smits (2005; 2007) surveyed engineers in a single industry (aerospace) about the importance of various competencies. The studies controlled for work environment – either engineering specialist or engineering manager.

Figure 2.1. "Ideal emphasis" in the curriculum ratings by faculty as reported in Stark, Lowther, and Hagerty, 1987.



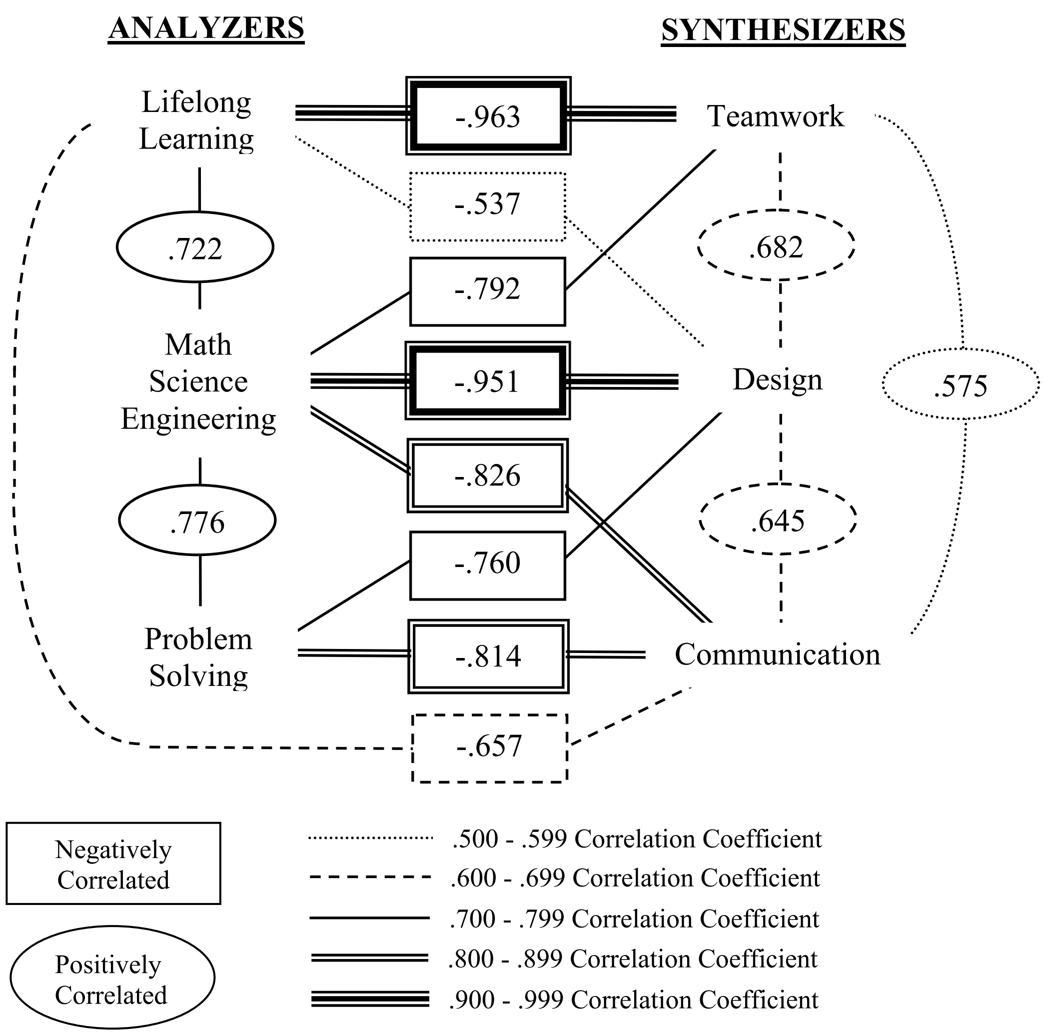
Saunders-Smits shared her data with me in a personal communication in December 2006. For each study, I calculated the average importance rating for each competency by work environment (either engineering specialists or engineering managers). Then, I used all four importance ratings for each competency to create a 6 X 6 correlation matrix. Statistically significant correlations predominated ($\alpha = .01$).

Figure 2.2 depicts the complex intercorrelations among the competencies for the two work environments. The analyzers are the engineering specialists, and the synthesizers are the engineering managers. The left column shows the three competencies prized by analysts: analytical skills (e.g., "math, science, and engineering knowledge"), problem solving, and life-long learning. These three competencies were positively correlated with each other. The right column shows the three competencies prized by synthesizers: the ability to synthesize (e.g., design), teamwork, and communication (the average of "written communication skills" and "oral communication skills"). These three competencies were positively correlated with each other. Focusing on the negative correlations in the center column (Figure 2.2) leads to a third critical observation. The competencies prized by analyzers and synthesizers were negatively correlated with each other. That means that the competencies prized by analyzers are much less important to synthesizers and vice versa. Taken together, these three observations lead to a definitive conclusion: *the pattern of importance ratings for various competencies depends on engineering work environment.*

2.3 Important Competencies for Engineers beyond ABET's

Determining the purposes of the curriculum – what the outcomes of college should be – is a difficult issue (Alexander & Stark, 1986; Lattuca & Stark, 2001). Bowen (1977) made a long list of possible outcomes, which includes goals for the individual student and goals for society. His five areas for the individual are: cognitive learning, emotional and moral development, practical competence, direct satisfactions from college education, and avoidance of negative outcomes. In academic programs that prepare students for a profession, such as engineering, medicine, or law, the curriculum will ideally include, among several goals, development of competencies that are important for professional success (Stark & Lattuca, 1997). Many theorists and researchers have sought to define the competencies that are important for professional success. This section discusses and compares the resulting lists, revealing a common core that includes competencies beyond ABET's list of eleven.

Figure 2.2 Statistically significant correlations (α = .01) between competencies as reported in Saunders-Smits'(2005, 2007) data.



2.3.1 Four Perspectives on Professional Expertise

Kennedy (1987) reviewed the literature on expertise and how it is acquired. First I describe the four perspectives and then apply them to ABET's eleven competencies.

2.3.1.1 Overview of the Four Perspectives

Kennedy (1987) proposed four perspectives on expertise: "Expertise as …[specialized] skill", "expertise as the application of theory or general principles", "expertise as critical analysis", and "expertise as deliberate action". The specialized skill perspective views expertise as the specific tasks that the professional must perform. Educational examples of this perspective are nursing education before 1970, engineering education before 1950, and some teacher education before 1985. This view prescribes how practitioners will handle situations using specialized skills. This perspective holds three assumptions: that "the constituent skills can be identified; that the skills can be transmitted to prospective practitioners; and that they can be appropriately drawn on in practice" (Kennedy, 1987, p. 135). Kennedy points out a major flaw in the pure form of this perspective. It overlooks the decisions about whether and when to use specific skills, the theory and principles relevant to the profession, and analytic capacity.

Another perspective is expertise as application of theory or general principles. Educational examples of this perspective are engineering programs from 1950-2000 and medical school until the recent competency emphasis. This view prescribes how practitioners will handle situations using theory and principles by treating particular cases as examples of known categories. This perspective assumes that

> theory and general principles can be applied to particular situations, an assumption that raises three questions. The first question has to do with how the practitioner recognizes a particular case as an example of a general principle; the second with how the practitioner adjusts predictions derived from a general principle to accommodate the specific features of the case; and the third with how practitioners blend the variety of potentially relevant principles to form an integrated body of knowledge that can be applied to specific cases (Kennedy, 1987, p. 139-140)

This perspective overlooks the decisions about whether and when to apply theory and general principles.

A third perspective is “expertise as critical analysis”. Educational examples of this perspective are law school, business school, and university arts and sciences curricula. This view prescribes how practitioners will examine and interpret situations using their critical analysis skills. In this approach, practitioners analyze particular cases with a certain mindset. This perspective overlooks codified knowledge, can narrow practitioners’ perspective so that they cannot embrace alternative perspectives, and does not indicate how the practitioner should act on his or her analysis.

A fourth perspective is “expertise as deliberate action”, which has been adopted by some teacher education programs. This view prescribes how practitioners will analyze situations in the context of action, emphasizing the interaction between analysis and action and how ideas and goals are altered by context. In this approach, practitioners analyze situations to define the problem and to build a mental model of how things work based on a mental catalogue of means and ends. This approach requires a highly developed sense of purpose, which is the criterion for judging both ideas and action. Life-long learning is a hallmark of this approach. There are several disadvantages to this approach. Several have to do with biases in human judgment. “Without training, people are not very careful when inducing principles from experience. They are likely to overestimate the degree of correlation among events” (Kennedy, 1987, p. 150). Also, heuristics learned inductively from specific instances are often generalized only across content areas, not across problem structures. In addition, the idea that purpose and goals are developed in response to situations is problematic for professional accountability.

2.3.1.2 Applying the Four Perspectives to Engineering Education

Engineering education in the U.S. has shifted among these perspectives on expertise. In the late 1940’s, critics such as Dougherty (1950) complained that engineering education concentrated on technique while failing to discuss the principles and concepts on which the techniques were based (Kennedy, 1987). This was the period of the *specialized skills perspective*, and it ended with changes in ABET’s accreditation requirements. During the late 1980’s many critics pointed out that the complete exclusion of technical skills in favor of theory and principles left graduates unprepared for practice (Kennedy, 1987). Harrisberger (1985) noted that

> 80% of the … engineering curriculum is comprised of the 'ics' – physics, mathematics, dynamics, electronics – but that engineering practice consists of 'ings' – consulting, designing, planning, evaluating. He posed the rhetorical question should not a professional education program be prepared to certify that its graduates can competently perform the tasks of engineer*ing*? (Kennedy, 1987, p. 136)

The second half of the 20th century was the period of the *theory and general principles perspective*. In response to widespread agreement with Harrisberger's observation, the accreditation requirements changed yet again, this time to competency-based EC2000.

ABET's current criteria require that graduates demonstrate eleven learning outcomes. As I interpret them, these competencies cover all four of Kennedy's perspectives on expertise. The root perspective on expertise of the past 50 years, the theory and general principles perspective, is represented in two outcomes:

- (a) an ability to apply knowledge of mathematics, science, and engineering
- (b1) an ability to design and conduct experiments.

The specialized skills perspective, the root perspective before 1950, is represented in four outcomes:

- (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
- (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice
- (d) an ability to function on multi-disciplinary teams
- (g) an ability to communicate effectively

ABET's list includes a strong component of the "critical analysis" perspective on expertise. These are the competencies that allow a person to 'think like an engineer':

- (e) an ability to identify, formulate, and solve engineering problems
- (b2) [an ability] to analyze and interpret data
- (f) an understanding of professional and ethical responsibility

Three outcomes embody the underlying mechanism of "deliberate action":

- (i) a recognition of the need for, and an ability to engage in life-long learning
- (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
- (j) a knowledge of contemporary issues

The life-long learning outcome, as written, does not emphasize learning from the interplay between action and context. However, some programs might interpret it in that way. The context competencies allow engineers to analyze situations adapting to context.

When analyzed using Kennedy's (1987) lens of perspectives on expertise as I do above, ABET's new requirements exhibit a paradigm shift in what constitutes engineering expertise. The shift is from the "theory and general principles" perspective that dominated from 1950-2000 to a combination of all four perspectives on expertise: "theory and general principles", "specialized skills", "critical analysis", and "deliberate action". My analysis of ABET's outcomes based on Kennedy's (1987) perspectives (above) indicates that *long-term emphasis on the "theory and general principles" perspective has created a culture that tends to underemphasize decision-making about 1) whether and when to apply theory, general principles, analytical skills, and technical skills and 2) how to act on one's analysis. Decision-making may be an important omission from ABET's eleven*.

2.3.2 Competencies in Models for Superior Performance

The competencies in Spencer and Spencer's models are not simply observable behaviors, but capture intent. The competencies are achievement orientation, concern for quality and order, initiative, interpersonal understanding, customer service orientation, impact and influence, organizational awareness, relationship building (e.g., networking), directiveness, teamwork and cooperation, developing people, team leadership, technical expertise, information seeking, analytical thinking, conceptual thinking, self-control (e.g., stress resistance), self-confidence, organizational commitment (e.g., business-mindedness), and flexibility (Spencer et al., 1994; Spencer & Spencer, 1993). *After comparing to ABET's eleven competencies, possible omissions are revealed: achievement orientation (e.g., commitment to achieving goals), initiative, and flexibility.*

2.3.3 Generic Outcomes of Professional Programs

Stark, Lowther, and Hagerty (1986) defined eleven generic outcomes of professional programs. In Table 2.1, I map ABET's outcomes onto their generic outcomes. Two major omissions are revealed. Integrative competence – the ability to

Table 2.1 Comparing Stark and associates' (1986) generic outcomes to ABET's outcomes.

Generic Outcomes for Graduates of Professional Preparation Programs		**Required Outcomes for Graduates of Engineering Programs** (ABET, 2006, p. 1-2)
Professional Competences Correspond to the common notion of the technically competent practitioner †	"The graduate should…" ††	"Engineering programs must demonstrate that their students attain…"
Conceptual competence	Understand the body of knowledge that is basic to practice of the profession; that is, the theoretical base or the professional knowledge base	(a) an ability to apply knowledge of mathematics, science, and engineering [typically taught with more emphasis on understanding than on application]
Technical competence	Be able to perform the fundamental skills or tasks required in professional practice.	(e) an ability to identify, formulate, and solve engineering problems (b) an ability to design and conduct experiments, as well as to analyze and interpret data (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability (d) an ability to function on multi-disciplinary teams (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
Contextual competence	Understand the social, environmental, economic, and cultural setting in which the profession is practiced.	(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context (j) a knowledge of contemporary issues
Interpersonal communication competence	Be able to use written and oral communication effectively.	(g) an ability to communicate effectively
Integrative competence	Be able to integrate theory and practice; that is, select the knowledge and skills applicable to a particular professional work setting or problem.	This is implied in the wording of many of ABET's outcomes.

Adaptive competence	Demonstrate the ability to anticipate and adapt to changes in society and technology that are important to the profession.	
Professional Attitudes Encompass multiple dimensions of professional commitment †		
Professional identity	Have developed an identification with the professional role.	
Ethical standards	Know and apply ethical principles and professional conduct standards of the professional field.	(f) an understanding of professional and ethical responsibility
Career marketability	Not only meet basic standards for entrance into the profession (such as licensing or certification where they exist), but also be a competitive applicant for a beginning position.	
Motivation for continued learning	Actively seek opportunities to update professional knowledge.	(i) a recognition of the need for, and an ability to engage in life-long learning
Scholarly concern for improvement	Be willing to cooperate with or participate in research or other scholarly activities that improve professional practice.	

† (Stark et al., 1986, p. 13)

†† Quoted from the survey instrument of the Professional Preparation Study, p. 2-3

integrate theory and practice – is merely implied, not emphasized, in the wording of the other competencies. Adaptive competence, which is adapting to external changes that are important to the profession, is not present. *The ability to integrate theory and practice effectively in professional work and adaptability are possible omissions from ABET's list of outcomes. Integrating theory and practice is actually decision-making about when to apply theory and general principles. Adaptability could also be called flexibility.*

2.3.4 Empirical Work in Engineering

Two literature reviews (Cupp, Moore, & Fortenberry, 2004; Woollacott, 2007) focused on determining what competencies are important for engineers, as did several studies (e.g., Gauthier, 2002; Katz, 1993; Martin, Maytham, Case, & Fraser, 2005; Palmer, 1999; Scott & Yates, 2002; Society of Petroleum Engineers, 2006; Todd, Sorensen, & Magleby, 1993). Findings typically confirmed the importance of ABET's competencies and often identified additional competencies as important. For example, commitment to doing one's best, listening skills, and adapting to changing work environments were identified by Meier, Williams, and Humphreys (2000). Oral communication was more important than written communication among engineering alumni (Murphy, 1994; Sageev & Romanowski, 2001). Iowa State University's critical incident study identified quality orientation, cultural adaptability, initiative, and judgment as important (Brumm, Hanneman, & Mickelson, 2005; Mickelson, 2001, 2002). Leadership was highly rated in two studies (Burtner & Barnett, 2003; Donahue, 1997). Watson (2000) did a case study of what increases an engineering graduate's likelihood of receiving a job offer. The findings included project management skills and initiative.

The twelve studies included in my meta-analysis (Appendix B) listed 28 distinct non-ABET competencies. My meta-analysis examines their relative importance.

2.4 Faculty Rate Importance Differently than Practitioners

Three theories predict that different patterns of importance ratings among competencies are based on work environment (Holland, 1997; Spencer & Spencer, 1993;

Stark et al., 1986). Six survey studies confirm this theoretical prediction (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Saunders-Smits, 2005, 2007; Shea, 1997).

Four of these studies found that engineering faculty's importance ratings *differed substantially* from engineering practitioners (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Shea, 1997). No disconfirming evidence was found. For example, in two studies, faculty rated engineering science knowledge substantially higher than practitioners did. Specifically, in Evans et al. (1993), faculty rated engineering science knowledge second out of seven competencies vs. practitioners' fourth place rating. In Shea's (1997) study of ten competencies, faculty rated engineering science knowledge second vs. practitioners' seventh place rating. Faculty in Shea's study also rated engineering fundamentals substantially higher than practitioners (3.6 vs. 2.8 on a 5-point scale). In the 1995 study by ASME, faculty and industry respondents had moderate agreement on the pattern of importance ratings. However, faculty rated finite element analysis and experiments in their top 20, while industry respondents did not. Instead, industry respondents rated concurrent engineering, reliability, and geometric tolerancing in their top 20, while faculty respondents did not. Bankel et al. (2003) concluded "overall, an image emerges that the faculty are slightly more interested in detailed, deterministic, and analytic processes, while industry is slightly more interested in higher level, more conceptual processes in the face of uncertainty" (Crawley, 2001, p. 27).

These empirical findings are consistent with theory. Kennedy classified 1980's engineering education as a profession whose education structure emphasizes codified knowledge of theory and principles. Therefore, theory predicts and studies confirm that *faculty's view of engineering competence is weighted toward the "theory and general principles" perspective of expertise, while practitioners' view is more balanced among Kennedy's (1987) four perspectives*.

Recall that Stark, Lowther, and Hagerty's (1986) generic outcomes were built on faculty perspectives. This means that the generic outcomes offer evidence of faculty opinions about competencies. I analyzed Stark, Lowther, and Hagerty's (1986) generic outcomes with respect to Kennedy's (1987) four perspectives on expertise. The results of the 1985 faculty survey by Stark and associates generally agree with Kennedy's classifications. However, Kennedy's "critical analysis" perspective is weakly represented. Only two of the generic outcomes – "professional identity" and "ethical standards" – address critical analysis. Neither competency captures the essence of thinking like a professional in one's field. *The weak presence of Stark, Lowther, and Hagerty's (1986) generic outcomes in the area of "critical analysis" may indicate that faculty underemphasize competencies related to critical analysis. For engineers, these are the competencies that allow a person to 'think like an engineer', such as:*

- *(e) an ability to identify, formulate, and solve engineering problems and*
- *(b2) [an ability] to analyze and interpret data*

2.5 Importance Ratings Depend on Wording

Relative importance ratings depend on survey wording. Shea's (1997) survey asked each respondent to 1) rate each competency and 2) choose the single most important competency. In the ratings, communication was most important. In the ranking, communication was third behind problem solving and teamwork. This raises the question, how do the results change with different survey wordings?

2.6 Synopsis: Problem, Theory, Literature, and Research Questions

As a result of trends in quality assurance (e.g., accreditation), engineering faculty *worldwide* face a culture change resulting from two paradigm shifts. The first is a shift from viewing teaching as *instruction* to seeing teaching as facilitating *learning*. The second is a shift from viewing engineering expertise as the application of theory to seeing expertise as the integration of theory, specialized skills, critical analysis, and deliberative action. The new competency focus "has significant implications for what knowledge and skills faculty need" (Doherty et al., 1997, p. 182). Under the learning paradigm with a competency focus, curriculum designers consider questions of purpose, such as, in our academic program "what competencies should students have at graduation?" and "what should the relative emphasis be among those competencies?" These practical questions inspired this study – an effort to gather the opinions of engineering graduates on these questions which faculty are grappling with, worldwide.

Competencies are the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action), in complex and uncertain situations such as professional work, civic engagement, and personal life. I assume that competencies are the foundation of successful professional practice throughout a career. *Expertise* is the proficient coordination of multiple competencies that leads to consistently effective performance in a variety of unique, complex, and uncertain situations.

Importance ratings among competencies depend on practice setting. Three theories predict that different patterns of importance ratings among competencies are based on academic discipline and work environment (Holland, 1997; Spencer & Spencer, 1993; Stark et al., 1986). Six survey studies confirm this theoretical prediction for different engineering work environments (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Saunders-Smits, 2005, 2007; Shea, 1997).

There are competencies important for engineers beyond ABET's eleven outcomes. Theory and empirical work all confirm the importance of ABET's eleven outcomes for engineering practice. However, several additional competencies have been repeatedly deemed important. Theory identified four important non-ABET competencies that were confirmed by studies of engineers:

- **decision-making** about 1) whether and when to apply theory, general principles, analytical skills, and technical skills and 2) how to act on one's analysis (Kennedy, 1987; Mickelson, 2001, 2002; Stark et al., 1986). Also present in ASEE's (1994) list by deans and industry.
- **achievement orientation** (e.g., commitment to achieving goals) (Meier et al., 2000; Mickelson, 2001, 2002; Spencer & Spencer, 1993; Woollacott, 2007). Also present in ASEE's (1994) list by deans and industry.
- **initiative** (Mickelson, 2001, 2002; Spencer & Spencer, 1993; Watson, 2000)
- **flexibility** (Meier et al., 2000; Mickelson, 2001, 2002; Spencer & Spencer, 1993; Stark et al., 1986). Also present in Boeing's list (McMasters & Komerath, 2005).

One non-ABET competency was identified only in theory: **the ability to integrate theory and practice in a professional work setting** (Stark et al., 1986). Two non-ABET competencies were identified solely in empirical work: **leadership** (Burtner

& Barnett, 2003; Donahue, 1997), which also appeared in ASEE's (1994) list by deans and industry, and **project management** (Watson, 2000). Studies also show that communication skills are exceedingly important. It may be essential to distinguish between the more important **oral communication** and the less important **written communication** (Murphy, 1994; Sageev & Romanowski, 2001). **Listening skills** may also be a useful distinction (Meier et al., 2000). Boeing's list (McMasters & Komerath, 2005) also distinguished between these three types of communication.

Engineering faculty rate the importance of various competencies differently than practitioners. Theories predict that different patterns of importance ratings among competencies are based on work environment, and studies show that engineering faculty's ratings differ substantially from engineering practitioners' (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Shea, 1997). Engineering faculty's view of professional competence is weighted toward the "theory and general principles" perspective of expertise, while practitioners' view is more balanced among Kennedy's (1987) four perspectives. Comparing Stark, et al.'s (1986) generic outcome to Kennedy's (1987) perspectives indicates that faculty in professional programs may under emphasize competencies related to critical analysis. For engineers, these are the competencies that allow a person to 'think like an engineer', such as:

- (e) an ability to identify, formulate, and solve engineering problems and
- (b2) [an ability] to analyze and interpret data.

Altogether, the theory and literature made the three points above and also showed that relative importance ratings depend on survey wording. All four points have implications for addressing the research questions. Recall the research questions: in the opinion of engineering graduates, "**what competencies should students have at graduation?**" and "**what should the relative emphasis be among those competencies?**" Because theory and literature show that importance ratings vary by work environment, my study differentiates by practice setting, including engineering faculty. I have designed my study to consider competencies beyond ABET's list and to explore the effect of survey wording on importance ratings.

The point that faculty ratings of importance differ from practitioner ratings bolsters the motivation for my study. For curriculum design decisions, faculty will gain fresh perspective from the opinions of engineers practicing in a wide variety of industries and roles. In this research, I assume that the importance of any specific competency *for professional engineering practice in a specific setting* is best determined by engineers currently practicing in that setting.

CHAPTER 3. METHODS

This study synthesizes the opinions of engineering graduates about *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* These are the research questions. To answer them, two data sets were coordinated. To identify aggregate patterns, I conducted a meta-analysis of 10 published studies plus two unpublished surveys from the University of Michigan (U-M). To delve into differences by sub-group, I further analyzed U-M's 4225 survey responses. *Both analyses used the same strategy: statistically testing the null hypothesis that there are no differences in the importance ratings for the various competencies.* To accomplish this, I used protected post-hoc, all-pairwise multiple comparisons in which each competency is analogous to an experimental treatment. This method includes two steps. 1) Determine if any statistically significant differences exist among the importance ratings for the competencies. 2) If significant differences exist, perform a multiple comparison test to determine which competencies differ significantly with respect to importance ratings.

Coordinating the analysis of these two data sets increases the generalizability. Naturally, data from a single institution, a single survey, and a prescribed set of competencies (i.e., ABET's list) would lead to uncertainty about generalizability. The meta-analysis of 10, 203 responses addresses these sources of uncertainty. On the other hand, aggregated data from a meta-analysis would lead to uncertainty about differences among sub-groups and changes over time. The UM analysis addresses these concerns. By coordinating the two data sets, the findings can be generalized with confidence.

During preliminary analysis, the research questions splintered, leading to cascading questions of greater detail. The results pertinent to each sub-question will be compared, contrasted, and triangulated to obtain more robust results. For the analysis, the central research questions were broken into more specific questions. According to engineering graduates,

- Which competencies are important for engineering graduates? (Meta-analysis)
- What should the relative emphasis be among competencies for engineering graduates? (meta-analysis)
- Questions for refining the analysis:
    - Are there relationships between subsets of competencies? (UM)
    - How does the relative emphasis among competencies differ by sub-groups, such as engineering discipline, environment of engineering practice, number of years since graduation, and demographic groups? (UM)
    - How does the relative emphasis among competencies change over time, such as by survey year, by graduation year, and by years since graduation? (UM)
    - How does the relative emphasis among competencies change with alternate wording of the survey questions? (UM)
    - What sampling limitations in the Michigan data, when compared to national data sets, might limit the generalizability of the findings? (UM-NSF)

This chapter contains descriptions of the methods employed to answer these questions, including data collection procedures, descriptions of the data analysis, and an explanation of the limitations. First, the meta-analysis is described, then the analysis of the U-M data.

3.1 The Meta-Analysis

This entire study synthesizes the opinions of 10, 203 engineering graduates about *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* These are the research questions. This meta-analysis of 10 published studies plus two unpublished surveys will answer two questions:

- Which competencies are important for engineering graduates?
- What should the relative emphasis be among competencies for engineering graduates?

3.1.1 Research Design for the Meta-Analysis

The aim of synthesizing research is to compare and combine the results of individual studies to answer a particular, focused research question (Rosenthal, 1994). There are nine methods for integrating results across studies: the traditional narrative approach, the traditional vote counting method, two approaches to the cumulation of p-values across studies, and five approaches to meta-analysis (Hunter & Schmidt, 1990). Given the nature of the data reported in the studies in Appendix B (i.e., mean ratings devoid of inferential statistics), meta-analysis is the preferred approach.

In essence, meta-analysis answers a research question by re-analyzing the quantitative summaries of multiple empirical studies. Meta-analytic approaches can be applied to all types of quantitative studies (Cooper & Hedges, 1994; Glass, McGaw, & Smith, 1981; Hunter & Schmidt, 1990; Krathwohl, 1998). Whether the studies are experimental, correlational, or simple rates, the purpose and strategy are the same:

> Meta-analysis provides for the statistical integration of empirical studies of a common phenomenon. The findings of all the studies must be expressed on some common scale for their integration to be feasible. The findings are the dependent variable in the statistical analysis. The independent variables in the analysis are the substantive and methodological characteristics of the studies. (Glass et al., 1981, p. 93)

My meta-analysis uses the Glassian approach (Hunter & Schmidt, 1990). For instance, I include all studies in the analysis, regardless of their quality. A limitation of the classic, Glassian approach is that studies judged of different levels of quality are combined with equal weights. Also, due to constraints on the analysis, findings could not be weighted by sample size. Instead the unit of analysis was the study. Meta-analysis involves four steps after forming the research questions: 1) identifying the studies to include, 2) classifying the characteristics of the studies, 3) transforming study findings to a common metric, and 4) meta-analysis, i.e., combining findings in an analysis (Cooper & Hedges, 1994).

3.1.2 Identifying the Studies to Include in the Meta-analysis

An extensive literature review completed in July 2006 identified twelve studies published since 1990 that share my study's purpose and scope. Each study seeks practicing engineers' ratings of the importance of various competencies (ASME, 1995; Bankel et al., 2003; Benefield, Trentham, Khodadadi, & Walker, 1997; Evans et al., 1993; Koen & Kohli, 1998; Lang et al., 1999; Lattuca, Strauss, & Volkwein, 2006; Lattuca, Terenzini et al., 2006; National Society of Professional Engineers (NSPE), 1992; Saunders-Smits, 2005, 2007; Shea, 1997; Turley, 1992).

Turley's (1992) and ASME's (1995) studies were excluded from the meta-analysis because their ratings of importance were incompatible with the others. The other 10 studies, described in Appendix B, are included in the meta-analysis, regardless of their publication status. This decision was made based on the rationale of Glass, et al. (1981, p. 57): "Locating studies is the stage at which the most serious form of bias enters a meta-analysis, since it is difficult to assess the impact of a potential bias." They go on:

> No survey would be considered valid if a sizable subset (or stratum) of the population was not represented in the cumulative results. Neither should a meta-analysis be considered complete if a subset of its population is omitted. One very important subset of evidence is the subset of unpublished studies. To omit dissertations and fugitive research [unpublished studies such as those archived in ERIC documents] is to assume that the direction and magnitude of effect is the same in published and unpublished works. (Glass et al., 1981, p. 64)

Hunter and Schmidt (1990) concur with Glass and associates on the inclusion of all studies regardless of methodological quality and publication status.

The search was conducted as follows. Preliminary searches based on my experience in the field of engineering education identified three studies. These pointed to two key concepts for indexing: competencies (or job skills) and engineering (or professions). A research librarian designed queries for three data bases, Proquest's Dissertation Abstracts, Engineering Village 2 (Compendex and Inspec), and ERIC (Education Resources Information Center). For every relevant or closely-related study, the reference list was reviewed in detail and citations were explored using ISI Web of Science and Google Scholar. Although great care was taken to make a comprehensive search, there are suspected limitations in coverage. Two of the three initial studies were not identified in the data base searches. One was published in a European journal that is not indexed in ISI Web of Science and the other was published as an ABET report. These omissions indicate that additional studies may exist, especially unpublished studies for informing faculty decision-making.

3.1.3 Classifying the Characteristics of the Studies

Classifying the characteristics of studies allows "the overall relationship …[to be] checked separately for different subdivisions of the data, and checked for statistical significance in the differences" (Glass et al., 1981, p. 80). These studies have several interesting characteristics: respondents' industry, respondents' experience level, year of data collection, differences between rankings and ratings of importance, and the nature of the target position for the importance ratings, such as experience level and type of job specified for the rating. Unfortunately, features of the data allow only one subdivision to be explored statistically, respondents' industry. Subdivision by respondents' industry was based on how the survey recipients were selected: were recipients chosen because of their alumni status with an engineering college or because of their affiliation with organizations where engineering is practiced?   These groups include respondents of many engineering disciplines in each of the categories, *alumni*, *faculty*, and *practicing* engineers. The other characteristics of the studies merit exploration in future research.

3.1.4 Transforming Study Findings to a Common Metric

The central challenge of meta-analysis is combining the assorted concepts and metrics from a variety of studies into a common metric that is useful and valid.

> Combining estimates of effect size from different studies would be easy if studies were perfect replicates of each other – if they made the same methodological choices about such matters as within-study sample size, measures, or design, and if they all investigated exactly the same conceptual issues and constructs….The unbiased estimate of the population effect would then be the simple average of observed study effects; and its standard error would allow computation of confidence intervals around that average. (Shadish & Haddock, 1994, p. 262)

Creating a common metric requires *common constructs* and then a *common scale*. Because only one of the studies replicated the wording of competencies from a previous study, I identified *common constructs*, or wordings, for direct comparison. I selected ABET's eleven competencies as the set of common constructs because they are familiar constructs among engineering faculty worldwide. Then the competencies from each of the twelve studies were mapped onto ABET's. The wording of the survey questions in each study was examined in context to determine what ideas the respondent might have had in mind while answering the survey. For the mapping, I relied on my experience as an engineer, engineering educator, and specialist in assessment in engineering education. I finalized the mappings (Appendix C) prior to any analysis, to reduce bias.

With common constructs, a *common scale* can be created. "The findings of all the studies must be expressed on some common scale [or metric] for…integration to be feasible. The findings are the dependent variable in the statistical analysis" (Glass et al., 1981, p. 93). Although all twelve studies in the meta-analysis rate importance on Likert-type scales, this is not necessarily a common metric. In fact, Hall, Tickle-Degnen, Rosenthal, and Mosteller (1994) specifically recommend using effect sizes for Likert-type ratings because "a difference of mean ratings of 0.5 implies something quite different in studies with great variation in responses versus studies with little variation (e.g., raters employ all 7 points of the rating scale or only 4 and 5 points)" (p. 23).

Effect sizes express the original variable in relation to a comparison group and the variable's own standard deviation. Effect sizes have no units, i.e., they standardize the variable. Effect size (d) for a study is the difference between the mean value of the variable of interest (X_{imean}) and the mean value for a comparison group (X_{cmean}) divided by a relevant standard deviation (s): $d = (X_{imean} - X_{cmean})/s$. For this meta-analysis, the mean variable of interest is the mean rating for a specific competency in a study, such as "the ability to work in teams". The decisions about comparison group and standard deviation should be informed by the purpose of the meta-analysis, which is to determine the *relative emphasis among the competencies*. **Thus, it is not the absolute importance ratings that are of interest, but the rank-order of the importance ratings for the various competencies.** A measure that allows rank ordering must compare a specific competency's rating to the "typical" rating for all competencies in that study, considering the dispersion of the ratings in the study.

The "typical" rating selected for this meta-analysis is the *ABET mean*. The *ABET mean* for a study population is the average rating for the subset of competencies that match ABET's Criterion 3a-k, which is widely viewed as a comprehensive basket of competencies. The *ABET mean* and its corresponding standard deviation eliminate extraneous competencies. However, there is a limitation to this metric: only four of the studies included all eleven of the ABET competencies. When studies didn't include all eleven of the ABET competencies, the *ABET mean* omits competencies of interest in the meta-analysis and, therefore, it groups different competencies for each study.

Although the *ABET mean* has limitations, it is the best choice among alternatives. The *overall mean* includes all competencies in the study but was rejected because it includes extraneous competencies that have no counterparts in other studies. A third alternative, the *common mean*, was also rejected. The common mean has the most face validity because it is based on the three competencies included in all but one of the studies (problem solving, communication, and life-long learning). However, the tiny standard deviations for the common competencies led to unstable effect sizes, ranging from 0.1 to 50. "Effect sizes that bounce around from 20 to 3 to 5 to whatever else depending on one or another assumption indicate that something is fundamentally wrong….[such as] the measurement scales" (Glass et al., 1981, p. 111). In summary, the *ABET mean* was selected as the "typical" rating for this meta-analysis because the resulting effect sizes are stable and meaningful.

3.1.5 Calculating overall mean ratings for ABET competencies

With a common metric, analysis can commence. Altogether, the 12 studies in this meta-analysis surveyed 21 populations and had a total of 10, 203 respondents. The mean ratings for each competency were standardized for each population in each study (Figure 3.1) as described above. Then these were further combined. For each competency, the 21 mean ratings for each population in the 12 studies were averaged to create an *overall mean*, representing all 10, 203 respondents. Figure 3.1 shows clear differences between the overall mean ratings for the eleven competencies. The question is, "which of these apparent differences are statistically significant?"

The horizontal "tie lines" at the top Figure 3.2 show the groups of competencies which are *not* significantly different. Interpreting the graph, there are seven distinct levels of importance ratings. In the *overall means*, the top level of importance consists of three competencies: problem solving, communication, and data analysis. The next two lower levels of importance are ethics followed by life-long learning and teamwork. Then there are four competencies at the same level of importance: experiments and data analysis combined, engineering tools, design, and "math, science, and engineering knowledge". At the fifth level of importance from the top is the competency "math, science, and engineering knowledge". The competencies deemed of least importance by

Figure 3.1. Standardized importance ratings from 12 studies, the raw data for the meta-analysis.

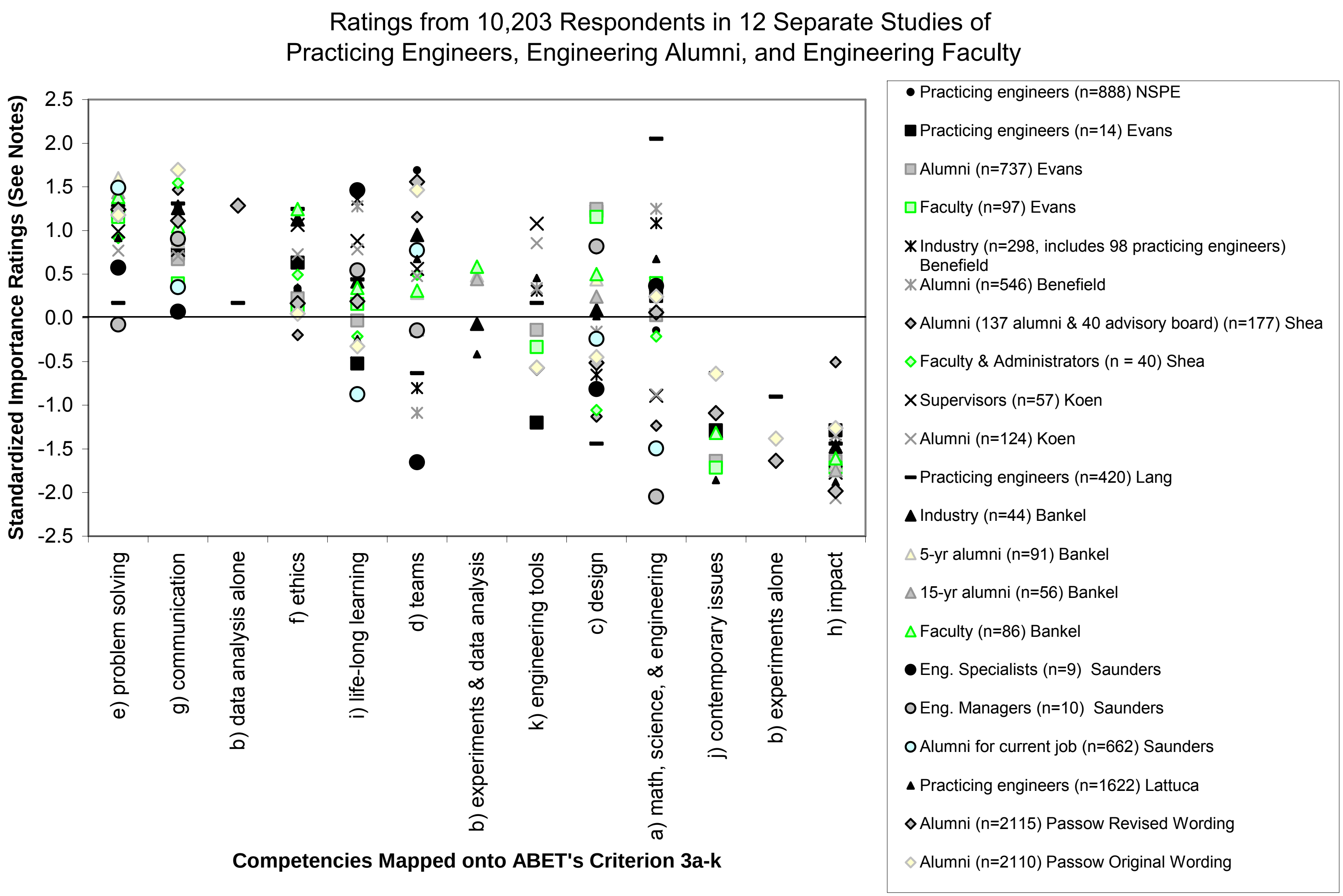
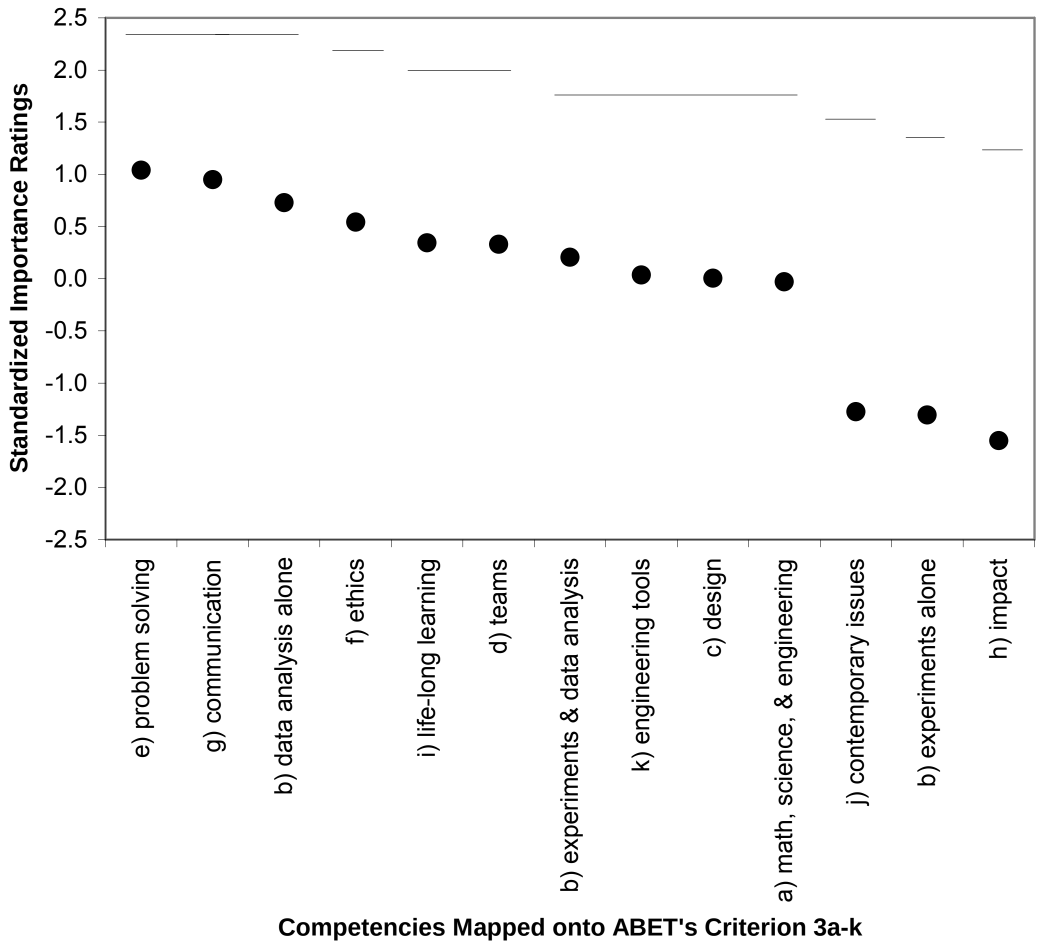


Figure 3.2. A hypothetical graph for demonstrating statistical "tie lines".



Note

Tie lines show 7 levels of importance

Horizontal "tie lines" above the data "tie together" competencies whose overall mean ratings are not significantly different (studywise α = 0.05).

the respondents are contemporary issues, experiments alone, and impact. The simple "tie lines" display the seven statistically distinct levels of importance.

3.1.6 Determining the statistically distinct levels of importance

The statistics to create the "tie lines" required many decisions and assumptions, which I will now describe. Note that two facts constrain the analysis. 1) Eight of the studies report only the mean rating for each competency, without a standard deviation. 2) Eight of the studies did not include the complete set of ABET competencies. In light of these constraints, I designed the analysis and refined it based on the recommendations of Brady West, Lead Statistician at the Center for Statistical Consultation and Research (CSCAR) at the University of Michigan. The rationale for choosing ANOVA for detecting differences in ratings for different competencies is described in Appendix D.

An ANOVA confirmed that the ratings differed significantly [$F(10, 220) = 21.18$, $p < .001$] at $\alpha = .05$, so the question became, "Which ones differ?" A multiple comparison test identified which competencies' ratings differed statistically from one another. Because each competency was compared to every other one after the data was collected, this is called a post-hoc, all-pairwise comparison. The design of my analysis is a balanced, one-way model, and my question is about practical equivalence as opposed to confidence intervals (Hsu, 1996). The parametric tests for post-hoc, balanced, all-pairwise comparison for practical equivalence are: Tukey's Honestly Significant Difference (HSD) test, Student-Newman-Keuls, Duncan, and the Least Significant Difference (LSD) test (Klockars & Sax, 1986). All these tests assume normality, independence, and homoscedasticity. Miller (1981) states that departures from these assumptions have not been explored. However, he speculates that only a single, extremely large variance would put the analysis in great peril. A Levine's test for homogeneity of variances shows that we cannot reject the null hypothesis that the variances are equal ($\alpha = .05$). Thus, the assumptions are met.

Of the available tests, Tukey's HSD is the most conservative, followed by Student-Newman-Keuls, Duncan, and LSD (Klockars & Sax, 1986). Conservative tests reduce the chance of incorrectly declaring significant differences, but are less likely to detect real differences. Because the Tukey's HSD test is considered "a little unnecessarily conservative" (Miller, 1981, p. 44), I chose the next most conservative. I performed the Student-Newman-Keuls test (studywise $\alpha = .05$) on the standardized ratings based on the weighted sub-group means, as in the ANOVA (Appendix D). Results are displayed in "tie lines", such as those in Figure 3.2. A confirmatory Duncan test (studywise $\alpha = .05$) yielded identical results.

3.1.7 Meta-analysis of non-ABET competencies

All competencies that were not mapped to the ABET competencies are listed in Table C12 by descending mean rating. With respect to non-ABET competencies, the meta-analysis is designed to identify competencies that are important with respect to the ABET competencies. *The meta-analysis is not designed to identify non-ABET competencies as "unimportant"*. The aim of this portion of the analysis is to identify competencies with standardized ratings comparable to the top two levels of importance among the ABET competencies. Such competencies bear consideration for further study and possible inclusion in the ABET list.

3.2 Analysis of the University of Michigan Data

This entire study synthesizes the opinions of 10, 203 engineering graduates about *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* These are the research questions. The U-M data is from three surveys. Two surveys of alumni of University of Michigan's College of Engineering (CoE) yielded 4225 responses, and a survey of seniors supplied supplemental data for one facet of the analysis. U-M's Behavioral Sciences Institutional Review Board (IRB) determined that this project is exempt from review (Study eResearch ID # HUM00003236). Analysis of the U-M data will answer these questions:

- What sampling limitations in the Michigan data, when compared to a national data set, might limit the generalizability of the findings?
- Are there relationships between subsets of competencies?

- How does the relative emphasis among competencies differ by sub-groups, such as engineering discipline, environment of engineering practice, number of years since graduation, and demographic groups?
- How does the relative emphasis among competencies change over time, such as by survey year, by graduation year, and by years since graduation?
- How does the relative emphasis among competencies change with alternate wording of the survey questions?

3.2.1 Data Collection

In 1997, the CoE's ABET committee led a college-wide effort to create ongoing improvement cycles within each department based on assessment of student learning. During 1997 and 1998, the committee developed a survey of recent alumni, a survey for graduating seniors, and a survey for employers. The alumni survey was based on a long-standing annual survey conducted by the mechanical engineering department. The committee consulted with Eric Dey and other researchers at U-M's School of Education to develop each of the surveys (in 1997-1998). Later, a team charged with administering the surveys annually, that is Jeanne Murabito and myself, consulted with Nancy Birk, a researcher at U-M's School of Education to revise the alumni survey (in 2002-03) and the senior survey (2003-04).

Table 3.1 is an overview, or blueprint, of the data collection from the alumni and senior populations over eight years. Only surveys yielding data used in this study are included. Specifically, every survey year, alumni from three graduation years were surveyed: 10 years since graduation, 6 years (or 5 years) since graduation, and 2 years since graduation. All alumni with graduation dates in targeted *calendar years* (not academic years) were surveyed. For example, in the 2005-2006 academic year, surveys were sent to all alumni who had graduated during any semester in 1995 and 1999 and 2003. The alumni data, from the survey in Appendix E, are the primary data in this analysis. The alumni survey response rate was 20.9% for all years lumped together. In addition, every semester we surveyed seniors during their last semester. The senior survey questions paralleled the alumni survey on the items that are relevant to this study. The senior survey response rate was 50.8% for all semesters lumped together. Details about the recipients, survey distribution, collection, response rates, and comparing respondents to the population are in Appendix F.

Table 3.1 Blueprint for the UM data collection from the alumni and senior populations.

CoE Graduates sampled by graduation year	**Survey Year**						
	99-00 †	**00-01**	**01-02**	**02-03**	**03-04**	**04-05**	**05-06**
2006							seniors
2005						seniors	seniors
2004					seniors	seniors	
2003					seniors		2 yr
2002						2 yr	
2001					2 yr		
2000				2 yr			
1999			2 yr				6 yr
1998		2 yr				6 yr	
1997	2 yr ††				6 yr		
1996				6 yr			
1995			6 yr				10 yr
1994	5 yr	6 yr				10 yr	
1993					10 yr		
1992				10 yr			
1991			10 yr				
1990		10 yr					
1989	10 yr						

† Gray-shading indicates original wording on the survey. Unshaded survey years had some reworded items. For the items pertinent to this study, most items had identical wording for the original and the new surveys, while some had alternate wording for similar concepts on the new surveys.

†† Number of years between the year of the survey and the year of graduation, what I call *years since graduation*. Alumni were surveyed 10, 6, and 2 years since graduation and seniors were surveyed during the semester in which they graduated. The 1999-2000 alumni survey included alumni 5 years since graduation instead of the usual 6 years since graduation.

3.2.2 Reducing Non-response Bias

Demographic questions on the surveys allow comparison to demographic information about the U-M population of graduating seniors. Specifically, population data was available in the University of Michigan's Data Warehouse for College of

Engineering graduates starting with the August 1992 graduation date for six parameters included in the surveys: gender, race, cumulative grade-point-average, undergraduate major, graduation semester, and how the graduates entered the CoE (as a 1st year student, a transfer from another institution, or a transfer from another U-M school or college).

To determine discrepancies between the observed and expected frequencies on specific variables, the chi-squared test was used with matching subsets of population data and survey data. For the alumni survey data, responding alumni with graduation dates in 1993 through 2003 were compared with population data for the same graduation years. Also, responding seniors were compared with population data for the matching semesters. The chi-squared tests showed that weighting to reduce non-response bias should be considered for the variables: gender (alumni and senior), race (alumni and senior), year of graduation (alumni only), semester of graduation (senior only), undergraduate major (alumni only), and how the graduate entered the CoE (senior only).

The tradeoff between reducing non-response bias and the statistical instabilities introduced by differentially weighting cases was carefully considered. Then, the following variables were weighted because of their high likelihood of affecting the analysis: gender, race, and year (or semester) of graduation. I used customary procedures for weighting and normalizing (Dey, 1997). For the alumni survey data, multivariate weighting was based on a three-dimensional table, gender (male/female) by race (8 options) by year of graduation (1993 through 2003). For the senior survey data, multivariate weighting was based on a three-dimensional table, gender (male/female) by race (8 options) by semester of graduation (Aug 2003 through April 2006).

3.2.3 Comparing Respondents to the U.S. Engineer Population

In 2002, I analyzed national data on occupations of people with engineering degrees. My aim was to categorize the occupations in order to build survey questions that captured the major occupation categories of engineering alumni. This data now allows comparison of the UM sample to the national population of engineers.

The data set was the National Science Foundation's (NSF) Scientists and Engineers Statistical Data System (SESTAT). It "captures that part of the science and engineering population who either received a college degree (bachelor's or higher) in a Science and Engineering (S&E) field or those who work in an S&E occupation with a bachelor's degree or higher in any field" (Kannankutty & Wilkinson, 1999, p. 3). It covers engineering graduates, specifically any person age 75 or under residing in the U.S. in 1999 who had received a bachelor's or higher degree in an engineering field. I analyzed the responses of 24,716 engineering graduates, weighted by NSF to represent the 2.3 million employed people who have at least one degree in engineering (Burton & Parker, 1998). Lawrence Burton of NSF provided the unpublished data (personal communication, July 2002). He also reviewed my analysis.

On the surveys, respondents identified their "job code" from a two-page list. NSF tabulated and weighted the responses, and I organized them into six categories. I also estimated a split within engineering occupations into those that matched the engineering degree (such as someone working in industrial engineering who holds an industrial engineering degree) and those occupations that do not match the degree (such as someone working in industrial engineering who holds a mechanical engineering degree). Based on the results (Figure 3.3), I created a survey item: "If you are employed or self-employed, which category below BEST describes your job?"

Comparing the national occupation data (Figure 3.3) to the U-M occupation data (Figure 3.4) there is striking similarity. "Engineer" was reported by 53% of the UM respondents vs. 55% of the NSF estimates. "Science/technology related work that is NOT engineering" was reported by 6% of the UM respondents vs. 14% of the SESTAT total. Marketing and sales was selected by 5% of UM respondents vs. 7% for NSF. Jobs in management were reported by 13% of UM respondents vs. 16% of the SESTAT total. The "other" category was selected by 12% of UM respondents, compared to 8% for SESTAT. Also, 10% of the UM survey respondents opted not to answer this question.

In short, the distributions are similar, except for the UM data having a noticeably smaller portion of the science and technology work that does not include engineering.

Figure 3.3. Occupations of U.S. engineering graduates, from NSF data.

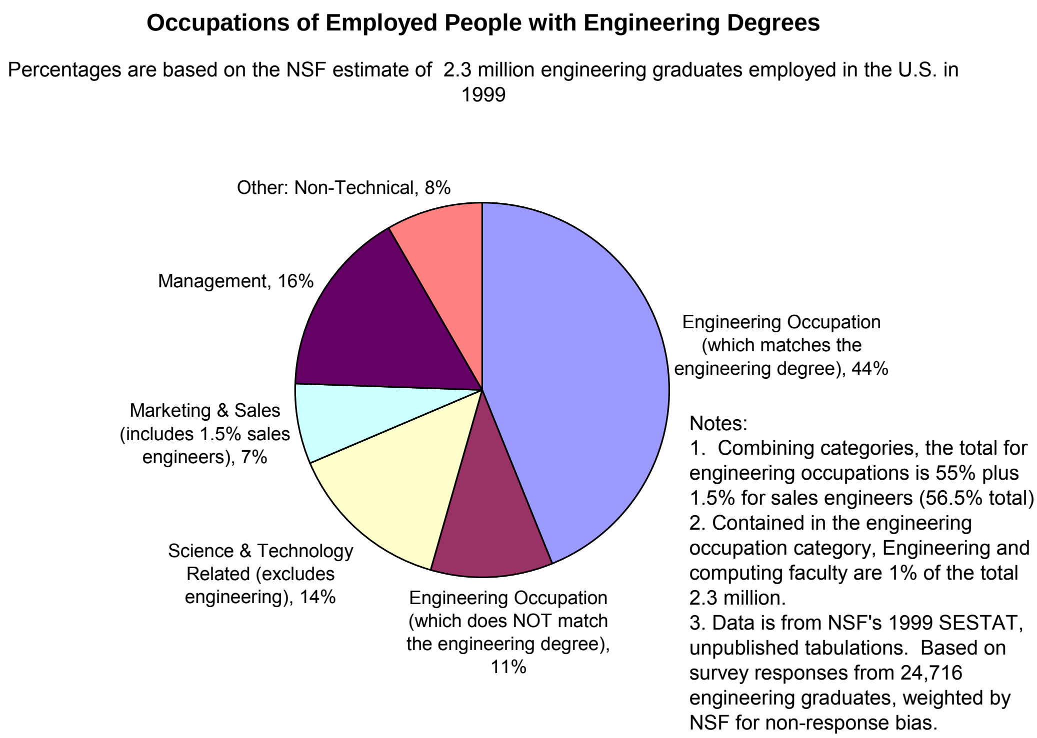
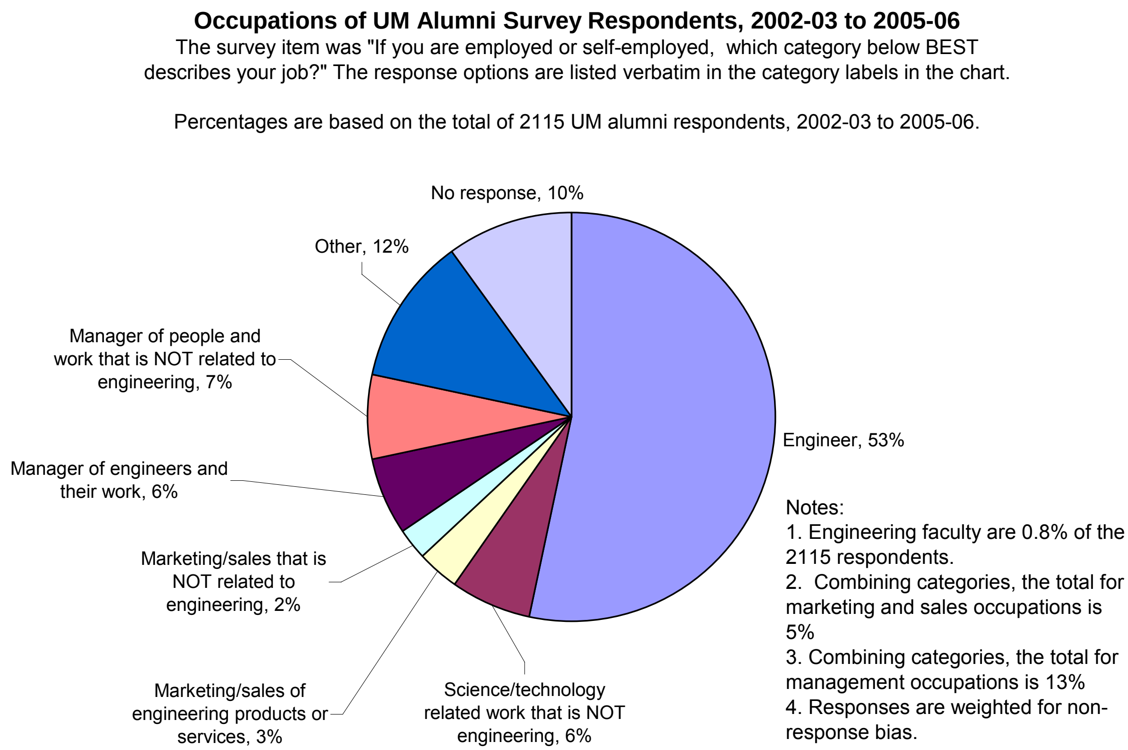


Figure 3.4. Occupations of UM alumni survey respondents, self-reported.



The close percentages of managers is a little surprising because the UM data is limited to those 10 years after graduation, while the SESTAT data includes all employed engineers up to 75 years of age. Taken altogether, it appears that *the UM sample is fairly representative of the U.S. population of engineers with respect to occupation*.

3.2.4 Overview of Data Analysis

Analysis of the UM data will answer these questions:

- Are there relationships between subsets of competencies?
- How does the relative emphasis among competencies differ by sub-groups, such as engineering discipline, environment of engineering practice, number of years since graduation, and demographic groups?
- How does the relative emphasis among competencies change over time, such as by survey year, by graduation year, and by years since graduation?
- How does the relative emphasis among competencies change with alternate wording of the survey questions?

The UM Passow data is appropriate for exploring importance ratings by subgroup in the meta-analysis. I presented a preliminary version of the meta analysis based only on published data (Passow, 2007). Later, I reran the meta-analysis including two sets of new data: the Passow original wording and Passow revised wording studies. *There was <u>no change</u> in the sequence of the descending means by introducing the Passow studies.* The standardized importance ratings for the Passow revised wording study are comparable to the ratings in the meta-analysis (Table 3.2). The only notable changes between the preliminary and final versions are that three competencies changed in importance levels. These shifts were analyzed extensively, and the only one that is of practical significance is for teamwork, which will be discussed in detail in a later section. **I conclude that the Passow data can reveal patterns in groups that should be generalizable to the aggregated meta-analysis results.**

3.2.5 Analyzing Relationships between Subsets of Competencies

Extensive graphing by sub-groups, such as undergraduate majors, field of employment, race, and gender, showed substantial differences in rating patterns among sub-groups. On first exploration, the sub-group data appeared to be a dizzying jumble of

Table 3.2. Comparing the statistically significant importance levels for the meta-analysis and for the Passow data.

Highest Importance Level	**Meta-analysis of 12 separate studies 10, 203 respondents (includes Passow studies – revised & original wording)**	**Differences †**	**Passow data (Revised wording) 2,115 respondents**	**Highest Importance Level**
1	Problem solving Communication Data analysis alone		Teamwork Data analysis alone Problem solving	***1***
2	Ethics		Communication	***2***
3	Life-long learning Teamwork		Life-long learning Ethics Math, science, and engineering skills *Average rating*	***3***
4	Engineering tools Design *Average rating* Math, science, and engineering knowledge		Design Engineering tools	***4***
5	Contemporary issues		Contemporary issues Experiments alone	***5***
6	Experiments alone			
7	Impact		Impact	***6***
Lowest Importance Level				**Lowest Importance Level**

† Arrow types denote differences in level of importance. Solid arrows denote a two-level change, while dashed arrows denote a single-level change. Changes of sequence within a level of importance are not statistically or practically significant.

deviations from the overall pattern of differences among ratings of competencies for the entire data set. However, a strong underlying pattern is evident when the competencies are divided into two categories: professional competencies and technical competencies. The concept of grouping by technical and professional competencies was inspired by a published definition. Shuman, Besterfield-Sacre, and McGourty (2005) defined "professional skills" as ABET's d) teamwork, f) ethics, g) communication, h) understanding impact, i) life-long learning, and j) contemporary issues. They also defined "technical skills" as ABET's a) math, science, and engineering knowledge, b) experiments and data analysis, c) design, e) problem solving, and k) engineering tools. Correlations in the Passow data between importance ratings for the different competencies confirmed that these groupings might apply here and led to factor analysis.

3.2.6 Analyzing Patterns in Importance Ratings

My aim is to determine the overall pattern of differences among the importance ratings of competencies for the sample as a whole, which is the main effect, and also for sub-groups within the sample, such as undergraduate major and gender. Therefore, the design challenge is to choose appropriate statistical tests for comparing the various competencies while minimizing errors.

Four features of the study are critical for selecting tests. First, because each survey respondent rated all twelve competencies, their ratings are related. In other words, the ratings are not independent for each competency because each respondent rated every competency. Thus, in statistical terminology pertaining to the design of experiments, each respondent is a block and each competency is a treatment, which makes this a two-way layout or two-way classification. The two-way layout helps control for variations among raters (harsher and more generous raters), and therefore substantially reduces the chance of failing to detect a difference when, in truth, there is a difference (Type II error) (e.g., Spiegel, 1990; Trumbo, 2002). Second, because the respondents chose their own ratings, the ratings are random variables for each of the twelve fixed competencies (e.g., Devore, 1995; Hogg & Ledolter, 1987). Third, because there are twelve competencies (or treatments) to compare, a post-hoc multiple comparison procedure is recommended for minimizing false detections, in other words detecting a difference when, in truth, there is no difference (Type I error) (e.g., Hsu, 1996; Miller, 1981; Trumbo, 2002). Fourth, histograms of the ratings for the various competencies show that the ratings are not normally distributed. The respondents predominantly used the upper end of the 5-point rating scale, so the ratings are highly skewed and show dramatic ceiling effects. Consequently, because normal distributions cannot be assumed, only nonparametric statistics will be used (e.g., Daniel, 1990; Trumbo, 2002). Thus, statistically speaking, I need to make nonparametric, post-hoc multiple comparisons of location for a mixed-effects, complete block, two-way layout.

To perform nonparametric protected post-hoc multiple comparisons for a two-way layout, methods based on Friedman's rank sums are most commonly used in practice (e.g., Hsu, 1996; Miller, 1986; Zar, 1999). *The first step is to find out if any differences exist among the ratings of the competencies*. To accomplish this, the distribution-free Friedman rank sum test will be used to test the null hypothesis that the population distributions for the treatments are the same (Wagner, 1992), or more specifically that the medians of all the treatments are equal (Daniel, 1990; Trumbo, 2002). This test is "a nonparametric analogue of the parametric two-way analysis of variance" (Daniel, 1990, p. 262). The technique, proposed by Friedman (1937; 1940), assumes that

1) the blocks (respondents in this analysis) are mutually independent,
2) the variable of interest (importance rating in this analysis) is continuous,
3) there are no interactions between blocks and treatments (between respondents and competencies in this analysis), and
4) the observations for each block (or respondent) may be ranked in order of magnitude (Daniel, 1990).

Assumptions 1), 3), and 4) are satisfied. Assumption 2) is not met because the 5-point rating scale is discrete, not continuous. However, there are no nonparametric alternatives for non-continuous data, so this test is the best of the available options. I will perform the test by using the NPAR command in SPSS, using $\alpha = .05$ as the level of significance.

If the first step finds that differences do exist as determined in the Friedman rank sums test, the second step is to perform a multiple comparison test based on the Friedman rank sums which was first proposed by Nemenyi (1963). This test is widely recommended for non-parametric multiple comparisons for complete blocks in a two-way layout (e.g., Daniel, 1990; Hollander & Wolfe, 1973; Miller, 1981, 1986; Oude Voshaar, 1980; Zar, 1999). The null hypothesis being tested is: the distributions are the same for specific pairs of treatments (competencies in this analysis). As with any multiple comparison procedure, the critical values are chosen to limit the Type I error rate *for the entire analysis* instead of for each individual comparison. This is called the experiment-wise error rate or study-wise error rate. Thus, the test sets the global level of significance in the analysis. In this analysis, the level of significance (α = .05) is split among the many comparisons made (typically 66 in this analysis), which properly controls the risk of declaring a difference when that difference is due purely to sampling error, not to real differences in the populations (statistically speaking, a Type I error.) This multiple comparison test reveals the overall pattern of differences in ratings of the competencies.

For this study, I chose Miller's large sample formula for the multiple comparison test (Miller, 1981, equation 131, p. 174).

$$\left|\overline{R}_i - \overline{R}_{i'.}\right| \le q_{k,\infty}^{\alpha}\left[\frac{k(k+1)}{12n}\right]^{1/2} i, i' = 1,\ldots,k$$

where $\overline{R}_i$ is the mean rank for competency *i*, *k* is the number of competencies in the analysis, *n* is the number of respondents in the analysis, and $q_{k,\infty}^{\alpha}$ is the percentage points of the Studentized range (Miller, 1981, Table B1, p. 234-237). In my analysis, the mean ranks for each competency were obtained from the SPSS output for the Friedman rank sums test, k and n were chosen appropriately for each analysis, and q was selected for the corresponding k and for the study-wise error rate of α = .05.

3.2.7 Analyzing Differences in Patterns for Sub-Groups

Recapping so far, I used the Friedman rank sum test and its corresponding Nemenyi multiple comparison test to determine a statistically significant pattern of importance levels in the data set as a whole. I repeated the analysis for each of the 133 sub-groups which are distinguished by demographic variables, time-related variables, undergraduate variables, and post-graduate variables. Altogether, this created 134 graphs like Figure 3.2. My next challenge was to devise an approach for identifying sub-groups whose pattern of ratings differ with statistical significance from the aggregate pattern.

Visual inspection revealed two types of differences from the aggregate pattern. A within-factor shift is a change in the sequence of competencies within the two factors – the professional competencies factor and the technical competencies factor. A between-factor shift is a relative change in ratings between the two factors. I devised three statistical criteria to determine which groups had a pattern of importance ratings that differed significantly from the aggregate. Two criteria address within-factor shifts: the professional competency sequence criterion and the technical competency sequence criterion. A third criterion, the cluster independence criterion, addresses between-factor shifts. Triangulating these three criteria clearly identified 23 groups whose patterns of importance rating differed significantly from the aggregate.

All three criteria are approaches for comparing the statistically significant results of multiple comparison procedures for each group. I used the following procedures for the two criteria that address within-factor shifts: the professional competency sequence criterion and the technical competency sequence criterion. For each sub-group, I examined the statistical "tie lines" for each competency. If any competency was "tied" to another that was beyond an adjacent level in the aggregate, that group violated the criterion. Here is an example. In the Passow revised wording data, the technical competency sequence in the aggregate is 1) problem solving tied with data analysis, 2) "math, science, and engineering", 3) design tied with engineering tools, and 4) experiments. The chemical engineering majors had experiments tied with "math, science, and engineering". In other words, a competency that is at level 4 in the aggregate was tied with level 2, so it leaped above the adjacent level in importance. In this way, chemical engineering was identified as a group that differs with statistical significance on the technical competency sequence criterion.

I used the following procedure for the cluster independence criterion. For each sub-group, I examined the statistical "tie lines" for each competency. If any competencies from the top and bottom clusters were "tied", that group violated the criterion. Here is an example. The top cluster competencies are problem solving, communication, and data analysis, while the bottom cluster competencies are contemporary issues, experiments, and impact. The "materials science and engineering" majors had experiments tied with problem solving and communication. In other words, a competency in the bottom cluster was tied with the top cluster, so it violated the cluster independence criterion with statistical significance.

Only 16 groups have statistically significant deviations from the cluster independence criterion as determined by the Student-Newman-Keuls (SNK) multiple comparison test (studywise $\alpha = .05$). In the SNK, the difference between the mean ranks for pairs of competencies are compared with a critical value based on the total number of competencies, the alpha level, and the number of individuals in the sample (n). For $n = 228$, the critical value for the difference in mean ranks is 1.0, which has intuitive meaning. For smaller n, the critical value for the difference is bigger. The large number of competencies in this analysis creates a very high critical value for groups with small n. Thus, the strict statistical criterion judged that all small groups differed significantly on cluster independence, even when the criterion was clearly met using graphical means. So for the SNK cluster criterion, I used the standard critical value for $n \geq 228$ but modified it for $n<228$. For groups with $n<228$, I used 1.0 as the critical value for the difference in mean ranks. This is equivalent to claiming that $n = 228$ for all the small groups. Practically speaking, this is still a conservative test because the critical value is more than 5 times larger than for the aggregated sample. Some groups, such as "materials science and engineering" majors exceeded the modified critical value and were flagged as differing statistically from the aggregate and so are included in the list of 16 groups that have statistically significant deviations on the cluster independence criterion.

3.2.7 Analyzing Differences over Time and for Alternate Wording

Differences over time were examined as for any other sub-group. I used the three statistical criteria: the professional competency sequence criterion, the technical competency sequence criterion, and the cluster independence criterion.

Differences in importance ratings due to alternate wordings were examined by direct comparison. The “tie lines” for the two data sets were compared to determine statistically significant differences in the pattern of importance ratings.

3.3 Limitations

This study synthesizes the opinions of 10, 203 engineering graduates about *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* These are the research questions. To answer them, two data sets were coordinated. To identify aggregate patterns, I conducted a meta-analysis of 10 published studies plus two unpublished surveys from the University of Michigan (UM). To delve into differences by sub-group, I further analyzed UM’s 4225 survey responses. *Both analyses used the same approach: statistically testing the null hypothesis that there are no differences in the importance ratings for the various competencies.* To accomplish this, I used protected post-hoc, all-pairwise multiple comparisons in which each competency is analogous to an experimental treatment.

There were limitations in data collection for the meta-analysis. Although great care was taken to make a comprehensive search, there are suspected limitations in coverage of the literature for included studies. Two of the three initial studies were not additionally identified in data base searches. Thus, additional, related, studies may exist, especially unpublished studies made to inform faculty decision-making.

There were limitations in the data collection for the UM data. The response rates on the UM surveys were low enough to cause concern about non-response bias. To compensate, differential weighting to reduce non-response bias was considered for the variables: gender (alumni and senior), race (alumni and senior), year of graduation (alumni only), semester of graduation (senior only), undergraduate major (alumni only), and how the graduate entered the CoE (senior only). After considering the tradeoff between reducing non-response bias and the statistical instabilities introduced by differentially weighting cases, the following variables were chosen for weighting because of their likely affect on the analysis: gender, race, and year (or semester) of graduation.

There were limitations in the data analysis in the meta-analysis. The first limitation was in calculating the effect sizes. Effect size is based on a comparison group, for which I chose the *ABET mean*: the average rating for the subset of competencies that match ABET's Criterion 3a-k. The *ABET mean* and its corresponding standard deviation eliminate the problem of extraneous competencies. However, only two of the studies included all eleven of the ABET competencies. When studies did not include all eleven of the ABET competencies, the *ABET mean* omits competencies of interest in the meta-analysis and, therefore, it groups different competencies for each study. Yet, the *ABET mean* is a more uniform metric than an alternative metric, the *overall mean*, which includes all competencies in the study, whether or not they are included in other studies.

There were limitations in the data analysis for the UM data. Histograms of the ratings are highly skewed and not normally distributed. The respondents predominantly used the upper end of the 5-point rating scale, showing dramatic ceiling effects. Consequently, because normal distributions cannot be assumed, only nonparametric statistics were used. The non-parametric Friedman test assumes that the variable of interest (importance rating in this analysis) is continuous. This assumption is not met because the 5-point rating scale is discrete rather than continuous. However, there are no nonparametric alternatives for non-continuous data, so this test is the best available.

As described above, there are limitations in the data collection and data analysis phases for both the meta-analysis and the analysis of the UM data. However, strong agreement in the results from twelve independent data sources and two independent approaches to the analysis reduces concern over these limitations.

1) The two approaches to data collection – meta-analysis and the UM data – greatly compensate for limitations. Although there may be studies omitted from the meta-analysis, the agreement with theoretical predictions and other empirical work outside of

the meta-analysis mitigates this concern. Response rates for the U-M data may have been low, but occupations in the UM sample are strikingly similar to the national population of engineers and weighting reduced non-response bias.

2) By triangulating the results of two entirely different sets of statistical tests, limitations in analysis counteract each other. Specifically, the meta-analysis uses a limited *ABET mean*, but multiple levels of aggregation allow for parametric statistics. Although the UM data would ideally be continuous for the non-parametric Friedman test, the strong agreement of results with the meta-analysis indicates that this is not a serious limitation.

Overall, combining results across different studies and employing two complementary analyses overcomes many limitations. For example, limitations due to using one wording are transcended in such a way that the results determine the relative emphasis among the constructs that underlie the wording of any particular competency. The study design, which coordinates multiple data sources and two approaches to analysis, enhances the generalizability of the results.

CHAPTER 4. RESULTS

The new competency focus for engineering education "has significant implications for what knowledge and skills faculty need" (Doherty et al., 1997, p. 182). Under the learning paradigm with a competency focus, curriculum designers consider questions of purpose for each academic program, such as "what competencies should students have at graduation?" and "what should the relative emphasis be among those competencies?" These practical questions are the research questions of this study.

Four findings from published research undergird this study. First, the overall pattern of importance among competencies depends on the practice setting; this central hypothesis of this study has wide support in theory (e.g., Holland, 1997) and empirical work. Second, there are competencies important for engineering graduates beyond ABET's eleven according to theory about competency in the professions and empirical studies. Third, theories predict and surveys show that faculty's pattern of importance ratings differs noticeably from that of other engineers, which implies different opinions about ideal emphasis in the curriculum and motivates my study. Thus, for curriculum design decisions, faculty will gain fresh perspective from the opinions of practicing engineers. Fourth, importance ratings depend on survey wording.

This study synthesizes the opinions of engineering graduates about *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* These are the research questions. To answer them, two data sets were coordinated. To identify aggregate patterns, I conducted a meta-analysis of 10 published studies plus two unpublished surveys from the University of Michigan (UM). To delve into differences by sub-group, I further analyzed UM's 4225 survey responses. Both analyses used the same strategy: statistically testing the null hypothesis that there are no differences in the importance ratings for the various competencies. Coordinating these two data sets increases the generalizability of the findings. Naturally, data from a single institution, a single survey, and a prescribed set of competencies (i.e., ABET's list) would lead to uncertainty about generalizability. The meta-analysis of over 10, 000 responses eliminates these sources of uncertainty. On the other hand, aggregated data from a meta-analysis would lead to uncertainty about significant differences among sub-groups and changes over time. The U-M analysis addresses both these concerns. By coordinating the two data sets, the findings can be generalized with confidence.

During preliminary analysis, the research questions splintered, leading to cascading questions of greater detail. Results are reported by these specific questions. According to engineering graduates,

- Which competencies are important for engineering graduates?
- What should the relative emphasis be among competencies for engineering graduates?
- Questions for refining the analysis:
    - Are there relationships between subsets of competencies?
    - How does the relative emphasis among competencies differ by sub-groups, such as engineering discipline, environment of engineering practice, number of years since graduation, and demographic groups?
    - How does the relative emphasis among competencies change over time, such as by survey year, by graduation year, and by years since graduation?
    - How does the relative emphasis among competencies change with alternate wording of the survey questions?

4.1 Important Competencies for Engineering Graduates

According to engineering graduates, which competencies are important for engineering graduates? The meta-analysis answered this question for ABET-mapped and for non-ABET competencies. For each study in the meta-analysis, the lowest rated ABET competency was selected. The lowest ratings ranged from 2.48 to 3.99 – mean of 3.22 – on a five-point scale, with "5" being most important. Consider how respondents would rate a competency they deemed unimportant. The lowest possible rating on the scale is "1", so a competency deemed unimportant would have a mean rating close to 1.0. At 2.48, the lowest rated ABET-mapped competency is far above the theoretic minimum.

Therefore, the absolute importance of the lowest rated competency is still important (2-4 on a 5-point scale).

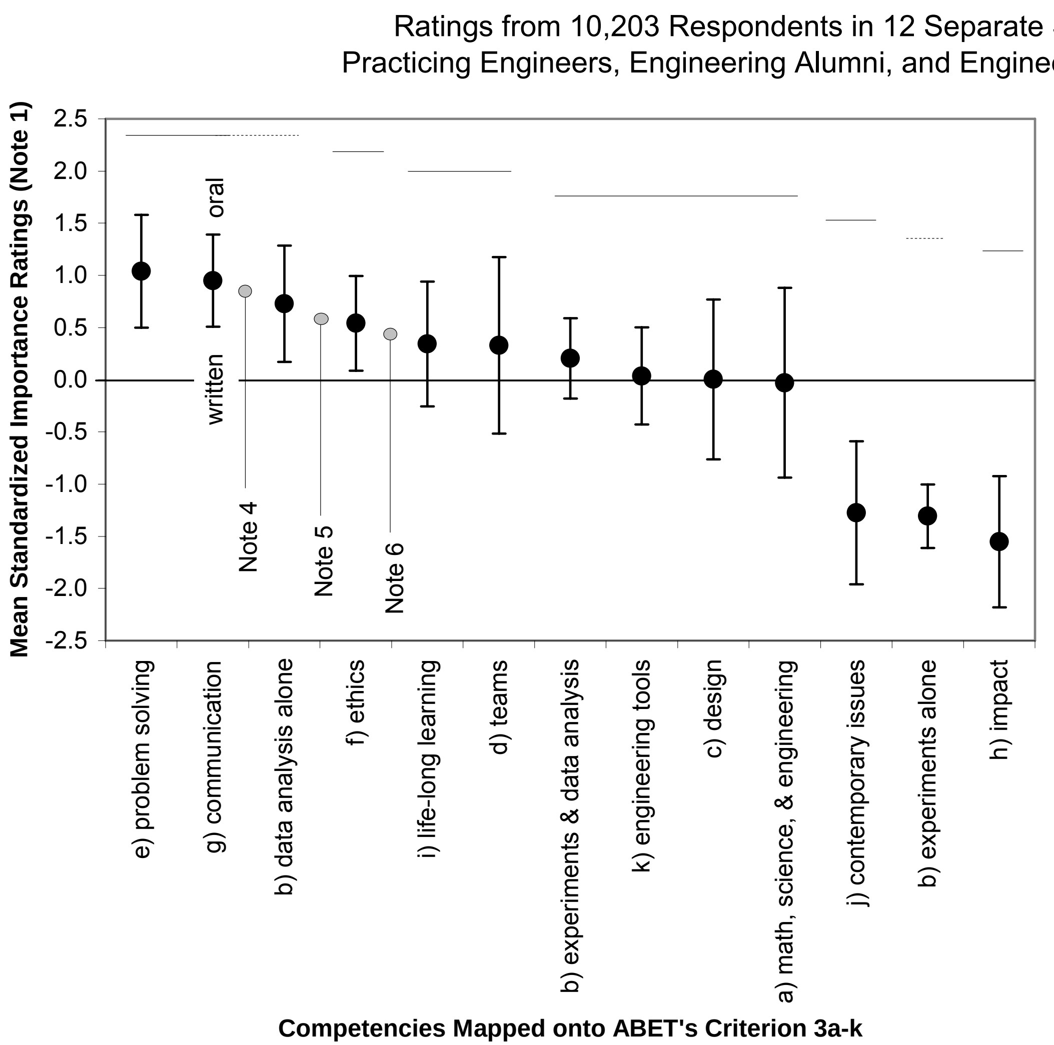
Non-ABET competencies were compared to ABET-mapped competencies. Note in Figure 4.1 that the highest standardized rating in the third level of importance is .34, which is far above the average of zero (0). Practically speaking, any rating above .40 is equivalent to the highest two importance levels. By this criterion, several non-ABET competencies (Table C12) were deemed important, including decision-making (highest importance), commitment to achieving goals, the ability to integrate theory and practice, leadership skills, and project management (lowest importance).

One other non-ABET competency is of note: business practices. Business practice was omitted from ABET's program outcomes even though it was listed in all three of ABET's source documents (American Society for Engineering Education, 1994; McMasters & Komerath, 2005; National Research Council, 1995). In the meta-analysis, six items in four separate survey studies address business practice with items referring to accounting, business strategies, economic analysis, business context, and management practices and skills. In every one of the ten diverse populations surveyed by these questions, the standardized importance ratings fell well below the mean. This is weak evidence that business practices may be a competency deemed relatively unimportant in comparison to the ABET competencies. Research designed to test this idea is warranted.

4.2 Relative Emphasis among Competencies

One of the specific research questions is, according to engineering graduates, "What should the relative emphasis be among competencies for engineering graduates?" The meta-analysis provides *aggregate* answers to this question (Figure 4.1), which will be refined by later results. There are three key findings to note. 1) The competencies were rated in seven statistically distinct levels of importance (studywise $\alpha = .05$), denoted by the "tie lines" at the top of the graph. For example, problem solving, communication, and data analysis have descending standardized ratings, but their importance levels do not differ with statistical significance. Yet, ethics' level of importance differs statistically from both data analysis and life-long learning.

Figure 4.1. Mean importance ratings of competencies from the meta-analysis.



● Overall means (n= 21 populations from 12 studies, 10203 respondents), Error bars are +/- 1 standard deviation

Notes

1) **Standardized ratings**
Ratings were standardized for each *population* :
(mean rating for a competency - grand mean rating for all competencies in the ABET basket)/
(standard deviation of mean ratings in ABET basket). Thus,
- standardized rating = 0 indicates the average importance rating for the ABET-mapped competencies
- standardized rating > 0 indicates an above average importance in that population
- standardized rating < 0 indicates a below average importance in that population

2) **Tie lines show 7 levels of importance**
Horizontal "tie lines" above the data "tie together" competencies whose overall mean ratings are not significantly different (studywise $\alpha = 0.05$). Solid lines include all studies, dashed lines are for competencies in only 3 studies.

Notes on non-ABET competencies

3) For **communication**, oral rated significantly higher than written (5 studies, 8 populations, n=3821, $\alpha = 0.01$)

4) ***Importance Level 1*** : Decision-making (1 study), Commitment to achieving goals (2 studies)

5) ***Importance Level 2:*** Ability to integrate theory and practice effectively in professional work settings (1 study)

6) ***Importance Level 3:*** Leadership skills (1 study) and project management (1 study)

2) Oral communication rated significantly higher than written communication in five studies (a total of 8 populations and n = 3821, $\alpha = .01$). 3) Data analysis alone is rated as much more important than experiments alone. When data analysis and experiments are combined in a single competency, as in ABET's criteria, the rating is essentially the average of the two separate ratings. Evidence for this finding is based on question wording. Two studies worded their competency as a combination of data analysis and experiments. Lattuca, et al. (2006) used ABET's wording, verbatim: "ability to design and conduct experiments as well as to analyze and interpret data." Bankel, et al. (2003) wrote "Experimentation and knowledge discovery; hypothesis formation; survey of print and electronic literature; experimental inquiry; hypothesis testing and defense." Two studies worded their competencies distinctly. Lang, et al. (1999) included a "demonstrated ability in data analysis and interpretation" and a "demonstrated ability in design of experiments". My own data from the UM revised wording study used the "ability to analyze and interpret data" and "ability to design and conduct experiments". These findings indicate that these are truly two distinct competencies, although currently ABET lists them as one.

How universal is this aggregate pattern of importance ratings? The four refining research questions address universality. For example, Holland's theory predicts that each work environment or academic discipline has a distinctive pattern of competencies, values, attitudes, interests, and self-perceptions. These distinct patterns are maintained and transmitted both through self-selection of congruent individuals and socialization for all individuals in the field. In short, a person's undergraduate major and their post-graduate work environment will each strongly influence their competencies and related values. Thus, Holland's theory predicts differences in the pattern of importance ratings of competencies based on undergraduate major and post-graduate work environment. Do other subgroups, such as demographic groups, differ from the aggregate pattern? Does the aggregate pattern vary over time or career stage? These questions were addressed in subsequent sections.

4.3 Relationships Between Subsets of Competencies

A question about the aggregate pattern is, "Are there relationships between subsets of competencies?" The Passow data (UM revised wording data) answered this question. The large number of positive correlations between importance ratings prompted a factor analysis. The assumptions for factor analysis were met. 1) The Kaiser-Meyer-Olkin measure of sampling adequacy (KMO) is .772, so there is a "middling" degree of common variance. 2) The Bartlett's test of sphericity is 2901 with $p < .00001$, which indicates that there is enough shared variance among the importance ratings for the various competencies to proceed with a factor analysis. For the 2115 respondents to the UM alumni survey (revised wording), the most interpretable factor solution is two factors, which explain 44.78% of the variance in the importance ratings in the competencies. Three factor and four factor solutions had multiple cross-loadings.

Table 4.1 shows the partial correlation between each competency and the rotated factor. Using the typical cut-off, partial correlations above .35 are interpreted as loading on a factor. The result is two factors that are consistent with a popular, published grouping that has face validity for many engineering faculty. Shuman, Besterfield-Sacre, and McGourty (2005) defined "professional skills" as ABET's d) teamwork, f) ethics, g) communication, h) understanding impact, i) life-long learning, and j) contemporary issues. They also defined "technical skills" as ABET's a) math, science, and engineering knowledge, b) experiments and data analysis, c) design, e) problem solving, and k) engineering tools. Also confirming the validity of my factors is a related study. Factors of similar composition were found in a study of 4,400 recent engineering graduates (Volkwein & Yin, 2007). That survey asked for self-assessed ability levels at the time of graduation for various competencies. Ability level at the time of graduation and importance in the workplace are completely distinct concepts. However, the resemblance of my factor solution to Volkwein and Yin's is confirming. In light of theory (Holland, 1997; Spencer & Spencer, 1993; Stark et al., 1987), I call my two factors *professional competencies* and *technical competencies*. The importance ratings for each competency are shown in Figure 4.2.

Table 4.1 The two factors rotated component matrix

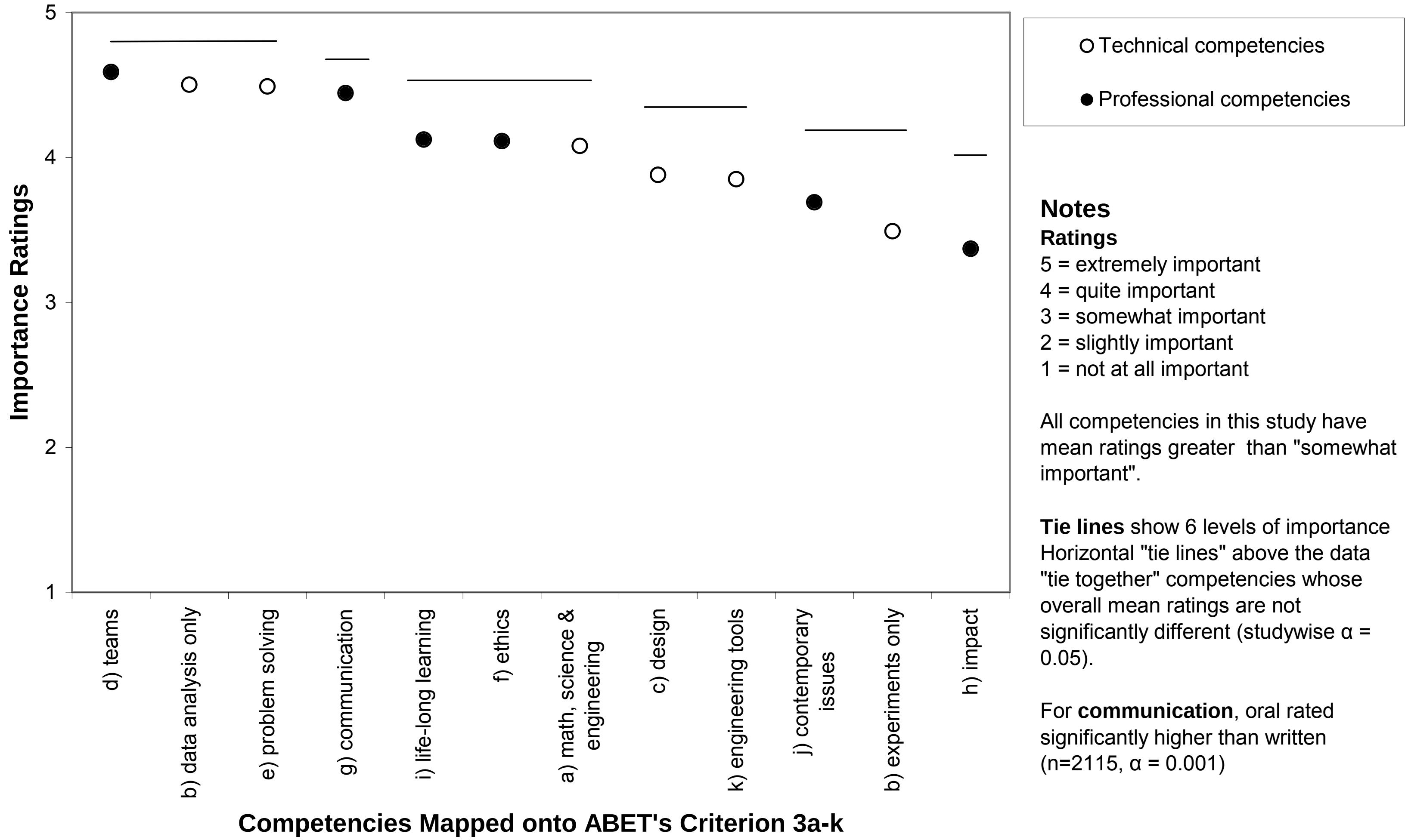
		Component	
		1	2
Technical competencies	Engineering tools	.733	.101
	Math, science & engineering knowledge	.698	.072
	Experiments alone	.694	.042
	Problem solving	.687	.097
	Data analysis alone	.620	.195
	Design	.615	.063
Professional competencies	Understanding impact	.042	.736
	Ethics	.012	.697
	Contemporary issues	.129	.681
	Communication	.028	.646
	Life-long learning	.203	.565
	Teamwork	.128	.509

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.
a Rotation converged in 3 iterations.

For subsequent analysis, differences among the groups are of primary interest. Can these two factors replace the individual competencies for further analysis? The answer is not entirely. Factors combining professional competencies and technical competencies illuminate some general trends, but the 12 independent competencies are necessary to fully capture differences in importance ratings among groups. The factors appeared without any cross-loading in many groups, including men and women, all three alumni years (2-yrs-out, 6-yrs-out, 10-yrs-out), and five undergraduate majors (aerospace engineering, chemical engineering, electrical engineering, industrial and operations engineering, and mechanical engineering). However, for some groups, especially groups with small n (n<100), there was moderate cross-loading between the factors. Examples are

- transfer students from a two-year college
- several majors (civil engineering, computer engineering, "materials science and engineering", "naval architecture and marine engineering", and "nuclear engineering and radiological sciences"), and

Figure 4.2. Importance ratings in the aggregated Passow data (revised wording) with factors.



- several engineering job categories (engineer, marketing/sales of engineering products or services, and manager of engineers).

Furthermore, for groups less related to engineering the cross-loading was so substantial that the factors were meaningless. Examples are those with law degrees and those with non-engineering job categories (science/technology related work that is not engineering, marketing/sales that is not related to engineering, and manager of people and work that is not related to engineering). Together, these findings show that factors are incapable of capturing all of the differences in importance ratings among sub-groups that are a central aim of this analysis. Therefore, the 12 individual competencies cannot be abandoned in favor of the factors. Both competencies and factors will be employed in the statistics.

4.4 Differences in Relative Emphasis by Subgroup

How does the aggregate pattern of importance ratings in Figure 4.1 change by sub-groups, such as engineering discipline, environment of engineering practice, number of years since graduation, and demographic groups? Theories (Holland, 1997; Spencer & Spencer, 1993; Stark et al., 1987) predict differences in the pattern of importance ratings of competencies based on undergraduate major and post-graduate work environment. Empirical work confirms this prediction for engineering work environments (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Saunders-Smits, 2005, 2007; Shea, 1997). Further exploration of differences among sub-groups requires a large data set for sufficient statistical power. I explored the Passow data (UM revised wording data and original wording data) to determine which subgroups differ and how.

4.4.1 Which subgroups differ?

As described in the methods, I devised three statistical criteria to identify groups whose pattern of importance ratings differs significantly from the aggregate. Two criteria address within-factor shifts: the professional competency sequence criterion and the technical competency sequence criterion. A third criterion, the cluster independence criterion, addresses between-factor shifts. Triangulating these criteria identified groups whose patterns of importance ratings differed significantly from the aggregate.

4.4.1.1 Overview of results of three statistical criteria

For the revised survey wording, there are 79 out of 133 groups that match the aggregated overall patterns according to my three criteria. When criteria are applied to determine if the differences from the aggregate pattern are statistically significant, only 23 out of 133 groups had significant differences from the aggregate.

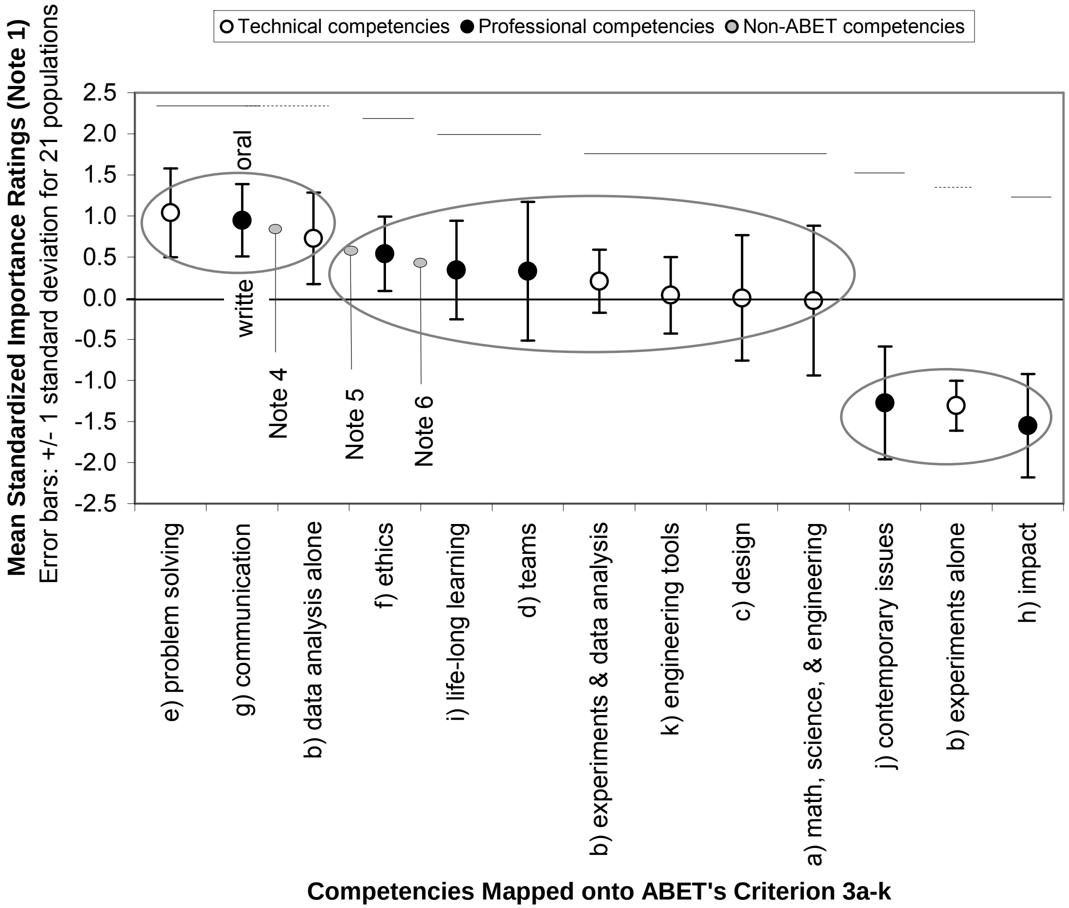
1) *Professional competency sequence criterion* – The descending sequence of the mean ratings for the professional competencies matches the aggregate: teamwork, communication, life-long learning, ethics, contemporary issues, and understanding the impact of one's work. Of all 133 groups, 107 match the aggregate on professional competency sequence. Only one (1) group's sequence differs significantly among the professional competencies.

2) *Technical competency sequence criterion* – The descending sequence of the mean ratings for the technical competencies matches the aggregate: problem solving, "math, science, engineering knowledge", design, engineering tools, and experiments. Of all 133 groups, 88 match the aggregate on technical competency sequence. Only 13 groups' sequence differs significantly among the technical competencies.

3) *Independent clusters criterion* – In the meta-analysis data, there are seven, statistically distinct importance levels (Figure 4.1). When the importance levels are combined into clusters (Figure 4.3), the aggregated Passow data and most of its groups resemble this pattern. From this perspective, the competencies in the highest level of importance – problem solving, communication, and data analysis – can be called the *top cluster*, while the competencies in the lowest two levels – contemporary issues, experiments, and impact – can be called the *bottom cluster*. This creates an *intermediate cluster* of the remaining competencies: ethics, life-long learning, teamwork, engineering tools, design, and "math, science, and engineering knowledge". The independent clusters criterion is as follows: the ratings for all competencies in the top cluster are statistically distinct from all competencies in the bottom cluster, while competencies in the intermediate cluster may be statistically tied to the top or bottom clusters. Note that the

Figure 4.3. Statistically distinct levels of importance among competencies for engineering graduates. Clusters of importance hold across all demographic, developmental, and time-related variables. The only exceptions to this pattern (Table 4.2) are for groups based on work environment or academic discipline.

Ratings from 10,203 Respondents in 21 populations from 12 Separate Studies of Practicing Engineers, Engineering Alumni, and Engineering Faculty



Notes

1) Standardized ratings

Ratings were standardized for each *population* :
(mean rating for a competency - grand mean rating for all competencies in the ABET basket)/ (standard deviation of mean ratings in ABET basket). Thus,

- standardized rating = 0 indicates the average importance rating for the ABET-mapped competencies
- standardized ratings > 0 are above average
- standardized ratings < 0 are below average

2) Statistically significant levels of importance

- Horizontal "tie lines" above the data "tie together" competencies whose overall mean ratings are not significantly different (studywise α = 0.05) in the 21 populations in the meta-analysis. Solid lines include all studies, dashed lines are for competencies in only 3 studies.
- Gray ovals denote clusters of importance consistent across all demographic groups, developmental levels, time-related variables, and most majors and work environments (1 population (n=2115)). The clusters are are statistically significant (studywise α = 0.05). The rule: top cluster competencies consistently rate as significantly more important than bottom cluster competencies, while those in the intermediate cluster may be statistically tied to the top or bottom clusters, depending on work environment or academic discipline. See Table 4.5 for the few exceptions.

Notes on non-ABET Competencies

3) For **communication**, oral rated significantly higher than written (5 studies, 8 populations, n=3821, α = 0.01)
4) Decision-making (1 study), Commitment to achieving goals (2 studies) **5)** Ability to integrate theory and practice effectively in professional work settings (1 study)
6) Leadership skills (1 study) and project management (1 study)

statistically significant three clusters of competencies correspond with the discontinuities in mean rating. Of all 133 groups, 102 match the aggregate on cluster independence.

Only 16 groups have statistically significant deviations from the cluster independence criterion as determined by the Nemenyi multiple comparison test (studywise $\alpha = .05$). In other words, the clustered levels of importance (Figure 4.3) hold for 88% of the 133 sub-groups in the Passow revised wording study. Of the 16 groups that differ significantly from this rule, 15 had one or more competencies in the bottom cluster rated very high, which resulted in their statistical equivalence with the top cluster. In eleven (11) of these groups, experiments rated high, in five (5) issues rated high, and in four (4) impact rated high. In eight (8) of the sixteen (16), one of the competencies in the top cluster rated low, which resulted in their statistical equivalence with the bottom cluster. In five (5) of these groups, problem solving rated low and in three (3) communications rated low. These 16 groups will be described in combination with those identified by the other statistical criteria in the next section.

4.4.1.2 Triangulated results of the three statistical criteria

As described above 79 groups matched the aggregate perfectly on all three criteria. These 79 groups included every group defined by the following questions: gender, grade-point-average, professional engineering status, number of additional degrees, and the year of survey collection. Other groups had deviations from the criteria that were not statistically significant. These included all groups distinguished by race, alumni year (or years since graduation), graduation year, method of entry to the College of Engineering (1st time freshman, transfer student, etc.), satisfaction with career services, number of undergraduate majors, and job category (engineering, management, marketing, etc.). **In all, the majority of groups (110 out of 133 groups or 83%), match the aggregate pattern on all three statistical criteria.**

Thus, the aggregate pattern is strong and holds for a wide variety of groups. However, the questions that arise are: a) Which are the 23 groups that do not statistically match the aggregate pattern? and b) What are the common themes among those groups?

Only 9 of the 24 questions on the survey defined groups that had statistically significant deviations from the aggregate pattern shown in Figure 4.3. These groups are:

- employer's business (7 of 18)
- undergraduate major (4 of 11)
- engineering job type (4 of 13)
- type of additional degree (3 of 8)
- number of employers since graduation (1 of 7)
- employment status (1 of 4)
- career satisfaction (1 of 5)
- annual income (1 of 8)
- satisfaction with the undergraduate experience (1 of 5 groups).

All 23 of the groups exhibiting a statistically distinctive pattern of importance ratings were based on academic field or work environment, as predicted by Holland's theory. None of the groups of statistical difference involved demographic or time-related variables. Eighteen (18) of the groups obviously represent either a work environment (e.g., employer's business or type of engineering job) or an academic field (e.g., undergraduate major and additional post-graduate degrees). **Note that one of the significantly different groups is engineering faculty**.

The remaining five (5) groups do not at first seem directly related to work environments or academic fields, but on deeper investigation proved to be so. One group is "neither working nor students". This is actually the null option for work environment. Another group (income = 2, $21k-40k) appears to be totally unrelated to work environment. However, examining the individual responses in this group reveals that respondents in this group are either students – typically graduate students in engineering – or employed in fields outside of engineering. For example, 10% worked as K-12 teachers, 7% were in the military, others were working for non-profits, and one had become a missionary. A few were starting up consulting work in IT or in finance. In light of this discovery, I split the group into "income2 – students" and "income2-employed" and then reanalyzed the importance ratings for each group. Thus, "income=2" is actually a group based on work environment. The group "numempl0" (those with zero employers since graduation) turned out to be entirely composed of students, predominantly students in professional schools such as medical and law school. In short, this variable also represents a type of work environment.

The group "satcareer=1" (very dissatisfied with career) are bound together by a yearning for career change away from engineering. Over 70% of this group had already made dramatic career changes, such as to managing a hotel or becoming a veterinarian, or were in the process of doing so. Another 14% were jobless. The comments of all these individuals revealed a strong underlying theme: the respondents realized that their values and interests were not aligned with engineering work environments and they were seeking a better fit. This is the essence of Holland's self-selection to work environments. Similarly, the group "satunderg=1" felt a lack of fit with their undergraduate major. Two-thirds of the group eloquently described how their undergraduate environment did not support their learning. The other third clearly stated how their undergraduate curriculum omitted the skills and competencies that were of the highest value to them.

In summary, "which subgroups differ from the aggregate pattern of relative emphasis?" The majority of groups (110 out of 133 groups or 83%), match the aggregate pattern on all three statistical criteria. All 23 of the groups exhibiting a statistically distinctive pattern of importance ratings were based on academic field or work environment, as predicted by Holland's theory. Note that one of the significantly different groups is engineering faculty.

4.4.2 How do the subgroups differ?

The three statistical criteria – professional competency sequence, technical competency sequence, and cluster independence – identified 23 groups that differed statistically from the aggregate. These were examined for themes in how they differ.

The qualitative nature of differences from the aggregate can be best described with simple language. I chose a descriptive threshold based on "jumps"[2]. I chose a threshold of three jumps, which is .375 on the 5-point importance rating scale, for identifying importance ratings that differ from the aggregate with practical significance. I say that a group's rating for a competency is "above the aggregate" if it is more than

[2] A "jump" is the average distance between two competencies in the aggregate data. Therefore, an increase of one jump ties a competency with its neighbor in the aggregate sequence, two jumps places it beyond its neighbor (however neighbors switching order is not notable for subgroups), and three jumps positions a competency far beyond its neighbors in the aggregate sequence, which is surely different.

.375 above the aggregate rating (on the 1 to 5 importance scale on the survey). I say that a rating is "below the aggregate" if it is more than .375 below the aggregate rating. Similarly, I call a rating "far above" or "far below" if it is six jumps (or .75) away from the aggregate rating for that competency. Table 4.2 describes *how* the statistically differing groups differ from the aggregate. These significant differences from the aggregate can inform faculty when designing curriculum for specific academic programs.

4.4.2.1 Differences from the aggregate by major or work environment

Table 4.2 identifies how specific majors and work environments differ from the aggregate in the Passow revised wording data. I used the same three statistical criteria to examine differences from the aggregate pattern for each major in a second dataset. The Passow original wording data (n=2110) surveyed the same majors: aerospace engineering, chemical engineering, civil engineering, computer engineering, electrical engineering, "industrial and operations engineering", "materials science and engineering", mechanical engineering, "naval architecture and marine engineering", and "nuclear engineering and radiological sciences". *Not one of the ten majors differed significantly from the cluster pattern in the aggregate.* However, there were some differences from the aggregate on specific competencies. As in the Passow revised wording data, "materials science and engineering" majors rated experiments significantly above the aggregate, but not enough to violate the cluster independence criterion. Also, the computer engineering majors rated design significantly above the aggregate sequence as in the revised wording data. In the original data, civil engineering majors rated learning significantly below the aggregate and impact significantly above. The same pattern of differences is graphically evident in the revised wording data, but it is not statistically significant. Likewise, "nuclear engineering and radiological sciences" majors rated design significantly below the aggregate in the original wording data – a statistically significant instance of a pattern seen graphically in the revised wording data.

Table 4.2. Descriptions of each group that differs significantly from the aggregate pattern in Figure 4.3.

Undergraduate majors that differ significantly from the aggregate

- ***Chemical engineering*** and "***materials science and engineering***": Experiments rate above the aggregate.
- ***Computer engineering*** and ***computer science***:
  Design and engineering tools rate above the aggregate, while impact rates below the aggregate.

Work in engineering environments that differ significantly from the aggregate

- ***Communications industry:*** Experiments rate far above the aggregate, and engineering tools and teamwork rate above the aggregate.
- ***Computer hardware:*** Experiments and engineering tools rate above the aggregate.
- ***Engineering faculty***: Experiments, design, and learning rate far above the aggregate and teamwork, problem solving, communication, and impact are above the aggregate, while engineering tools rate below.
- ***Engineering research*** (engineering researchers and those holding a doctorate in engineering): Experiments rate far above the aggregate and "math, science, and engineering knowledge" rate above the aggregate. The doctorate holders additionally rate problem solving, life-long learning, and engineering tools above the aggregate.
- ***Medical devices***: Experiments rate far above the aggregate and "math, science, and engineering knowledge", engineering tools, and design rated above.
- ***Pharmaceutical/biotech***: Experiments and impact rate above the aggregate.
- ***Software engineering***: Design, engineering tools, and rate above the aggregate, while impact rates below the aggregate.
- ***Test engineering:*** Experiments rate above the aggregate.

Work environments and jobs outside of engineering that differ significantly from the aggregate

Several jobs and work environments were outside of engineering: **medical doctors** and **health services**, and assorted **others**. Among these, one technical competency (or more) rates below or far below the aggregate. The medical doctors rate ethics, life-long learning, contemporary issues, and impact above the aggregate, while they rate problem solving, engineering tools, and design below the aggregate.

4.4.2.2 Differences from the aggregate by theme

Themes among differences are also informative. There are two consistent subsets of competencies (factors) – professional competencies and technical competencies. In the meta-analysis, the professional competencies are: oral communication (most important), written communication, ethics, life-long learning, teamwork, contemporary issues, and understanding the impact of one's work (least important). In the Passow revised wording study, the professional sequence criterion shows a universal order of importance for over 99% of the groups. Only two majors rate any professional competencies below the aggregate – computer engineering and computer science majors. Both rate impact below the aggregate, though it maintains its position in the descending order of importance. This pattern is repeated among those working on computer hardware and computer software. The two findings above demonstrate that the professional competencies are consistently rated as important across all engineering majors and post-graduate work environments, even among groups that differ statistically from the aggregate. **Essentially, graduates in all engineering majors value the professional competencies at the aggregate level and sequence.**

In the meta-analysis, the sequence of technical competencies is: (most important) problem solving, data analysis, engineering tools, design, "math, science, and engineering knowledge", and experiments (least important). In the Passow revised wording study, the technical sequence criterion shows that more than 90% of the groups rated the technical competencies in a single order of importance. In the 13 groups that differed from this sequence of technical competencies, all of the differences have face validity based on work environment or academic discipline. For example, chemical engineering majors and "materials science and engineering" majors rate experiments higher than design and engineering tools. A plausible explanation for this is that these fields rely heavily on experimentation because chemical and material phenomena are more complex than can be predicted by mathematical modeling alone. Also, majors in computer engineering and computer science rate design and engineering tools above "math, science, and engineering knowledge". Likely, this is because design and engineering tools are more valuable competencies in software engineering, their typical field of practice.

Essentially, graduates in all engineering majors value the technical competencies at the aggregate level and sequence. There are two exceptions: 1) majors in chemical engineering and "materials science and engineering" rate experiments above design and engineering tools, and 2) majors in computer engineering and computer science rate design and engineering tools above "math, science, and engineering knowledge".

More than 2/3 of the groups having a statistical tie between the top and bottom clusters differ because they rated experiments very high. Only one cluster-crossing group is an undergraduate major. **Essentially, graduates in all engineering majors value the competencies in the clusters described in the aggregate. There is one exception: "materials science and engineering" majors rate experiments equal to the top cluster.**

Two distinctive themes emerged for specific work environments. 1) Competency with experiments is prized by researchers in any field, including those holding doctorates (in engineering or outside of engineering), engineering researchers, engineering faculty, and engineering graduate students. 2) Life-long learning is rated above the aggregate by medical doctors, students in professional schools, those who hold doctorates in engineering, and graduate students in engineering. Engineering faculty rate life-long learning far above the aggregate.

4.4.2.3 Understanding the large variance for teamwork in the meta-analysis

In the meta-analysis, teamwork has the largest variance of any competency (Figure 4.3). This was also true in a preliminary version of the meta-analysis which omitted all the Passow data. Although the meta-analysis was unchanged by adding the two Passow studies, it is perplexing that teamwork was consistently the second-rated competency in the Passow original wording data and consistently the first-rated competency in the Passow revised wording data, yet its mean rating in the meta-analysis is in the middle of the pack. Table C4 shows wordings and ratings for this competency.

One hypothesis was that the importance of teamwork increased when the defense industry dominance of the Cold War gave way to globalization in engineering. The data conclusively contradicts this hypothesis. Teamwork's highest rating was in the earliest study (1992) and its second highest rating is in the Passow data which was collected annually from 1999 to 2005 with a consistent importance rating throughout the period.

A second hypothesis was that teamwork is highly sensitive to wording. It appears that surveys containing "teamwork" or "work in teams" have higher ratings (Table C4). However, the columns in Table C4 describe different approaches to sampling, and the ratings clearly vary with sampling approach as well. Table C4 is an example of the confounding of wording and work environment (as a result of sampling approach). Such confounding prevents evaluation of this hypothesis with the data in this study.

A third hypothesis was that teamwork is more important in some work environments than others. This hypothesis was inspired by the data collected by Saunders-Smits (Figure 2.2) based on work roles, which shows that engineers for whom the "ability to synthesize" is important rate teamwork highly while engineers for whom "analytical skills" are important rate teamwork much lower. Unfortunately, other surveys did not distinguish between engineering "roles" as the Saunders-Smits study did. The Passow data did distinguish between work environment and undergraduate major. However both wordings of the Passow data show essentially no change in rating of teamwork across work environment or undergraduate major. Therefore, the two data sources in this study cannot be reconciled to evaluate this hypothesis.

In summary, it remains perplexing that a) teamwork has the largest variance of any competency in the meta-analysis and b) teamwork was consistently the second-rated competency in the Passow original wording data and consistently the first-rated competency in the Passow revised wording data, yet its mean rating in the meta-analysis is in the middle of the pack. I developed three hypotheses that might explain this, but only the first one could be tested – and was ruled out. The second and third hypotheses cannot be fully tested with the current data. Future research should delve into survey wording, work environments, work roles, and interactions among the three to investigate variance in the importance of teamwork.

4.5 Stability in Relative Emphasis over Time

How does the relative emphasis among ABET competencies change over time, such as by survey year, by graduation year, and by years since graduation? The Passow (UM) data answers this question. **None of the statistical criteria identified time-related groups as differing statistically from the aggregate**. The stability of the ratings over time is evident in three graphs: importance ratings by survey year (Figure 4.4), importance ratings by alumni year (Figure 4.5), and importance ratings by graduation year (Figure 4.6). In all three graphs, the lines that link the importance ratings for a competency across time are essentially horizontal and parallel. This indicates stable ratings over time. Note that a) the "top cluster" competencies remain distinct from the "intermediate cluster" and b) the "bottom cluster" competencies remain consistently at the bottom and are far from mingling with importance ratings in the "top cluster". These graphs are examples of the type of minor differences in importance ratings which did not differ significantly from the aggregate patterns.

Figure 4.4 shows results from two versions of a survey. Both versions were labeled as an "importance" scale. However, on the original version the definitions of the ratings were stated as frequencies while on the revised version definitions of the ratings were worded as an importance scale (see the note on Figure 4.4). The wording of the competencies remained identical except for three. 1) "Communications skills" was split into two distinct competencies, "written communication skills" and "oral communication skills". 2) "Appreciation for the ethical values of being a professional" became "understanding of professional and ethical responsibility". 3) "Interest and ability to keep up-to-date through continuing education (formal or informal)" became "ability to continue formal or informal learning". These three competencies change importance ratings across the wording change, but are essentially stable for a given wording.

Both Figures 4.5 and 4.6 combine ratings from the original and revised wordings into individual data points. Similar graphs for data from only the revised wording survey showed slightly less variation; neither differed with statistical significance from the pattern in the aggregated data. Figure 4.5 shows that seniors – those at zero years since graduation – agree with alumni on the aggregate pattern of importance ratings even

Figure 4.4. Importance ratings by survey year, Passow data.

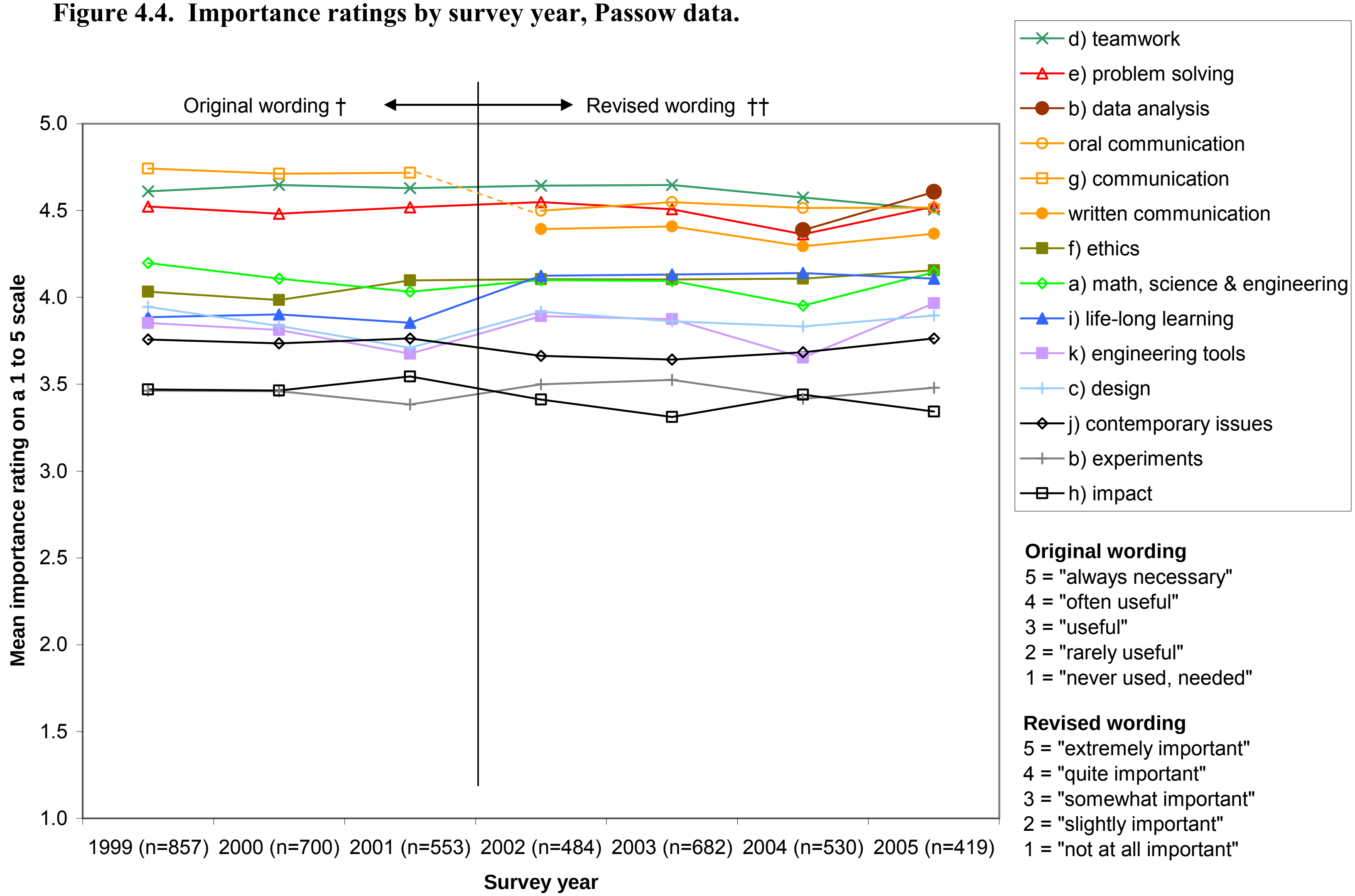


Figure 4.5. Importance ratings by alumni year, Passow data

includes both original and revised survey wordings

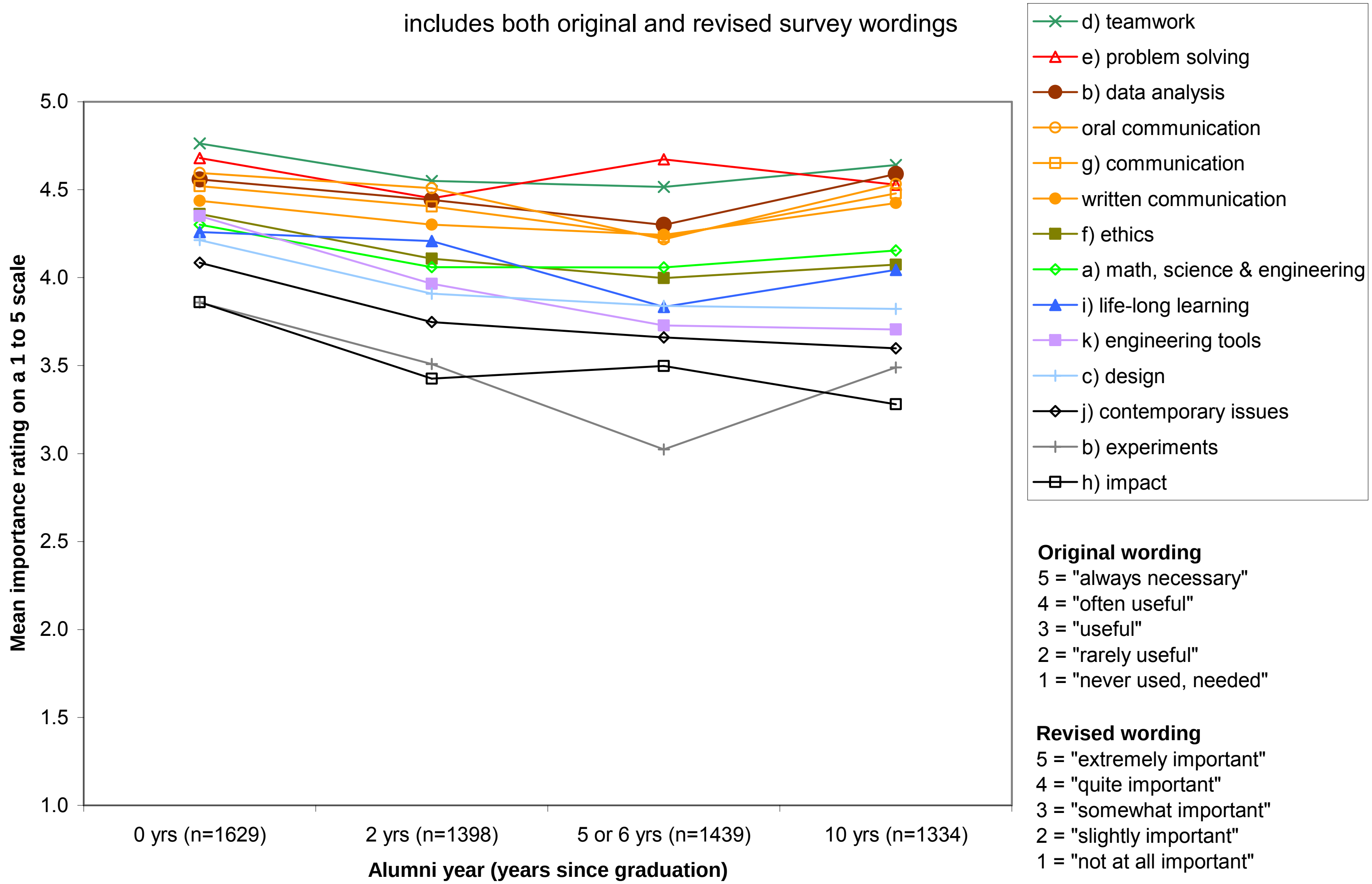
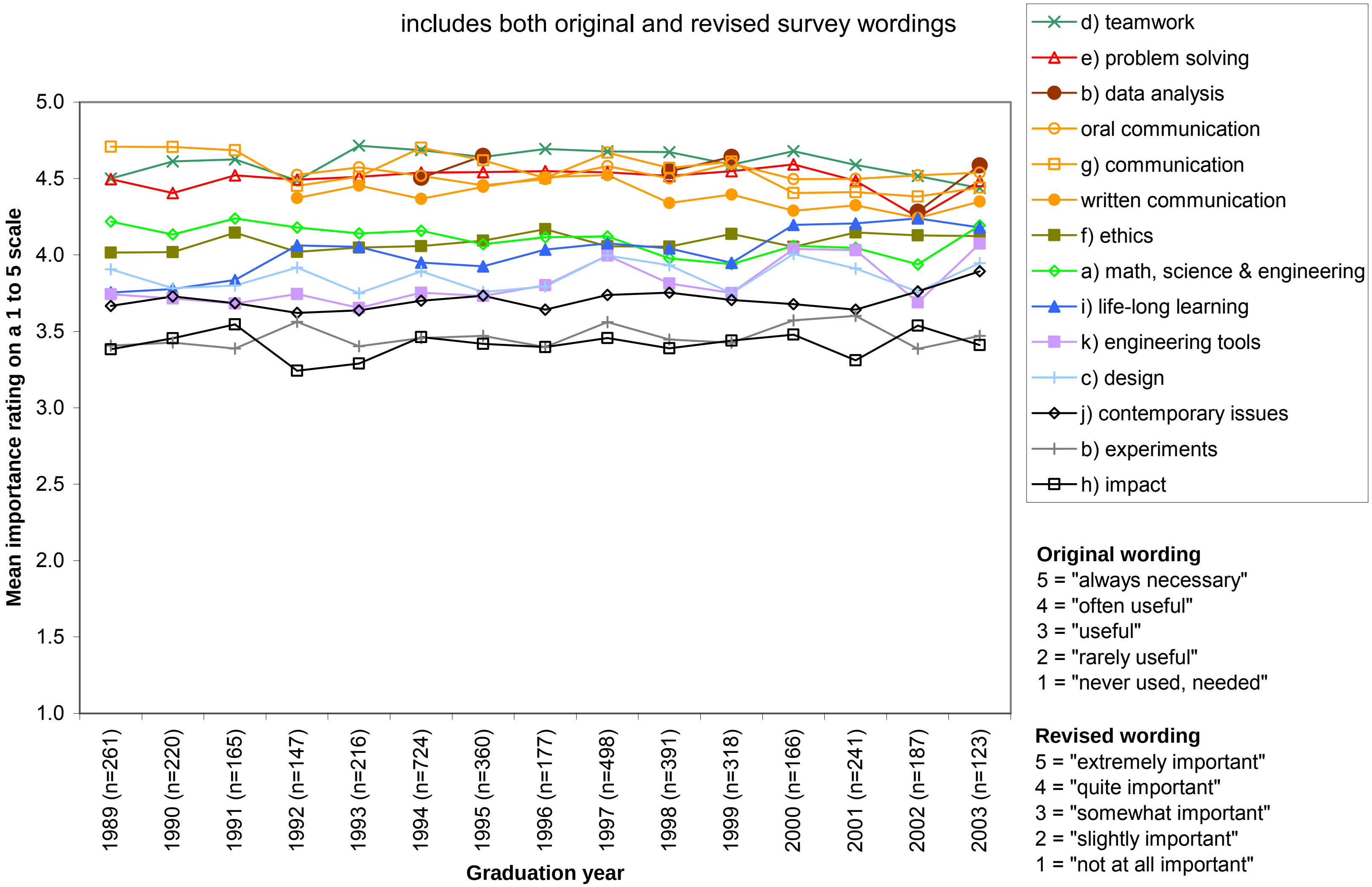


Figure 4.6. Importance ratings by graduation year, Passow data.



though seniors' ratings have a slightly higher mean rating and have a little smaller range than the alumni. Figure 4.6 has slightly more variation from the other two graphs (as expected for groups of smaller n), but still shows a pattern of importance ratings consistent with the aggregate pattern.

4.6 Differences in Relative Emphasis with Alternate Wording

How does the relative emphasis among the ABET competencies change with alternate wording of the survey questions? Shea's (1997) results show that relative importance ratings depend strongly on wording, while Bankel, et al. (2003) reported minimal effects. Only two other studies address this question, the Passow original and revised wording surveys. In these two studies, the sampling methods were identical. Eight of the eleven competencies were worded identically on the two surveys, but the wording for three of the competencies was revised for the second survey. The identically worded questions showed no change from the original to the revised surveys (Figure 4.4). The competencies whose wording changed had changes in importance rating (Table 4.3).

Table 4.3 Changes in importance ratings with wording changes in the Passow data.

Original Survey		Revised Survey	
Wording	**Mean rating**	**Wording**	**Mean rating**
"Communication skills"	4.71	Mean of written and oral competencies	4.44
		"Written communication skills"	4.37
		"Oral communication skills"	4.52
"Appreciation for the ethical values of being a professional"	4.04	"Understanding of professional and ethical responsibility"	4.11
"Interest and ability to keep up-to-date through continuing education (formal or informal)"	3.88	"Ability to continue formal or informal learning"	4.12

The rating changes (Table 4.3) alter the sequence of the professional competencies, however, the clusters of importance are unchanged. Specifically, communication dropped from the highest level of importance in the original wording to the second level of importance in the revised wording. Life-long learning rose one level of importance with the wording change. Both of these changes were statistically significant, but the change in ethics was not. Thus, **alternate wordings for a competency lead to different ratings and different relative emphasis among ratings.**

The other ten studies in the meta-analysis each have different wordings on their surveys, however, the different sampling methods in these studies confound survey wording and work environment. Future research will be needed to determine how survey wording affects the importance ratings of various competencies, research in which wording and work environment are both controlled. Although such research might be helpful, **the meta-analysis across a variety of wordings is a sound approach for transcending wording altogether and determining the relative emphasis among the constructs that underlie the wording of any particular competency**.

CHAPTER 5. DISCUSSION AND IMPLICATIONS

After a synopsis of the findings in this study, I discuss implications for many constituencies within higher education. There are implications for curriculum theory, for competency-based assessment, for future research on competencies, for ABET, for students, for employers of graduates, and for faculty.

5.1 Synopsis of the Study

As a result of trends in quality assurance (e.g., accreditation), engineering faculty *worldwide* face a culture change resulting from two paradigm shifts. The first is a shift from viewing teaching as *instruction* to seeing teaching as facilitating *learning*. The second is a shift from viewing engineering expertise as the application of theory to seeing expertise as the integration of theory, specialized skills, critical analysis, and deliberative action. The new competency focus "has significant implications for what knowledge and skills faculty need" (Doherty et al., 1997, p. 182). Under the learning paradigm with a competency focus, curriculum designers consider questions of purpose, such as in our academic program "*what competencies should students have at graduation*?" and "*what should the relative emphasis be among those competencies*?" These practical questions, that faculty are grappling with worldwide, inspired this study – an effort to gather the opinions of engineering graduates.

By *competencies*[3], I mean the knowledge, skills, abilities, attitudes, and other characteristics that enable a person to perform skillfully (i.e., to make sound decisions and take effective action), in complex and uncertain situations such as professional work, civic engagement, and personal life. I assume that competencies are the foundation of

[3] My definition of competency draws on the description of competency and performance by the faculty of Alverno College (Marcia Mentkowski and Associates, 2000) and other international leaders in the field of competency-based (also called ability-based) higher education (e.g., Heywood, 2005; Hutcheson, 1997). My definition includes language from the field of industrial psychology (e.g., Bemis et al., 1983; Ghorpade, 1988; Whetzel et al., 2000) and higher education for the professions (Curry & Wergin, 1997)

successful professional practice throughout a career. By *expertise*[4], I mean the proficient coordination of multiple competencies that leads to consistently effective performance in a variety of unique, complex, and uncertain situations.

This study is built on four findings from published research. First, *the overall pattern of importance in competencies depends on the practice setting*; this central hypothesis of this study has wide support, in theory (Holland, 1997; Spencer & Spencer, 1993; Stark et al., 1987) and in empirical work (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Saunders-Smits, 2005, 2007; Shea, 1997). Second, *there are competencies important for engineering graduates in practice beyond ABET's list* according to theory about competency in the professions and empirical studies. These include:

- *decision-making* about 1) whether and when to apply theory, general principles, analytical skills, and technical skills and 2) how to act on one's analysis (American Society for Engineering Education, 1994; Kennedy, 1987; Mickelson, 2001, 2002; Stark et al., 1986).
- *achievement orientation* (e.g., commitment to achieving goals) (American Society for Engineering Education, 1994; Meier et al., 2000; Mickelson, 2001, 2002; Spencer & Spencer, 1993; Woollacott, 2007)
- *the ability to integrate theory and practice effectively in professional work settings* (Stark et al., 1986)
- *initiative* (Mickelson, 2001, 2002; Spencer & Spencer, 1993; Watson, 2000)
- *flexibility* (McMasters & Komerath, 2005; Meier et al., 2000; Mickelson, 2001, 2002; Spencer & Spencer, 1993; Stark et al., 1986)
- *leadership* (American Society for Engineering Education, 1994; Burtner & Barnett, 2003; Donahue, 1997) and
- *project management* (Watson, 2000)
- *oral communication* and the less important *written communication* (McMasters & Komerath, 2005; Murphy, 1994; Sageev & Romanowski, 2001)
- *listening skills* (McMasters & Komerath, 2005; Meier et al., 2000).

Third, theories (Kennedy, 1987; Stark et al., 1986) predict and surveys show that *faculty's pattern of importance ratings differs noticeably from that of other engineers*

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[4] My definition of expertise draws on cognitive science (e.g., Ericsson & Smith, 1991) and is echoed in literature on expertise in the professions (e.g., Curry & Wergin, 1997; Kennedy, 1987). In my study, expertise is the holistic combination of assorted competencies and is an ultimate goal of professional education and lifelong learning.

(ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Shea, 1997), which implies different opinions about ideal emphasis in the curriculum and motivates my study. Thus, for curriculum design decisions, faculty will gain fresh perspective from the opinions of practicing engineers. Specifically, theory predicts that faculty may undervalue competencies for "thinking like an engineer", such as problem solving and data analysis. Fourth, *importance ratings depend on survey wording* (Shea, 1997).

This study synthesizes the opinions of engineering graduates about *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* These are the research questions. To answer them, two data sets were coordinated. To identify aggregate patterns, I conducted a meta-analysis of 10 published studies plus two unpublished surveys from the University of Michigan (U-M), including a total of 10, 203 survey responses. To delve into differences by sub-group, I further analyzed U-M's 4225 survey responses. *Both analyses used the same strategy: statistically testing the null hypothesis that there are no differences in the importance ratings for the various competencies.* To accomplish this, I used protected post-hoc, all-pairwise multiple comparisons in which each competency is analogous to an experimental treatment. This method includes two steps. 1) Determine if any statistically significant differences exist among the importance ratings for the competencies. 2) If significant differences exist, perform a multiple comparison test to determine which competencies differ significantly with respect to importance ratings.

Coordinating the analysis of these two data sets increases the generalizability. Naturally, data from a single institution, a single survey, and a prescribed set of competencies (i.e., ABET's list) would lead to uncertainty about generalizability. The meta-analysis addresses these sources of uncertainty. On the other hand, aggregated data from a meta-analysis would lead to uncertainty about differences among sub-groups and changes over time. The UM analysis addresses these concerns. The strong agreement of the findings from the two coordinated analyses reduces concern over methodological limitations in each of the two portions of my study. By coordinating the two data sets, the findings can be generalized with confidence.

Which competencies are important for engineering graduates? To investigate, I meta-analyzed twelve studies that surveyed a total of 10, 203 engineering graduates. The lowest mean rating of importance among ABET competencies ranged between 2 and 4 on five-point scales, which indicates that *all the ABET competencies are deemed important* by engineering graduates. Also, *several competencies not listed by ABET were noted as important by engineering graduates, including decision-making (highest importance), commitment to achieving goals, the ability to integrate theory and practice effectively in professional work settings, leadership skills, and project management (lowest importance).* Of these non-ABET competencies, the most important three were predicted to be important by theory, and all five were shown to be important in studies outside of the meta-analysis. Weak evidence in the meta-analysis indicates that *business practices* may be deemed relatively unimportant in comparison to the ABET competencies, but this should be further explored by research expressly designed to determine the relative importance of this competency. Another finding of my meta-analysis is that "*data analysis" and "design of experiments" are distinct competencies* as evidenced by dramatically different ratings.

What should the relative emphasis be among competencies for engineering graduates? A study of 4225 engineering alumni that is included in the meta-analysis, revealed that *the pattern of importance ratings in the aggregate data (Figure 4.3) captures the underlying pattern in every subgroup. The few groups that differ statistically from the aggregate can be fully described by noting specific differences from the aggregate pattern. The only groups that differ significantly from the aggregate are based solely on work environment and academic major, not on variables that are demographic, time-related, or developmental***.** This is consistent with theory (Holland, 1997; Spencer & Spencer, 1993; Stark et al., 1987) and empirical work (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Saunders-Smits, 2005, 2007; Shea, 1997).

Essentially, graduates in all engineering majors value the competencies in the aggregate pattern (Figure 4.3), as described by statistically independent clusters of competencies. *With few exceptions, engineering graduates value a top cluster of competencies – problem solving, communication, and data analysis – significantly higher* *than a bottom cluster – contemporary issues, experiments, and understanding the impact of one's work*. Competencies in the intermediate cluster – ethics, life-long learning, teamwork, engineering tools, design, and "math, science, and engineering knowledge" – may be statistically tied to competencies in either the top or bottom cluster, depending on work environment or academic discipline. Note that *decision making is a non-ABET competency that is rated as a top-cluster competency*.

Also, engineering graduates perceive both *professional competencies* and *technical competencies* as important, subsets of competencies that concur with a published division (Shuman et al., 2005). In the meta-analysis, the professional competencies are: oral communication (most important), written communication, ethics, life-long learning, teamwork, contemporary issues, and impact (least important). The sequence of technical competencies is: problem solving (most important), data analysis, engineering tools, design, "math, science, and engineering knowledge", and experiments (least important).

Thus, *the aggregate pattern of importance (Figure 4.3) is an excellent first approximation of engineering graduates' preferences for curriculum design for any major, with few exceptions*. The only majors that differ significantly from the aggregate are chemical engineering and "materials science and engineering" – who rate experiments significantly higher than the aggregate – and computer engineering and computer science – who rate design and engineering tools significantly higher than the aggregate. All significant differences are detailed in Table 4.2.

Two distinctive themes emerged for specific work environments. 1) Competency with *experiments* is prized by researchers in any field, including those holding doctorates (in engineering or outside of engineering), engineering researchers, engineering faculty, and engineering graduate students. 2) *Life-long learning* is rated above the aggregate by medical doctors, students in professional schools, those who hold doctorates in engineering, graduate students in engineering, and engineering faculty.

The faculty work environment is of special note. Theories predict and surveys show that faculty's pattern of importance ratings differs noticeably from that of other engineers. In my study of 4225 engineering alumni, *engineering faculty's pattern of importance ratings are farther from the aggregate than any other group*. Engineering faculty rate experiments, design, and life-long learning far above the aggregate and engineering tools below the aggregate. This finding can be explained using Holland's theory: among engineering graduates, the work environment for engineering faculty requires and rewards a highly distinctive constellation of competencies.   Naturally, faculty value the competencies that bring success in their work environment. This finding, that faculty's ratings reflect a unique perspective on engineering work, confirms the potential of this study for informing faculty when they make curricular decisions.

These conclusions result from coordinating two approaches to analysis for 12 studies over a span of 13 years for various survey wordings, sampling approaches, work environments, and work roles. The design of the two complementary analyses overcomes many limitations and enhances the generalizability of the results. Unfortunately, none of the studies simultaneously controls wording, work environment, and work role, which is advisable in future research. Alternate wordings for a competency lead to different ratings and relative emphasis among ratings in my study of 4225 engineering alumni and others (Bankel et al., 2003; Shea, 1997). However, by combining results across different studies, the meta-analysis transcends wording, sampling, and work environment to determine the relative emphasis among the constructs that underlie the wording of any particular competency.

5.2 Implications for Curriculum Theory in Higher Education

Stark and Lattuca's theory (1997) lists seven elements of an academic plan: purpose, content, sequence, learners, instructional resources, instructional processes, and evaluation. "Purpose" is defined as both "knowledge, skills, and attitudes to be learned" and "intended outcomes" (p. 11). Note that "purpose" is worded as a singular element, yet the authors describe it in plural terms. I suggest that they use the plural term, "purposes" in their framework.   This is not simply a semantic shift. The change from choosing a single purpose during curriculum design to balancing competing purposes leads directly to the idea of *relative emphasis* among purposes.   Naturally, some purposes or outcomes will warrant greater emphasis than others. Therefore, *relative* *emphasis* is essential to an academic plan. I suggest that Stark and Lattuca's theory include *purposes* and *relative emphasis* as elements of an academic plan.

5.3 Implications for Competency-Based Surveys

The findings were consistent with theory in showing that the competencies a person needs for career performance depend on their work environment. In addition, survey wording clearly affects importance ratings. The combination of these ideas has strong implications for competency-based assessment. Ideally, competency-based surveys in any field will

- define the work environment, work role, and career stage to be considered while completing the survey
- fully-define each competency "in a way that makes it both relevant and valuable" (Letelier, Herrera, Canales, Carrasco, & Lopez, 2003, p. 277)
- use proficiency-level ratings *and* frequency of use ratings as opposed to importance ratings
- include another question that asks each respondent to *rank* the competencies in order of importance.

Later questions will, ideally, gather information about the respondent's work environment, work role, and career stage.

I recommend that future surveys synthesize the outstanding features by Bankel, et al. (2003), the University of Michigan, Shea (1997), Saunders-Smits (2007), and (ASME, 1995), while adding features absent from any known study. Each respondent should rate *and* rank the competencies for their own work environment (see Appendix G for an example survey). Here is my rationale. All data used in my study were *ratings*. However, Shea (1997) and Bankel, et al. (2003) both had separate items for *rankings.* After immersing myself in the ratings in all the studies and carefully examining the two examples of rankings, it appears that respondents find it easy to rate everything as fairly important. On the other hand, rankings require direct attention to relative importance and tradeoffs among competencies. I believe that *rankings* may be the only valid basis for deeming a competency as relatively unimportant.

After the data is gathered, differences in importance ratings should be analyzed statistically using multiple comparison procedures as in this study, Bankel et al.'s (2003), and Lattuca, Terenzini et al.'s (2006). This will greatly strengthen conclusions.

5.4 Implications for Future Research on Competencies

Future research on the importance of competencies and the relative emphasis among them should use multiple methods. Some additional survey research would be beneficial, but future research should emphasize other research methods. Additional survey research would be useful if it simultaneously controls wording, work environment, and work role and investigates interactions among them (see the section "implications for competency-based assessment"). The survey format that I suggest in that section will also enable the researcher to compare ratings of competencies with rankings, which forces the respondent to consider tradeoffs.

Interview studies are highly recommended. My preliminary interview studies demonstrate that interviews are ideal for showing how competencies integrate to bring about outstanding performance. Interviews incorporate wording, work environment, and work role far more effectively than surveys can.

Now that many existing survey studies have been meta-analyzed, studies of superior performance would yield highly useful information about various competencies and the relative emphasis among them. This research approach was used in over three hundred studies to create the "competence at work" model (Spencer & Spencer, 1993). An outstanding example of this genre is a study of competence in software engineers (Turley, 1992). Turley's purpose was to identify differences (or differential factors) between exceptional and non-exceptional engineers. Supervisors selected 10 exceptional engineers and then 10 non-exceptional engineers that matched the exceptional ones in job role and years of experience. Researchers who were blind to each employee's designation conducted interviews about critical incidents to delve into the competencies exhibited on the job. Turley used the interview results to create a survey for other exceptional and non-exceptional engineers. Such quasi-experimental, mixed-methods research could be triangulated with qualitative interviews and quantitative survey research to increase confidence in answering the following questions. According to engineering graduates, “what competencies should students have at graduation?” and “what should the relative emphasis be among those competencies?”

5.5 Implications for ABET

I suggest that ABET explicitly recognize that their new competency focus has created a culture change, as defined by Berquist (1992). The culture change results from a paradigm shift about teaching – from the instruction paradigm to the learning paradigm – and a paradigm shift about the nature of engineering expertise – from seeing expertise as the application of theory to seeing expertise as the integration of theory, specialized skills, critical analysis, and deliberative action. These paradigm shifts are defined by Barr and Tagg (1995) and Kennedy (1987), respectively. The new competency focus “has significant implications for what knowledge and skills faculty need” (Doherty et al., 1997, p. 182). ABET could design and offer training to support faculty in their new roles and encourage worldwide implementation of support.

The following implications are consistent with ABET’s commitment to “re-examine Engineering Criterion 3…with the goal of re-defining engineering for the public in a global context” (ABET, 2004, p. 8). In conversations I have had with ABET leadership, I heard explicit and deep commitment to ongoing assessment of ABET’s processes. In the natural course of such periodic assessment, I suggest that ABET review their competencies in light of the theories of competence at the interface of higher education and the work place. Any review should emphasize that each work environment has a distinctive pattern of competencies as predicted by Holland’s theory (Smart et al., 2000) and three other theories (Kennedy, 1987; Spencer & Spencer, 1993; Stark et al., 1986). Theory and empirical work on competence highlights several possible omissions from ABET’s list. My results confirm the importance of decision-making about 1) whether and when to apply theory, general principles, analytical skills, and technical skills and 2) how to act on one’s analysis; achievement orientation (e.g., commitment to achieving goals); initiative; flexibility; leadership; project management; oral communication; and written communication.

I recommend that when ABET next undertakes a survey, questions be included as described in the competency-based assessment section of this chapter. Such a survey would include each of ABET's Criterion 3a-k plus decision-making, commitment to achieving goals, the ability to integrate theory and practice effectively in professional work settings, leadership skills, project management, and also distinct competencies for data analysis, design of experiments, oral communication, and written communication. Including initiative and flexibility on the survey is also recommended. The relative ratings on the survey will show which competencies, if any, are deemed highly important in relation to ABET's current competencies.

After such a survey, ABET should consider revising Criterion 3a-k, which resulted from sincere effort to voice the collective values of the engineering profession in the early 1990's. The survey may, or may not, identify non-ABET competencies for inclusion. Other professional associations support the concept of additional competencies. For example, "project management" is included in the international agreement of the Washington Accord (International Engineering Alliance, 2007) and in the American Society of Civil Engineers (ASCE)'s (2007) list of competencies. "Leadership" is included in lists by ASCE and the National Academy of Engineering (NAE) (2004). NAE also lists flexibility. Only ongoing research, such as periodic surveys, can take the current pulse of collective opinion in the profession about the importance of various competencies, as ABET has already done with the Engineering Change study.

The findings of my study demonstrate definitively that ABET's competency b), which pertains to both experiments and data analysis, includes two distinct constructs. I suggest it be split into its two component parts, listing "data analysis" and "design of experiments" as distinct competencies.   ABET has already split the two competencies on their evaluator worksheets, but should complete the separation because engineering graduates view them quite differently.

5.6 Implications for Engineering Students

Many students choose engineering because they are good at math and science without regard to other competencies that practicing engineers need. Faculty often encounter resistance to their claims that communication, ethics, and teamwork are as essential for engineers as thermodynamics and electrical circuits. I am confident of these trends from my own teaching, from discussions with other engineering faculty, and from my reading of comments on thousands of surveys of engineering seniors and alumni. Students must gain a more accurate impression of the competencies required in engineering from high school guidance counselors, recruiters at engineering schools, recruiting materials from engineering organizations, and engineering faculty. (Note that recommendations for engineering faculty are in Section 5.8.) The findings in Figure 4.3 and Table 4.2 are strong evidence to support discussion with students. When armed with a clear understanding of the competencies that engineers need during their careers, students may be inspired to take responsibility for mastering those competencies and may commit to partnering with faculty throughout their educational programs to develop these competencies. As Pace wrote in 1979, "accountability for…student outcomes must consider both what the institution offers and what the students do with those offerings" (Stark & Lowther, 1986a, p. 51).

5.7 Implications for Employers of Engineering Graduates

Employers should consider Figure 4.3 and Table 4.2 when seeking employees. Employers would benefit from explicitly stating the key competencies required in each work role opportunity in their work environment. A competency perspective among employers would create a common language with faculty, on-campus career services, and potential candidates. A common language could lead to a more integrated process for developing individuals for life and work after graduation. Explicit awareness of required competencies would allow for behavioral interviewing and better selection of candidates according to the competence at work theory (Spencer & Spencer, 1993).

5.8 Implications for Engineering Faculty

Perhaps the most far-reaching implications of the findings are for engineering faculty, who constitute only 1% of engineering graduates in the U.S. First, I will describe the faculty's unique perspective, followed by an examination of current engineering curricula, and then suggestions for how faculty can facilitate integrated learning of competencies.

5.8.1 The Faculty's Unique Perspective

My findings show that faculty's importance ratings are outliers among engineering graduates, an observation which confirms previous studies (ASME, 1995; Bankel et al., 2003; Evans et al., 1993; Shea, 1997). No disconfirming evidence was found. The question arises, why the pronounced difference?

Several prominent engineering faculty who have worked extensively in industry are convinced that *the root cause of this striking difference is cultural*. In other words, the different values that faculty place on competencies result from different cultures in engineering research and engineering practice.

> Engineering schools are not, by and large, populated by engineer practitioners, but by engineering researchers. These researchers develop engineering science knowledge by conducting research with a reductionist approach that largely rewards the efforts of individuals. In contrast, in the…engineering [practice] context, the focus is on producing engineering products and systems by conducting development with an integrative approach that largely rewards team efforts. (Crawley, Malmqvist, Ostlund, & Brodeur, 2007, p. 14)

Dr. Frank Splitt, engineering faculty member at Northwestern University, states the same ideas in a different way: engineering programs have "a cultural problem that stems from the patterning of the academic engineering community after the academic scientific community – where published research is prime – rather than professional communities such as legal or medical [education]" (Splitt, 2003, p. 30). Consider the contrast between engineering education and medical schools, where the faculty must practice their profession (Splitt, 2003; Wulf, 2004). Dr. William Wulf, past president of the National Academy of Engineering, asserts:

> We actively discourage engineering faculty from practicing engineering. The promotion and tenure criteria for engineering are the same as for science faculty – research, teaching, and service. Nowhere in that list is the creation of a product that someone will

> buy or an addition to the enduring infrastructure of our country. What you measure is what you get. So, for the most part, our engineering faculty are superb engineering scientists; but they are not necessarily superb practitioners of the engineering discipline. At most engineering schools, it is hard to hire or promote an individual whose record rests on having produced a product in industry, as opposed to publishing papers in journals. Please understand, I am not criticizing my faculty colleagues. In fact, I "are one". I am criticizing a system that doesn't allow us to complement traditional faculty with people whose experience in the practice of engineering would be of enormous value to students. (Wulf, 2004, p. 32)

The prominent engineering faculty quoted above each has extensive experience in industrial practice. They each attribute faculty's unique perspective to a culture that discourages a certain type of diversity among faculty – diversity of perspectives on engineering work. Their cultural explanation is consistent with theoretical predictions (e.g., Holland, 1997; Spencer & Spencer, 1993; Stark et al., 1987) and empirical evidence that strongly indicate that the overall pattern of importance in competencies depends on the practice setting.

Engineering research is critically important. In fact, sustaining and strengthening science and engineering research was one of the four recommendations in "Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Economic Future" (National Academy of Sciences, 2007). Obviously, engineering research is a critical portion of the spectrum of what engineering graduates do. However, the ratio of engineering researchers to engineering practitioners is not uniform: it is high in academia and low in industry and government, creating different cultures. Therefore, it is not surprising that engineering faculty have a unique perspective on the relative importance of competencies among engineering graduates.

Clearly then, in their role as curriculum designers, engineering faculty can be informed by the opinions of the full spectrum of engineering graduates, the majority of whom are engineering practitioners. This study is one mechanism for bringing a composite of engineering graduates' opinions of relative emphasis to the attention of engineering faculty. This data may spark new topics of conversation between engineering faculty and their industry partners.

5.8.2 Do Curricula Achieve Graduates' Desired Emphasis?

This study focuses on what engineering graduates perceive as the relative importance of various competencies. The data in my study do not address the question of what current curricula are achieving. However, a natural question that arises when interpreting the findings is "*How do the outcomes of the current curricula, nationwide, compare with graduates' desired emphasis among competencies?*" Certainly, this is not a definitive question; there are other purposes for undergraduate engineering programs besides preparation for professional work. Faculty must weigh many purposes for a curriculum when they are designing it. Yet, comparing the outcomes of the current curricula to graduates' desired emphasis among competencies seems like a logical and responsible step in interpreting these findings.

A question about the outcomes of current curricula depends on assessment of learning outcomes, which is a challenging endeavor for any educator, engineering educators included. In fact, such assessment is a central issue in engineering programs that seek ABET accreditation. The results of direct assessments of learning outcomes are kept confidential by institutions. Therefore, no publicly available national assessment data directly addresses this outcomes question. However, several indirect measures are available, and these measures are a starting point for determining the outcomes of the current curricula.

From many reports of industry opinion (e.g., American Society for Engineering Education, 1987, 1994; National Research Council, 1995; National Science Foundation, 1995), we can be confident that during the 1980's and early 1990's the outcomes of engineering curricula nationwide were very far from matching graduates' ideal relative emphasis as expressed in Figure 4.3.

> The…emphasis on engineering science that characterized traditional undergraduate programs [in the 1980's] produced graduates who were technically proficient, but not well prepared to manage innovation and change or to work in teams. By the 1990's, engineering employers expressed their concerns that graduates lacked creativity and design capability, communication and teamwork skills, and had a narrow view of engineering and related disciplines. ABET sought to expand graduates' skills with the implementation of a new set of accreditation standards [Criteria 3a-k] that responded to employers' needs for engineers equipped with strong technical *and* professional skills [emphasis in the original]. (Lattuca, Terenzini et al., 2006, p. 109)

ABET's revised criteria, EC2000, became an explicit expression of the many conversations between industry and academia about what the outcomes of engineering curricula should be. Programs nationwide have been changing in response to these criteria since around 1995.

In 2002, ABET commissioned a study of the impact of EC2000 on curricula and on learning outcomes (Lattuca, Terenzini et al., 2006). According to engineering chairs and faculty, courses and curricula have "substantially increased attention to a number of professional skill areas and topics, including communication and understanding engineering solutions in social and global contexts" (Lattuca, Terenzini et al., 2006, p. 110). They also report "little change in the attention they give to the technical knowledge base that undergirds the field" (p. 110). In the same study, employers were surveyed about changes in the preparation of engineers.

> Most employers have yet to see the improvements reported by students and faculty. More than half of the employers report no change in new engineers' abilities since the implementation of EC2000. About thirty percent see modest improvements in graduates' professional skills – teamwork/communication and lifelong learning….About a quarter of employers perceive a decline in new hires' problem-solving skills. (Lattuca, Terenzini et al., 2006, p. 115)

How can these findings be reconciled? Clearly the faculty are changing the curricula, but employers are not yet seeing substantial changes in outcomes. It is possible that employers have not yet noticed changes in graduates' skills because of the time lag inherent in changing the curriculum. *Yet, examining the types of changes in the curricula may shed some light on this.*

Jarosz and Bush-Vishniac (2006) dissected all of the course syllabi for the entire mechanical engineering curriculum at nine diverse institutions. The authors chose mechanical engineering because it has the largest percentage of undergraduates (19.4%) and a large fraction of the engineering workforce (16.3%). They tallied specific topics on course syllabi, such as conduction, convection, design methodologies, economics, first and second laws of thermodynamics, gases, harmonic motion, and vector operations. They found that most syllabus topics mapped onto the most traditional ABET competencies: "math, science, and engineering knowledge", experiments, design, and problem solving. They also found little to no instructional emphasis on teamwork, communication, impact, and contemporary issues. Another important aspect of the study is about ABET competencies which do not have any topics mapped to them. For example, lifelong learning and engineering tools "are less about topical curriculum content than about the process of learning….We found no topics that map directly onto these two outcomes" (Jarosz & Busch-Vishniac, 2006, p. 246).

Note that the Jarosz & Busch-Vishniac (2006) study did not evaluate teaching approaches or assignments, only syllabus topics. Perhaps these programs responded to EC2000 by changing their teaching approaches and the types of assignments in which students engage. This seems likely because the *Engineering Change* study found that "faculty have increased their use of active learning methods, such as design projects, group work, and case studies, in their courses" (Lattuca, Terenzini et al., 2006, p. 110).

Another thought is, what can a study of syllabus topics tell us about the *aims* of the curriculum? Jarosz and Busch-Vishniac (2006) question whether the engineering and science topics were "connected and integrated together" (p. 244). Note that the language in the article consistently uses the term "body of knowledge" and does not use the term "competency" or synonyms such as "ability". Taken altogether, the topic mappings, the competencies that have no topics mapped to them, the questionable connection and integration between topics, and the language of the study combine as evidence of a point of view, or paradigm: it appears that the researchers, and perhaps the nine departments in the study, view the purpose of the curriculum as transmitting a body of knowledge, as opposed to developing student competencies. Thus, an implication of Jarosz and Busch-Vishniac's study is that *perhaps the curriculum perspective has not changed, despite ABET's new competency focus. The curriculum emphasis may still be on transmitting a body of knowledge, not on developing abilities or competencies.*

How does all this evidence answer my question? I will summarize and explain. A natural question that arises when interpreting the findings of my study is "How do the outcomes of the current curricula, nationwide, compare with graduates' desired emphasis among competencies?" I ask this question as an aid to interpreting my findings, not as a suggestion that the curriculum should be limited to achieving these competencies.

Here is a summary of the evidence explained above. From many reports of industry opinion, we can be confident that during the 1980's the outcomes of engineering curricula nationwide were very far from matching graduates' ideal relative emphasis as expressed in Figure 4.3, especially with respect to the professional competencies. Research evidence suggests that programs are increasing attention on professional competencies, such as communication and understanding engineering solutions in context without changing the attention given to the technical knowledge base. However, employers are not yet seeing substantial changes in outcomes. Perhaps examining the *types* of changes in the curricula can shed some light on this apparent contradiction. A 2006 study of syllabus topics in nine diverse mechanical engineering programs found a) that most syllabus topics mapped onto the pre-EC2000 ABET competencies – "math, science, and engineering knowledge", experiments, design, and problem solving – and b) that there was little to no instructional emphasis on teamwork, communication, impact, contemporary issues, lifelong learning, and engineering tools. Thus, it seems likely that these nine programs have changed their teaching approaches and assignments, two areas not examined by the Jarosz & Busch-Vishniac study. From the collected evidence, *it appears that the curriculum perspective may not have changed, despite ABET's new competency focus. The curriculum emphasis may still be on transmitting a body of knowledge that now encompasses some professional skills rather than on developing competencies.*

Now, let us return to the question: "How do the *outcomes* of the current curricula, nationwide, compare with graduates' desired emphasis among competencies?" My exploratory thoughts here indicate that *at this time, the collected outcomes do not closely resemble graduates' ideal relative emphasis as expressed in Figure 4.3, especially with respect to the professional competencies*. Certainly there are documented changes in curricula which are "encouraging points of light" (Wulf, 2004, p. 31). However, it may be time for further research on whether a *change in perspective* on the curriculum is the essence of the new vision for engineering programs. Perhaps employers will observe substantial change in outcomes only after the perspective of developing competencies transcends the aim of transmitting an expanded body of knowledge. Only further research can explore whether this idea is valid or not.

This question about outcomes and my tentative answer serve as a starting point for considering the implications of my findings for engineering faculty. Naturally, when considering action aimed at achieving goals, one must have a sense of the current state of the system. This basic principle from control theory applies to educational systems, too.

5.8.3 Facilitating Integrated Learning of Multiple Competencies

NAE's Educating the Engineer of 2020 report asserts that engineering education must change "if the United States is to maintain its economic leadership and be able to sustain its share of high-technology jobs." (The National Academy of Engineering, 2005, p. 4). The report goes on to say that "reinventing engineering education requires the interaction of engineers in industry and academe" (p. 4). My findings bring into focus the idea of relative emphasis among competencies, as opposed to topics in a body of knowledge. My results are an opportunity for faculty to hear the voice of over 10,000 engineering graduates. Faculty can consider these results, alongside other aims, when designing curricula.

My recommendations for faculty are organized around three questions that are central to success in many enterprises, including curriculum design:

- Where do we want to go and why do we have these goals?
- How will we get there from here?
- How will we know when we get there?

These are my adaptations of guiding questions in several fields: engineering design (e.g., Rouse & Boff, 1987; Ulrich & Eppinger, 1995), instructional design (e.g., Smith & Ragan, 1999), and management (e.g., Deming, 1986).

5.8.3.1 Where do we want to go and why do we have these goals?

The culture change that has swept through higher education is forcing faculty to adapt their paradigms. All faculty are now called to see their role not as teaching but as facilitating learning. Engineering faculty are additionally required to see expertise and competence as the integration of theory, specialized skills, critical analysis, and deliberative action. Together, these two paradigm shifts require that engineering faculty see their role as developing students' technical *and* professional competencies.

Simultaneously, faculty face the challenges inherent in curriculum design, including all the influences and elements included in Stark and Lattuca's (1997) theory for curriculum planning. Faculty are forced to make decisions and implement curricula that meet the near-term needs of graduates and prepare graduates to adapt to changing conditions throughout their lives. As the faculty of Alverno College has said:

> It is up to us as educators to manage the creative tensions that a relationship to the workplace and the community produces. We cannot flee – neither into a cloistered and silent existence, nor into an unthinking accommodation to the demands of the marketplace. (Mentkowski, et al., 2000)

ABET's list of competencies were carefully crafted to avoid "flavor of the month" skills and focus on broad, enduring competencies (McMasters & Komerath, 2005). Comparison of ABET's competencies with theory, as I did in the second chapter, 1) demonstrates that ABET's list competencies is very similar to competencies determined in studies of many professions and 2) reveals a handful of competencies that may additionally be important (Kennedy, 1987; Spencer & Spencer, 1993; Stark, et al., 1986). In short, the ABET list, with the additions identified in this study, is a list of competencies that faculty can wholeheartedly adopt as critical across many contexts and enduring over time. Note also that the aggregate pattern in my findings (Figure 4.3) was developed based on engineering graduates who work in engineering and non-engineering settings. This aggregate pattern holds for most sub-groups, including groups based on demographic, time-related, and developmentally related variables with the only exceptions for groups based on work environment or academic discipline (Table 4.2). Therefore, faculty can feel confident that the aggregate pattern of relative emphasis among competencies in this study can be a sound, first approximation of what graduates see as important across engineering disciplines.

Stated differently, my findings, which are summarized in Figure 4.3 and Table 4.2, can inform specifications for the design of engineering curricula as faculty "manage the creative tensions that a relationship to the workplace and community produces" (Mentkowski, et al., 2000). When designing engineering curricula, faculty should consider the findings and consider placing special emphasis on the "top cluster" competencies of problem-solving, communication, data analysis, and decision-making.

My suggestions in answer to the question "Where do we want to go and why do we have these goals?" flow from assumptions about curriculum design stated concisely by the Engineering Curriculum Task Force at Arizona State University (ASU) (Evans et al., 1993, p. 203-204):

> Establishing or modifying an engineering curriculum is truly a design problem….To avoid over-constraining the curriculum design problem, engineering education may now need a[n]…approach that first establishes curriculum purpose and emphasis (i.e., specifications) based on discussions and consensus agreements among employers of engineers, alumni, students, and faculty....Designing to meet these specifications should yield better curricula.

ABET's Criteria 3a-k are a collective attempt to establish curriculum purpose based on discussion and consensus among many engineering communities. However, ABET has not emphasized the idea of designing curricula to specifications.

I recommend that engineering programs apply their design skills to education. (Note that curriculum theorists Toombs (1977) and Toombs and Tierney (1991; 1993) describe creating a curriculum as a design endeavor.) I further recommend that engineering programs consider Criteria 3a-k and my findings when creating their specifications for each academic program. There is already precedent for designing academic programs to meet specifications in engineering (e.g., Davis, Beyerlein, & Davis, 2006; Meyer & Jacobs, 2000; Sardana & Arya, 2003). Engineering faculty are not the only educators to approach the design of curriculum in this manner – that is, from the perspective of designing curricula to specifications based, in part, on the competencies required for successful professional practice. For example, studies of practitioner opinions for the purpose of informing curriculum design have been published in medicine (Finocchio, 1995), marketing (Hyman & Hu, 2005), geoscience (Fattahi, Murer, & Myers, 2003), human resource development (Nitardy & McLean, 2002), and in a constellation of technology fields (specifically science, mathematics, engineering, and technology at the broadest level) (Meier et al., 2000).

5.8.3.2 How will we get there from here?

So how will we “reinvent” (Wulf, 2004), or re-design, engineering education to integrate the technical and professional competencies? There are really two questions here: 1) How can we move faculty to see their work as developing competencies rather than covering content? and 2) How can the curriculum itself change to develop competencies?

The first practical challenge is asking faculty to see their work as developing competencies rather than covering content. This is an embodiment of the shift from the instruction paradigm to the learning paradigm. A question arises, how can we get this to happen? By what process could faculty come to see their role as designing curricula to develop competencies? I have some speculations for how this could come about. Engineering programs could look at how medical schools have made this same transformation and how existing engineering programs in the CDIO Network have accomplished the paradigm shifts that I recommend. My examination of these processes at medical schools and at CDIO institutions reveals a critical institutional mechanism: hiring and retaining a faculty with diverse perspectives on practicing the profession, perspectives built through diverse professional experience. I believe that an institutional change to seek, include, and value diverse perspectives on engineering work will support a shift in perspective on curriculum design in engineering.

The second practical challenge is changing the curriculum to develop competencies. I will spend the remainder of this section developing this idea. Adding anything to the jam-packed curriculum is dismissed as impossible by many faculty. Engineering educators should feel comforted that other professions, such as medicine, business, accounting, teacher education, and nursing, are sharing the struggle to create curricula that develop students’ technical *and* professional competencies beyond the traditional body of technical knowledge (Carraccio, Wolfsthal, Englander, Ferentz, & Martin, 2002; Jones, 2002; "New Graduation Skills," 2007). For example, a literature review of several decades of effort at medical schools found the same challenges that have been encountered in engineering education: the need for strategic planning; the problem of clearly delineating a) the definitions of competencies, b) the benchmark evidence of each competency, and c) the thresholds for minimum competence; the difficulty of developing assessment tools to measure competence; and the struggle for faculty and learner buy-in on the solution to each of these challenges (Carraccio et al., 2002). Engineering educators are faced with the same challenges as faculty in other professional schools, and we can look to their efforts for inspiration and moral support.

The curricula in these other professions are remarkably different on the surface. Yet, when examined through the lens of a designer, a strong common principle emerges. Successful efforts do not simply “tack on” additional competencies. Successful curricula are redesigns, beginning with new specifications, which are the competencies. Here is a technical analogy. The successful designs don’t just cobble together separate functions like adding a fax machine and a stand-alone scanner to a computer system. The successful curricula start from scratch and combine the competencies in a more efficient package, like a combination printer-fax-scanner does. **Across the professions, curricula that develop and integrate the technical and professional competencies are built on a central design principle: embed the content in the context of professional practice.** This simple idea is transformational. It leads naturally to learning for decision-making, application, and action, where ethics, contemporary issues, and communication abound.

The curriculum design principle of embedding the content in the context of professional practice has also been applied in several innovative curricula in engineering. These innovative undergraduate programs emphasize learning the technical fundamentals in the context of hands-on engineering projects *throughout the undergraduate years*. This approach naturally helps students learn to integrate professional competencies with technical competencies. For several decades, the curriculum at Harvey Mudd College (2008) in Claremont, CA has embedded the content in the context of engineering practice. In the past eight years, two new engineering programs have been designed using the same principle at Olin College (2008) in Needham, MA and Smith College (2008) in Northampton, MA. Over the last fifteen years, 29 leading engineering schools in the U.S., Europe, Canada, U.K., Africa, Asia, and New Zealand have joined the CDIO initiative, a collaborative effort to re-design their existing undergraduate programs to embed the content in the context of practice (CDIO, 2008).

In these engineering programs, the context of engineering practice permeates the entire undergraduate experience, not simply a capstone course. Embedding all content in the context of professional practice was the typical model in engineering education before World War II (Ehrmann, 1979). As the leaders of CDIO have stated:

> As recently as the 1950's and more recently in some countries, university engineering faculty were distinguished practitioners of engineering. Education was based largely on practices and preparation for practice. The 1950's saw the beginning of the engineering science revolution, and the hiring of a cadre of young engineering scientists. The 1960's might be called the golden era, in which students were educated by a mix of the older practice-based faculty and the younger engineering scientists. However, by the 1970's, as older practitioners retired, they were replaced by engineering scientists. On average, the culture and context of engineering education took a pronounced swing toward engineering science. (Crawley et al., 2007, p 14-15)

This history suggests another approach to embedding content in context – create a blended faculty with some having extensive experience in engineering practice.

There are many possible approaches to embedding content in the context of engineering practice. Problem-based learning has been used to accomplish this at many medical schools, beginning around 1970 (Barrows, 2000). Engineering programs at the University of Liverpool (U.K.) teach technical content in the context of engineering failures (Stacey, Williamson, Schleyer, Duan, & Taylor, 2007). In my own teaching, I have re-designed traditional textbook problems in engineering science courses to incorporate decision-making. I describe an engineer's role in a sentence or two and ask each student to assume that role in their imagination. Then I briefly describe a decision-making situation from engineering practice for that engineer. The students then solve the problem using typical textbook approaches, but the answer is actually a recommendation or statement of a decision based on their calculations. This approach could be widely adopted in engineering courses without entirely restructuring the curriculum.

My findings suggest that, in every course, students could benefit from explicit instruction on the "top cluster" competencies of problem-solving, communication, data analysis, and decision-making. Instruction, practice, and feedback on these competencies should be fully integrated with instruction aimed at developing any other competency.

In summary, **creating curricula that help students develop and integrate the technical and professional competencies will require that we embed the content in**

the context of professional practice. Accomplishing this will require design. There are a multitude of curricular approaches to choose from: hands-on projects, problem-based learning, focusing on engineering failures, creating decision-based problems, teaching "top cluster" competencies in every course, and many others yet to be developed by inventive engineering faculty. Regardless of approach, the content must be embedded in the context of practice in an ongoing way throughout the undergraduate program. Concepts in learning theory such as cueing attention and spaced practice indicate that a single capstone-sized project cannot fully develop competencies. Integrating professional learning and context in a mutually reinforcing way may well lead to more liberally educated professionals (Lattuca & Stark, 2001). It is likely that the unique constraints on each engineering program will lead to a unique curriculum for each program. Therefore, the next challenge will be determining how effective different curricula are at helping students develop and integrate the technical and professional competencies.

5.8.3.3 How will we know when we get there?

The goal of the curriculum is to help each student develop the competencies that the faculty intend to help them learn. This is the output of the curriculum. Yet, there are actually two levels of measurement for this goal. At the student level is the question, "Did this individual student develop the intended competencies?" To determine if this goal is achieved, faculty need assessment of student learning. At the system level is the question, "Does this undergraduate program *reliably help all students* develop the intended competencies?" Engineering faculty understand that a system that simply suffices is not as robust as a system that optimizes. Engineers excel at applying design principles and control theory to complex systems in order to achieve and maintain optimum performance. Optimizing a curriculum's performance is the system-level goal. It can be achieved by applying design principles and control theory to curriculum design.

At the student level, engineering faculty, like medical faculty, face the problem of developing assessments for student competence. Student behavior is the output at the student-level. Effective assessment involves 1) defining in measurable terms a small number of performance indicators for each outcome and 2) designing feasible and effective measures for each performance indicator. Defining performance indicators in measurable terms "is the most difficult part of the [assessment] process" (Rogers, 2004, p. 4), but an excellent "buffet" of performance criteria to choose from are available at http://www.engr.pitt.edu/~ec2000/ec2000_attributes.html. Guidance for designing engineering assessments is available on ABET's website and in the "Assessment Handbook" at http://www.engin.umich.edu/teaching/assess_and_improve.

Assessment information can also be used at the system-level. Faculty can apply design principles and control theory to curriculum design using assessment information to support their efforts. Throughout the process, faculty have many competing purposes to balance:

> Academia and industry voice many, often contradicting, opinions about suitability of theory-oriented and practice-oriented educational models. Which of the two is better suited for a first job of a graduate and his/her later career development is impossible to answer, largely due to the huge variety of professional duties assigned to engineers. Universities must therefore strike a balance between a perfect preparation of engineers…for their first job (industry's short-term demand) and education for a lifetime of learning and changing demands (university's moral obligation which coincides with industry's long term demand). It needs to be emphasized that it is not the university's primary responsibility to concentrate on ready-to-use skills, as it is not industry's responsibility to teach a university graduate how to use his/her theoretical knowledge. (Prusak, 1998, p. 8)

5.8.4 Designing Curricula in the Context of Higher Education

Practitioners' opinions about competencies that are important for professional practice can inform engineering faculty and all of higher education. The report by the U.S. Secretary of Education's Commission on the Future of Higher Education (2006), The Spellings Report, urges faculty to make evidence-based decisions. Faculty can use my conclusions as evidence when addressing several challenges described in the Spellings report: designing curricula that are relevant to the needs of the workforce and defining broad measures both for learning and for "value-added" accountability.

However, I hope my conclusions may do even more. I believe that my findings will contribute to the culture shift from course-level planning for knowledge transmission to *design* of integrated curricula that develop students' competencies. Engineering faculty, with their knowledge of how to design-to-specification, could be leaders in such efforts. Ideally, my conclusions will inspire questions about what the specifications should be, or in other words, which competencies are important for *life* and work after graduation, and what should the relative emphasis be among them? Perhaps my conclusions will spark a kind of deeper thinking, thinking that “asks, in the deepest way, what education is for and what human traits it is meant to foster” (Brodhead, 2006).

APPENDIX A. ABET'S PROGRAM OUTCOMES

For ABET, the U.S. accrediting agency for engineering programs, the year 2000 marked a dramatic change. Since 1932, ABET (and its predecessor, Engineers Council for Professional Development (ECPD)) occasionally amended their criteria, typically by increasing the specificity. In the last quarter of the 20^{th} century, ABET prescribed most courses for each undergraduate engineering degree, an extremely prescriptive approach among accrediting agencies. The transformation to Engineering Criteria 2000 (EC2000) is profound, the most significant change in engineering accreditation during ABET's history (Proctor, 1998). With EC2000, ABET has

> moved from a quality assurance process based on evaluating program characteristics relative to minimum standards to one based on evaluating and improving the intellectual skills and capabilities of graduates. (Prados et al., 2005, p. 169)

There are eight areas in ABET's current EC2000 criteria: students, program educational objectives, program outcomes and assessment, professional component, faculty, facilities, institutional support and financial resources, and program criteria. The structure of the criteria and four of the areas have not changed with EC2000. The paradigm shift occurred in two of the three areas that constrain curriculum.   The new

> criteria place…strong emphases on defining program objectives (program differentiation rather than 'cookie-cutter' uniformity) and learning outcomes (intellectual skills of graduates rather than subject-area seat time). The specification of curricular content was significantly reduced. At the core of EC2000…[is] a continuous improvement process based on evaluating the achievement of these outcomes and objectives and using evaluation results for program improvement. ABET moved from a quality assurance process based on evaluating program characteristics relative to minimum standards to one based on evaluating and improving the intellectual skills and capabilities of graduates. (Prados et al., 2005, p. 169).

It is "program outcomes and assessment" (Criterion 3) that changes the purpose of undergraduate engineering programs from subject coverage to facilitating learning – a fundamental shift in the culture of engineering education. Criterion 3 specifies the intended learning outcomes for students and requires programs to demonstrate that students achieve the learning outcomes by graduation. ABET's Engineering Criteria 2005-06, Criterion 3 for Program Outcomes and Assessment states (ABET, 2006, p. 1-2):

> Program outcomes are statements that describe what students are expected to know and be able to do by the time of graduation. These relate to the skills, knowledge, and behaviors that student acquire in their matriculation through the program.
>
> Each program must formulate program outcomes that foster attainment of the program objectives articulated in satisfaction of Criterion 2 of these criteria. There must be processes to produce these outcomes and an assessment process, with documented results, that demonstrates that these program outcomes are being measured and indicates the degree to which the outcomes are achieved….Engineering programs must demonstrate that their students attain:
>
> (a) an ability to apply knowledge of mathematics, science, and engineering
> (b) an ability to design and conduct experiments, as well as to analyze and interpret data
> (c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability
> (d) an ability to function on multi-disciplinary teams
> (e) an ability to identify, formulate, and solve engineering problems
> (f) an understanding of professional and ethical responsibility
> (g) an ability to communicate effectively
> (h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context
> (i) a recognition of the need for, and an ability to engage in life-long learning
> (j) a knowledge of contemporary issues
> (k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

This list of program outcomes is familiarly known as "a-k" (pronounced "a through k"). Among these eleven, four are essentially new requirements since the 1980's:

d) teamwork
e) identifying, formulating, and solving engineering problems
f) professional ethics
i) life-long learning.

Two are a transformation from a seat-time requirement in humanities and social science courses to a requirement that the engineering faculty demonstrate that graduates have developed abilities with that knowledge:

h) understanding the impact of one's work
j) knowledge of contemporary issues.

Five essentially repackage requirements in the former criteria, stating them as competencies rather than bodies of knowledge:

a) applying knowledge of math, science, and engineering
b) designing and conducting experiments

c) designing a system
k) using engineering tools
g) communication.

Thus, the new criteria are radically different. First, they require that graduates demonstrate specific competencies in ABET's traditional areas (as opposed to the former "coverage" requirements for assorted bodies of knowledge). Second, they add four entirely new competencies. Third, they require that engineering faculty be responsible for the competencies gained in "outsourced" humanities and social science courses. In other words, the current criteria require faculty to design and implement curricula that help students achieve *prescribed* learning outcomes, what Stark and Lattuca (1997) call purposes, but leave all other curriculum design decisions to program faculty.

APPENDIX B. METHODS IN THE TWELVE STUDIES IN THE META-ANALYSIS

Study	Competencies	Relative Importance	Description of Data
NSPE (1992)	8 competencies by committee	Survey asked respondents to consider engineers within five years of graduation. The key question was "how much does your company/agency value preparation in the area?" The 8 items were worded as competencies. Ratings were made on a 5-point scale from "very high value" to "very low value".	Responses from 888 NSPE members (*registered engineers*) practicing in industry (55.3%) and government (44.7%), all with high professional titles. The mean was 25 years of work experience (most had over 20 yrs experience) (45% response rate).
Evans, et al. (1993)	10 competencies from literature review	Survey asked respondents to rate the relative importance of each of the 10 competencies. Specific wording is not reported (so importance *for whom* and *for what* are unclear). The ratings were unusual. Although a Likert-scale was offered for each question, respondents were asked to rate the most important attribute as "1" and the least important as "5" and then rate the other 8 in relation to the first two, each one on the 5-point scale.	Responses from 737 alumni in 12 disciplines (*aerospace, biomedical, civil, chemical, computer, electrical, engineering science, industrial, mechanical, materials, nuclear, and systems engineering* majors, 1 to 36 yrs since graduation) at Arizona State University (12.3% response rate), 97 from faculty (53.9% response rate), 101 from seniors (unreported majors, convenience sample). Focus group with 14 industry representatives established competencies using the nominal group method then completed the survey.

Study	Competencies	Relative Importance	Description of Data
Benefield, et al. (1997)	16 competencies from literature review	Telephone survey of alumni asked for rating, on a 4-point scale, of how essential (important) each attribute is for "engineers to be successful in the practice of their profession" (p. 58). Telephone survey of industry representatives asked to rate each attribute of recently graduated engineers for importance in performing successfully on the job (p. 58) on a 4-point scale.	Responses from 546 Auburn University alumni (*all engineering majors*, 1- 9 yrs since graduation). A parallel telephone survey of 298 industry representatives of companies that either recruit or hire co-op students at Auburn (98 of these with title engineer or engineering manager).
Shea (1997)	10 competencies from literature review	Survey asked for "ratings [on a 5-point scale] of relative importance of attributes for graduates" (p. 168).	Responses from 137 alumni (1-25 yrs since graduation, *Manufacturing and Industrial Engineering* Departments) of Oregon State University (64% response rate). Responses from 40 advisory board members (82% response rate). Responses from 35 seniors in the departments (64% response rate). Responses from 11 department faculty (100% response rate) and 29 department heads (57% response rate) nationwide.
Koen & Kohli (1998)	24 competencies from literature review- Mapped onto ABET's 11 †	Survey asked respondents to evaluate the importance of each skill to their company (p. 4) on a 5-point scale.	Responses from 124 recent alumni (*all engineering majors*, 1-3 yrs since graduation) of Stevens Institute of Technology (20% response rate) and their supervisors (57 respondents; 9% response rate).

Study	Competencies	Relative Importance	Description of Data
Lang, et al. (1999)	172 skills, knowledge descriptions & experiences (developed by committee) mapped onto ABET's 11 outcomes	Survey asked respondents for importance ratings, on a 5-point scale, for each competency for both entry-level engineers and for engineers with 3-5 years experience, but only ratings for entry-level engineers were published.	Responses from 420 engineers and engineering managers from fifteen of the twenty-four *aerospace and defense*-related companies in IUGREEE, a consortium for "enhancing engineering education". (114 of these respondents had aerospace or aeronautical engineering backgrounds).
Bankel, et al. (2003)	17 competencies with 4 to 7 sub-skills per competency (from literature and industry focus groups - Mapped to ABET's 11)	Survey asked to select a "level of proficiency" for each competency expected for a graduating senior. 1= "to have experienced or been exposed to" 2="To be able to participate in and contribute to" 3="To be able to understand and explain" 4="To be skilled in the practice or implementation of" 5="To be able to lead or innovate in"	Responses from 44 'industry leaders', 91 five-year alumni, 56 fifteen-year alumni, 86 faculty, 89 1st yr students, and 75 4th yr students. The respondents were affiliated with MIT's *aerospace* program and three Swedish universities with programs in *electrical, mechanical,* and *vehicle* engineering.
Saunders -Smits (2005)	12 competencies (9 from literature review plus 3 from panelists)	Survey asked respondents to rate, on a 5-point scale, the importance of each competency for an engineer to attain professional success.	Responses from a panel of 19 *aerospace engineers* practicing in the Netherlands, with eleven representing government-funded institutions and eight representing industry, from a total of 7 different organizations. The panelists classified themselves as specialists (9) or managers (10).
Saunders -Smits (2007)	12 competencies (Identified in her 2005 study.)	Survey asked respondents to rate, on a 5-point scale, the importance of each competency 1) in the respondent’s current job, 2) for an engineering specialist, and 3) for an engineering manager.	Responses from 662 alumni (5 to 30 years after graduation) of the *aerospace engineering* program at Delft University of Technology, The Netherlands. (40% response rate) Note only 86% of eligible alumni had addresses on record.

Study	Competencies	Relative Importance	Description of Data
Lattuca, et al. (2006)	ABET's 11 outcomes - verbatim	Survey asked respondents to rate, on a 5-point scale, the importance of each competency for "new engineering graduates" (item 7).	Responses from 1,622 practicing engineers in seven disciplines (*aerospace, chemical, civil, computer, electrical, industrial, and mechanical*). Representative sample of U.S. engineers of all experience levels. Selection criterion: all reported "having evaluated recent engineering graduates for seven years or more".
Passow (unpublished)	ABET's outcomes - reworded	Two surveys: original wording and revised wording. Surveys asked respondents to rate, on a 5-point scale, the importance of each competency in the respondent's "professional experience".	Original wording: 2,110 responses. Revised wording: 2,115 responses. All responses from engineering alumni of the University of Michigan in ten disciplines (*aerospace engineering, chemical engineering, civil engineering, computer engineering, electrical engineering, "industrial and operations engineering", "materials science and engineering", mechanical engineering, "naval architecture and marine engineering", and "nuclear engineering and radiological sciences"*). Alumni were 2, 6, or 10 years after graduation.

† Includes paraphrases of 9 of Evans, et al.'s 10 competencies and 8 of Benefield, et al.'s 16 competencies

APPENDIX C. META-ANALYSIS SURVEY WORDINGS AND IMPORTANCE RATINGS

Table C1. Original survey wordings for items mapped onto ABET's a) "math, science, and engineering knowledge"

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(a) an ability to apply knowledge of mathematics, science, and engineering	Meta-analysis	-0.03			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
Understanding of physical, life, and mathematical sciences	NSPE 1992	-0.14			
A fundamental understanding of mathematics and the physical and life sciences	Evans 1993	0.44		-0.11	0.56
A breadth and depth of technical background	Evans 1993	0.05		-0.11	0.62
In-depth technical knowledge in major engineering discipline	Benefield 1997	1.09		1.25	
Knowledge of engineering fundamentals. Includes calculus, chemistry, physics, and engineering sciences (e.g., statics, dynamics, thermodynamics)[author's emphasis].	Shea 1997	-2.07			-1.48
Knowledge of engineering topics that you identified in question five on the previous two pages (e.g., statistics, facility design, and computer integrated manufacturing) [author's emphasis].	Shea 1997	-0.40			1.05
Fundamental understanding of mathematics	Koen 1998		0.06	-0.04	
Fundamental understanding of Physical and Life Sciences	Koen 1998		-1.16	-1.28	
Breadth of engineering sciences(Ability to understand the basic concepts in most of the 7 engineering sciences): Mechanics of Soldis; Fluid Mechanics; Thermodynamics; heat, Mass & Momentum Transfer; Electrical Theory; Nature & Properties of Materials, and Information Theory)	Koen 1998		-1.04	-0.84	
Depth of engineering sciences (Ability to understand the basic concepts in most of the 7 engineering sciences)	Koen 1998		-1.42	-1.35	
Engineering courses with applications (2.5 years)	Lang 1999	2.05			
Have broad technical knowledge	Saunders 2005, 2007	-1.44	-0.28	-1.93	
Have specialist technical knowledge	Saunders 2005, 2007	1.46	-5.58	-3.75	
Analytical skills	Saunders 2005, 2007	1.08	-0.28	1.19	
(a) an ability to apply knowledge of mathematics, science, and engineering	Lattuca 2006	0.67			
Math, science, and engineering skills	Passow original			0.18	
Math, science, and engineering skills	Passow revised			0.06	
Not surveyed by Bankel					

Table C2. Original survey wordings for items mapped onto ABET's b) experiments.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	Meta-analysis	-0.04			
"Experiments & data analysis combined"					
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
Demonstrated ability in data analysis and interpretation	Lang 1999	0.17			
Experimentation and knowledge discovery (Hypothesis formulation; survey of print and electronic literature; experimental inquiry; hypothesis test and defense)	Bankel 2003	-0.07		0.72	0.84
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	Lattuca 2006	-0.42			
Ability to design and conduct experiments	Passow original			-1.78	
Ability to design and conduct experiments	Passow revised			-1.64	
Ability to analyze and interpret data	Passow revised			1.29	
Not surveyed by NSPE, Evans, Benefield, Shea, Koen, & Saunders					

Table C3. Original survey wordings for items mapped onto ABET's c) design.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(c) an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	Meta-analysis	0.003			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
Ability to design and implement useful systems and products	NSPE 1992	0.77			
An ability to identify and define a problem, develop and evaluate alternative solutions, and effect one or more designs to solve the problem.	Evans 1993	1.22		1.32	1.30
Experience in working on practical design projects	Benefield 1997	-0.65		-0.16	
Design skill. Ability to develop and implement solutions for a broad array of issues involving many disciplines and conflicting objectives. [author's emphasis].	Shea 1997	-1.13			-1.05
Demonstrated ability to design a component	Lang 1999	-1.44			
Conceiving and engineering systems (Setting system goals and requirements; defining function, concept, and architecture; modeling of system and ensuring that goals can be met; development project management)	Bankel 2003	0.14		0.11	0.63
Designing (The design process; the design process phasing and approaches; utilization of knowledge in design; disciplinary design; multidisciplinary design; multi-objective design	Bankel 2003	0.04		1.09	0.87
Ability to synthesize	Saunders 2005, 2007	-0.82	0.82	-0.24	
(c) an ability to design a system, component, or process to meet desired needs	Lattuca 2006	0.02			
Ability to design a system, component or process	Passow original			-0.66	
Ability to design a system, component or process	Passow revised			-0.51	
Not surveyed by Koen					

Table C4. Original survey wordings for items mapped onto ABET's d) teamwork.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(d) an ability to function on multi-disciplinary teams	Meta-analysis	0.33			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
Ability to work as part of a team	NSPE 1992	1.69			
Experiences with culturally, racially, and gender diverse people	Benefield 1997	0.55		-0.02	
Experience working with persons/students from other engineering disciplines to solve large scale problems	Benefield 1997	-1.48		-1.62	
Working with persons/students from outside engineering	Benefield 1997	-1.48		-1.62	
People skills. The ability to work effectively with customers,	Shea 1997	1.15			0.49
Able to function in a multicultural and diverse work	Koen 1998		0.26	0.19	
Effective team skills	Koen 1998		0.87	0.77	
Function on a team in laboratory science or engineering courses	Lang 1999	-0.63			
Teamwork (Forming effective teams, team operation, team growth and evolution, leadership, technical teaming)	Bankel 2003	0.95		0.32	0.55
Ability to work in teams	Saunders 2005, 2007	-1.65	-0.14	0.77	
(d) an ability to function on multi-disciplinary teams	Lattuca 2006	0.67			
Ability to function on a team	Passow original			1.64	
Ability to function on a team	Passow revised			1.56	
Not surveyed by Evans					

Table C5. Original survey wordings for items mapped onto ABET's e) problem solving.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(e) an ability to identify, formulate, and solve engineering problems	Meta-analysis	1.04			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
An ability to identify and define a problem, develop and evaluate alternative solutions, and effect one or more designs to solve the problem.	Evans 1993	1.22		1.32	1.30
Problem solving skills. The ability to identify and fix critical problems using sound engineering principles and following	Shea 1997	1.15			0.91
Effective problem solving.	Koen 1998		1.20	1.06	
Ability to develop innovative approaches.	Koen 1998		1.17	0.66	
Effective in dealing with real world complex and ambiguous problems.	Koen 1998		0.61	0.60	
Ability to formulate a range of alternative problem solutions	Lang 1999	0.17			
Engineering reasoning and problem solving (Problem identification and formulation, modeling, estimation and qualitative analysis, analysis with uncertainty, solution and recommendation)	Bankel 2003	1.35		1.89	1.68
Problem solving skills	Saunders 2005, 2007	0.57	-0.08	1.49	
(e) an ability to identify, formulate, and solve engineering problems	Lattuca 2006	0.91			
Engineering problem solving skills	Passow original			1.30	
Engineering problem solving skills	Passow revised			1.24	
Not surveyed by NSPE, Benefield					

Table C6. Original survey wordings for items mapped onto ABET's f) ethics.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(f) an understanding of professional and ethical responsibility	Meta-analysis	0.54			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
Recognition that engineering is sensitive to social needs, the fragility of the environment, and ethical considerations	NSPE 1992	0.34			
A high professional and ethical standard	Evans 1993	0.63		0.12	0.16
High ethical standard to job and personal life. Understands standards of the profession, and implications of actions to company, employees, and society. [author's emphasis].	Shea 1997	-0.20			0.49
High professional and ethical standards	Koen 1998		1.06	0.73	
Demonstrated understanding of the importance of *Honesty* in science and engineering	Lang 1999	1.25			
Professional ethics, integrity, responsibility and accountability	Bankel 2003	1.13			1.53
(f) an understanding of professional and ethical responsibility	Lattuca 2006	0.35			
Appreciation for the ethical values of being a professional	Passow original			-0.06	
Understanding of professional and ethical responsibility	Passow revised			0.17	
Not surveyed by Benefield, Saunders					

Table C7. Original survey wordings for items mapped onto ABET's g) communication.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(g) an ability to communicate effectively	Meta-analysis	0.95			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
An effectiveness in communicating ideas	Evans 1993	0.73		0.64	0.46
Written communication skills	Benefield 1997	1.09		1.14	
Oral communication skills	Benefield 1997	0.68		0.75	
Communication skills, both verbal and written. Ability to discuss complex issues in terms that customers, management and colleagues can understand. [author's emphasis].	Shea 1997	1.47			1.55
Effective listening skills	Koen 1998		0.97	0.87	
Effective oral communication.	Koen 1998		1.00	0.74	
Effective writing skills.	Koen 1998		0.36	0.51	
Interpersonal skills (verbal, non-verbal, and written) which maintain high professional quality, convey appropriate respect for individuals, groups, teams, and develop a productive working environment	Lang 1999	-0.10			
Communications (Communications strategy, communications structure, written communication, electronic/multimedia communication, graphical communication, oral presentation and inter-personal communication)	Bankel 2003	1.26		1.20	1.32
Written communication skills	Saunders 2005, 2007	0.69	-0.08	-0.20	
Oral communication skills	Saunders 2005, 2007	-0.55	1.88	0.90	
(g) an ability to communicate effectively	Lattuca 2006	1.31			
Communication skills	Passow original			1.92	
Written communication skills	Passow revised			0.90	
Oral communication skills	Passow revised			1.33	
Not surveyed by NSPE					

Table C8. Original survey wordings for items mapped onto ABET's h) impact.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	Meta-analysis	-1.55			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
Appreciation of the economic, industrial, and international environment in which engineering is practiced	NSPE 1992	-0.58			
Understanding of the humanities and social sciences	NSPE 1992	-2.08			
cultures	Evans 1993	-1.29		-2.08	-1.45
Well-rounded background in variety of non-engineering	Benefield 1997	-1.45		-1.34	
Manufacturing and business operations. Awareness of what it takes for a business to be succerssful. An understanding of the many economic, social, and cultural issues which influence business decisions. [author's emphasis].	Shea 1997	-0.51			-1.76
Appreciation and understanding of history, world affairs and cultures.	Koen 1998		-1.77	-2.07	
Understanding that engineering solutions are affected by and should be responsible to limited resource availability	Lang 1999	-1.44			
External and societal context (Roles and responsibility of engineers, the impact of engineering on society, society's regulation of engineering, the historical and cultural context, contemporary issues and values, developing a global perspective)	Bankel 2003	-1.47		-1.67	-1.47
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	Lattuca 2006	-1.88			
Understanding of the social, economic and environmental impact of my work	Passow original			-1.64	
Understanding of the social, economic and environmental impact of my work	Passow revised			-1.98	
Not surveyed by Saunders					

Table C9. Original survey wordings for items mapped onto ABET's i) lifelong learning.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(i) a recognition of the need for, and an ability to engage in life-long learning	Meta-analysis	0.34			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
A motivation and capability to continue the learning experience	Evans 1993	-0.52		-0.18	0.22
Ability to learn on one's own	Benefield 1997	1.35		1.28	
Continuously improving personal and organizational performance. Always gaining new skills. Able to detect and adapt to changing conditions. [author's emphasis].	Shea 1997	0.53			-0.21
Motivation and capability to acquire and apply new	Koen 1998		0.88	0.78	
Understanding that skill training is an employee's responsibility and part of life long learning	Lang 1999	0.44			
Curiosity and lifelong learning	Bankel 2003	0.42			0.58
Ability for life-long learning	Saunders 2005, 2007	1.46	0.54	-0.88	
(i) a recognition of the need for, and an ability to engage in life-long learning	Lattuca 2006	-0.24			
Interest and ability to keep up-to-date through continuing education (formal or informal)	Passow original			-0.51	
Ability to continue formal or informal learning	Passow revised			0.19	
Not surveyed by NSPE					

Table C10. Original survey wordings for items mapped onto ABET's j) contemporary issues.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		***Overall mean***			
(j) a knowledge of contemporary issues	Meta-analysis	-1.28			
Verbatim wording on each survey		***Practicing***	***Managers***	***Alumni***	***Faculty***
cultures	Evans 1993	-1.29		-2.08	-1.45
Demonstrated understanding that engineering is affected by information technology issues	Lang 1999	-0.63			
Contemporary issues and values	Bankel 2003	-1.30			-1.17
(j) a knowledge of contemporary issues	Lattuca 2006	-1.86			
Knowledge of contemporary issues that affect my work	Passow original			-0.89	
Knowledge of contemporary issues	Passow revised			-1.09	
Not surveyed by NSPE, Benefield, Shea, Koen, Saunders					

Table C11. Original survey wordings for items mapped onto ABET's k) engineering tools.

Competency	Study	Standardized importance rating			
Meta-analysis wording (that is, ABET's wording)		*Overall mean*			
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	Meta-analysis	0.04			
Verbatim wording on each survey		*Practicing*	*Managers*	*Alumni*	*Faculty*
An ability to use computers for communication, analysis, and design.	Evans 1993	-1.20		-0.31	-0.13
Experience with or aptitude for using existing software such as AutoCAD, Lotus or dBase to solve practical problems	Benefield 1997	0.31		0.34	
Ability to use computers for communication, analysis and	Koen 1998		1.08	0.86	
Computer literacy in analysis tools used in engineering	Lang 1999	0.17			
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	Lattuca 2006	0.46			
Ability to use modern enginering techniques, skills & tools	Passow original			-0.80	
Ability to use modern enginering techniques, skills & tools	Passow revised			-0.57	
Not surveyed by NSPE, Shea, Bankel, Saunders					

Table C12. Original survey wordings for items that did not map onto ABET competencies. Ratings for shaded items are comparable to the top two levels of ABET competencies.

Competency	Study	Standardized importance rating			
Verbatim wording on each survey		*Practicing*	*Managers*	*Alumni*	*Faculty*
Exert high levels of effort, strives to achieve goals.	Koen 1998		1.17	0.87	
Effective decision making (prioritizing goals, generating alternatives and choosing the best alternative).	Koen 1998		0.88	0.86	
Personal skills and attributes (Initiative and willingness to take risks, perserverance and flexibility, creative thinking critical thinking awareness of one's personal knowledge, skills, and attitudes, curiosity and lifelong learning, time and resource management)	Bankel 2003	0.95		0.43	0.69
Mature, responsible and open minded with a positive attitude towards life.	Koen 1998		0.59	0.54	
A mature, responsible, and open mind, with a positive attitude toward life	Evans 1993	0.63		0.20	-0.10
Able to transition from academic environment to the industrial	Koen 1998		0.59	0.50	
Commitment to achieve objectives which requires high expectations, a postive attitude, and an open mind to new ideas and ways of doing things	Shea 1997			0.53	-0.07
Effective project management skills	Koen 1998		0.06	0.50	
Effective leadership skills	NSPE 1992	0.43			
Recognition that engineering is an integrative process involving analysis and synthesis	NSPE 1992	0.34			
Professional skills and attitudes (professional ethics, integrity, responsibility and accountability, professional behavior proactively planning for one's career, staying current on world of engineer)	Bankel 2003	0.14		-0.16	0.07
System thinking (Thinking holistically, emergence and interactions in systems, prioritization and focus, trade-offs and balance in resolution)	Bankel 2003	0.04		-0.70	0.10
Fundamental understanding of cost estimation and accounting	Koen 1998		-0.83	-0.31	
Knowledge of business strategies and management practices.	Koen 1998		-1.09	-0.17	
Fundamental understanding of engineering economic analysis and decision making	Koen 1998		-0.93	-0.51	
Implementing (Designing the implementation process; hardware manufacturing process; software implementing process; hardware software integration; test, verification, validation, and certification; implementation management)	Bankel 2003	-1.07		-0.63	-1.25
People management skills	Saunders 2005, 2007	-2.61	0.89	-1.00	
A knowledge of business strategies and management practices	Evans 1993	-1.00		-0.90	-2.11
Co-op experience	Benefield 1997	-0.87		-1.56	
Operating (Designing and optimizing operations, training and operations, supporting the system lifecycle, system improvement and evolution, disposal and life-end issues, operations management)	Bankel 2003	-1.38		-1.12	-1.47
Other job experience working on practical projects	Benefield 1997	-1.37		-1.26	
Summer internships	Benefield 1997	-1.05		-1.76	
Net worker [Social networking skills]	Saunders 2005, 2007	-1.94	0.44	-2.10	
Knowledge of several areas of engineering outside of the student's major discipline	Benefield 1997	-1.94		-1.07	
Enterprise and business context (Appreciating different enterprise cultures, enterprise strategy, goals, and planning, technical entrepreneurship, working successfully in organizations)	Bankel 2003	-1.38		-1.87	-2.19
Operational management skills	Saunders 2005, 2007	-0.94	-1.18	-2.44	
Ability to develop computer software using FORTRAN, C or other high level languages for specific applications	Benefield 1997	-2.66		-2.20	
Knowledge of a foreign language	Benefield 1997	-4.40		-4.24	

APPENDIX D. STATISTICAL DECISIONS FOR THE META-ANALYSIS

The meta-analysis used two stages of analysis. First, statistical testing was needed to detect differences in ratings for different competencies. I used ANOVA. Second, after differences were detected, multiple comparison tests determined which competencies differ from each other. This appendix describes the decisions for using the ANOVA to detect differences.

The data set constrained my decisions. Eight of the studies report only the mean rating for each competency without a standard deviation, while another eight of the studies did not include the complete set of ABET competencies.

First, there were the decisions about the distribution of the data itself. There is no reason to believe that the raw ratings in the original studies were normally distributed. As a matter of fact, the high level of the means within each scale indicates that they likely were skewed toward the tops of their rating scales. However, by the central limit theorem, the distribution of the means of the samples will be an approximately normal distribution if the population mean and variance are finite, the population size is at least twice the sample size, and each sample is composed of at least 30 measurements (Spiegel, 1990). The population of engineering graduates is much larger than the sample size of 10, 203, with an estimated 2.2 million employed U.S. residents with a degree in engineering in 1998 (Burton & Parker, 1998). In my analysis, the smallest sample is composed of 223 measurements. Thus, the three conditions for the central limit theorem were met for the analysis. Therefore, parametric statistics can be used to determine which overall mean ratings are statistically different from each other.

Second, a specific test was required to determine if any of the overall mean ratings differed significantly. Statistically speaking, the null hypothesis that there are no differences between the ratings for the different competencies was tested with an analysis of variance (ANOVA). For the analysis, a balanced layout was important, which means the analysis requires a rating for each of the 11 treatments (competencies for this meta-analysis) for each of the "subjects" or "respondents" (21 populations reported in the 12 studies). However, only two of the studies included all eleven of the ABET competencies. One study included only five, two studies included only six, three studied included only eight, and two studies included only nine. *A primary challenge of the meta-analysis was to create balanced metrics on which to base the statistical comparisons.* In order to achieve a balanced ANOVA and subsequent post-hoc comparisons, study means could not be used directly.

Instead, the ANOVA was calculated based on sub-group means of all available observations from the studies. In other words, the "subjects" for the ANOVA were the means for practicing engineers, engineering alumni, and engineering faculty (see example calculations in Table D1). The *practicing mean* for each competency was the grand mean of the nine population means from the ten studies which surveyed practicing engineers. Likewise, the *alumni mean* was the grand mean of the nine population means from the eight studies which surveyed engineering alumni. The *faculty mean* was the grand mean of the three population means from the three studies which surveyed faculty. In the ANOVA, each sub-group mean ("subject") was weighted by the number of populations included in the average. In summary, the ANOVA was calculated on just three "subjects" for each competency. As shown in Table D1, these three "subjects" were the means for the following sub-groups: the practicing mean (weight = 9), the alumni mean (weight = 9), and the faculty mean (weight = 3). To verify this approach, the overall means were re-calculated based on these weighted sub-group means. The re-calculated means differed from the overall means only very slightly, with the largest difference being .055 standardized ratings. The one-way ANOVA of standardized ratings based on the weighted sub-group means by competency showed that the ratings for the competencies do differ [$F(10, 220) = 21.18$, $p < .001$] at $\alpha = .05$.

The one-way ANOVA assumes independence of the treatments, which are the 11 competencies in this meta-analysis. On initial examination, the one-way ANOVA does not seem appropriate for the data collection because the original surveys asked each respondent to rate

Table D1. Example calculations of standardized importance ratings for the ANOVA.

Population	n	e) problem solving	h) impact
Practicing mean (n= 9 populations from 8 studies, 3362 respondents)	**3362**	**0.74**	**-1.52**
Practicing engineers (n=888) *NSPE*	888		-1.33
Practicing engineers (n=14) *Evans*	14	1.22	-1.29
Industry (n=298, includes 98 practicing engineers)	298		-1.45
Supervisors (n=57) *Koen*	57	0.99	-1.77
Practicing engineers (n=420) *Lang*	420	0.17	-1.44
Industry (n=44) *Bankel*	44	1.35	-1.47
Eng. Specialists (n=9) *Saunders*	9	0.57	
Eng. Managers (n=10) *Saunders*	10	-0.08	
Practicing engineers (n=1622) *Lattuca*	1622	0.91	-1.88
Alumni mean (n= 9 populations from 8 studies, 6618 respondents)	**6618**	**1.26**	**-1.53**
Alumni (n=737) *Evans*	737	1.25	-1.64
Alumni (n=546) *Benefield*	546		-1.34
Alumni (137 alumni & 40 advisory board) (n=177)	177	1.15	-0.51
Alumni (n=124) *Koen*	124	0.77	-2.07
5-yr alumni (n=91) *Bankel*	91	1.60	-1.68
15-yr alumni (n=56) *Bankel*	56	1.44	-1.74
Alumni for current job (n=662) *Saunders*	662	1.49	
Alumni (n=2110) *Passow Original Wording*	2110	1.18	-1.98
Alumni (n=2115) *Passow Revised Wording*	2115	1.24	-1.26
Faculty mean (n=3 populations from 3 studies, 223 respondents)	**223**	**1.15**	**-1.69**
Faculty (n=97) *Evans*	97	1.16	-1.71
Faculty & Administrators (n = 40) *Shea*	40	0.91	-1.76
Faculty (n=86) *Bankel*	86	1.38	-1.61
Overall mean (n= 21 populations from 12 studies, 10, 203 respondents)	**10203**	**1.04**	**-1.55**
Overall std dev		0.54	0.57

each of (up to) 11 competencies, which is a repeated measures design. However, this *meta-analysis* has many levels of aggregation, first within studies to obtain population means, then across studies to obtain sub-group means. These doubly aggregated sub-group means are the data for the ANOVA, making it reasonable to assume that the values for the competencies are independent. This assumption of independence was verified using several approaches. There is essentially no intra-class correlation of competency ratings within sub-groups. Also, a repeated measures analysis of variance was performed assuming repeated measures on each of the three sub-groups ("subjects") being analyzed, treating *competency* as a within-subject factor, and results did not differ substantially from those for the one-way ANOVA. Thus, the one-way ANOVA is conceptually and statistically appropriate.

Brady West, Lead Statistician at the Center for Statistical Consultation and Research (CSCAR) at the University of Michigan reviewed the approach described above. This final approach incorporates his recommendations.

APPENDIX E. THE ALUMNI SURVEY FOR U-M'S COLLEGE OF ENGINEERING

COLLEGE OF ENGINEERING 2005-2006 ALUMNI SURVEY

This survey is designed to gather information on your post-graduation experiences and how those relate to experiences you may have had at the University while a student. Your input is important in helping the College evaluate and improve undergraduate education. The survey is anonymous and should take approximately 10 minutes to complete. **Please complete the survey online at http://www.zoomerang.com/survey.zgi?p=WEB224JKT5WRPG or return the completed survey in the enclosed envelope by March 10, 2006. Thank you.**

PART I. EDUCATIONAL BACKGROUND

1. How did you enter the U-M College of Engineering? As a:

θ First year student (freshman), first time in college
θ Transfer student from a two-year college
θ Transfer student from a four-year college
θ Transfer student from another U-M school or college

2. What year did you receive your undergraduate degree(s)?
θ 2003 θ 1999 θ 1995 θ Other (*specify*): _______________

3. What major(s) did you receive your undergraduate degree in? (*check all that apply*)

θ Aerospace Engineering
θ Atmospheric, Oceanic & Space Sciences
θ Biomedical Engineering
θ Chemical Engineering
θ Civil Engineering
θ Computer Engineering
θ Computer Science
θ Electrical Engineering
θ Engineering Physics
θ Industrial and Operations Engineering
θ Interdisciplinary Engineering
θ Materials Science and Engineering
θ Mechanical Engineering
θ Naval Architecture and Marine Engineering
θ Nuclear Engineering and Radiological Sciences
θ Other (*specify*): ___________________

4. What was your cumulative undergraduate GPA?

θ 2.0 or below θ 2.01 – 2.5 θ 2.51 – 3.0 θ 3.01 – 3.5 θ 3.51 – 4.0

5. What degrees do you hold other than those checked in question #3?

θ No Other Degrees
θ M.B.A.
θ Master's in an engineering field
θ Master's outside of engineering (and not an MBA)
θ J.D. (Law)
θ M.D.
θ Doctorate in an engineering field
θ Doctorate outside of engineering
θ Other (*specify degree title*) : _______________

PART II. UNDERGRADUATE EXPERIENCE

6 & 7 Please rate how *important* the following competencies and attitudes have been to you in your professional experience AND how *well* you feel your undergraduate program at the University of Michigan *prepared* you in these areas.
Circle the appropriate number for #6 & #7 using the following scales:

#6: 5=Extremely important 4=Quite important 3=Somewhat important 2=Slightly important 1=Not at all important
#7: 5=Excellent preparation 4=Good preparation 3=Adequate preparation 2=Unsatisfactory preparation 1=Poor preparation

	#6: Importance	#7: U-M Preparation
Math, science and engineering skills	5 4 3 2 1	5 4 3 2 1
Ability to design and conduct experiments	5 4 3 2 1	5 4 3 2 1
Ability to analyze and interpret data	5 4 3 2 1	5 4 3 2 1
Ability to design a system, component or process	5 4 3 2 1	5 4 3 2 1
Ability to function on a team	5 4 3 2 1	5 4 3 2 1
Engineering problem-solving skills	5 4 3 2 1	5 4 3 2 1
Understanding of professional and ethical responsibility	5 4 3 2 1	5 4 3 2 1
Written communication skills	5 4 3 2 1	5 4 3 2 1
Oral communication skills	5 4 3 2 1	5 4 3 2 1
Understanding of the social, economic and environmental impact of my work	5 4 3 2 1	5 4 3 2 1
Ability to continue formal or informal learning	5 4 3 2 1	5 4 3 2 1
Knowledge of contemporary issues that affect my work	5 4 3 2 1	5 4 3 2 1
Ability to use modern engineering techniques, skills & tools	5 4 3 2 1	5 4 3 2 1

1

8. How would you judge the *quantity* of your undergraduate preparation in:
Circle the appropriate number for the skills below using the following scale:
3=Too much preparation **2=Appropriate amount of preparation** **1=Too little preparation**

Math, science, and engineering skills	3	2	1
Ability to function on a team	3	2	1
Engineering problem solving skills	3	2	1
Understanding of professional and ethical responsibility	3	2	1
Written communication skills	3	2	1
Oral communication skills	3	2	1
Understanding of the social, economic, and environmental impact of my work	3	2	1
Ability to continue formal or informal learning	3	2	1
Knowledge of contemporary issues that affect my work	3	2	1

9. What do you consider to be the greatest strength of your undergraduate program?

10. What do you consider to be the greatest weakness of your undergraduate program?

11. What one or two specific curriculum changes would you recommend? Why?

12. Overall, how satisfied are you with:

a. Your undergraduate educational experience at the University of Michigan

θ Very satisfied θ Satisfied θ Neutral θ Dissatisfied θ Very dissatisfied

b. The career services offered to you by the College of Engineering

θ Very satisfied θ Satisfied θ Neutral θ Dissatisfied θ Very dissatisfied θ Does not apply

PART III. WORK EXPERIENCE AFTER UNDERGRADUATE SCHOOLING

13. How many different employers have you worked for since the receipt of your B.S.E./B.S. degree from the U-M College of Engineering? θ 0 θ 1 θ 2 θ 3 θ 4 θ 5 θ More than 5

14. What is your current employment status? (*check all that apply*)
    - θ Employed or self-employed
    - θ Student
    - θ Not currently employed (and not a student)
    - θ Other (*specify*): ______________

15. If you are employed or self-employed, what is your employer's main business? (*check the one that BEST fits*)
    - θ Aerospace
    - θ Automotive
    - θ Chemical/petroleum
    - θ Communications
    - θ Computer hardware
    - θ Computer software
    - θ Consumer products
    - θ Defense
    - θ Electronics
    - θ Engineering consulting
    - θ Financial services
    - θ Government agency or lab
    - θ Health services
    - θ Management consulting
    - θ Medical devices/biomedical devices
    - θ Pharmaceutical/biotech
    - θ Transportation or utilities
    - θ University or college
    - θ Other (*specify*): ______________

16. If you are employed or self-employed, which category below BEST describes your job?
    - θ Engineer
    - θ Science/technology related work that is <u>not</u> engineering (*specify*): ______________
    - θ Marketing/sales of engineering products or services
    - θ Marketing/sales that is <u>not</u> related to engineering
    - θ Manager of engineers and their work
    - θ Manager of people and work that is <u>not</u> related to engineering
    - θ Other (*specify*): ______________

17. If you are employed or self-employed *in engineering or engineering-related work*, which phrase below BEST describes your work?
    - θ Consulting engineer
    - θ Design engineer
    - θ Faculty member
    - θ Manager of engineers
    - θ Process or industrial engineer
    - θ Product engineer
    - θ Project manager/project leader
    - θ Quality engineer
    - θ Researcher
    - θ Sales engineer/technical sales
    - θ Software developer/programmer
    - θ Systems analyst/systems engineer
    - θ Test engineer/field engineer
    - θ Other (*specify*): ______________

18. What work-related skills or subjects have you learned *since completing your last degree*? Why did you start that learning? How did you learn each skill or subject (trial-and-error, self-guided study, working under a mentor, formal courses, etc.)?

    ____

    ____

    ____

    ____

19. Are you a registered professional engineer? θ Yes θ No If YES, specify branch: ______________________

20. Overall, how satisfied are you with your choice of career?

    θ Very satisfied θ Satisfied θ Neutral θ Dissatisfied θ Very dissatisfied

21. In what income range does your annual salary (gross) fall?
    - θ <$20K
    - θ $21-40K
    - θ $41-60K
    - θ $61-80K
    - θ $81-100K
    - θ $101-120K
    - θ $121-140K
    - θ Greater than $140K

PART IV. BACKGROUND

22. What is your gender? θ Female θ Male

23. Optional - If you are a U.S. citizen or Permanent Resident, please choose the race/ethnicity which best describes you:

- θ African American/Black (not of Hispanic origin)
- θ Asian or Pacific Islander (includes the Indian sub-continent)
- θ American Indian or Alaskan Native (Tribe:________________)
- θ Hispanic/Latino(a) (Spanish culture or origin, regardless of race)
- θ White (persons not of Hispanic origin, having origins in any of the original peoples of Europe, North Africa, or the Middle East)
- θ Multi-racial or multi-ethnic (please *specify*): ____________________

24. Please share any other comments you would like to make, such as recommendations for specific changes, comments about quality of life as a College of Engineering student and as a graduate, or descriptions of significant challenges you faced. ________________

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Please complete the survey online or return the completed paper survey in the enclosed envelope by March 10, 2006. Thank you.

APPENDIX F. DATA COLLECTION FOR THE UNIVERSITY OF MICHIGAN SURVEYS

This appendix details the U-M alumni and senior surveys: the recipients, survey distribution, collection, response rates, and a comparison of respondents to the population.

The Alumni Survey

The alumni survey of recent undergraduate alumni gathers 1) opinions about their undergraduate program including the quality of preparation in specific curricular outcomes, and 2) information about both their work experience and ongoing learning after graduation. Since the 1998-99 academic year, the survey has been conducted annually.

Recipients

The alumni survey can be viewed as a single survey that samples recent alumni by surveying the entire population in selected years. Alternatively, the alumni survey can be viewed as three separate, annual, census surveys of two-year alums, six-year alums, and ten-year alums. Each year, surveys are sent to *all* CoE alumni who received their undergraduate degree(s) two, six, and ten years prior to the academic year of the survey.

Recipients of the surveys were identified through an M-Pathways (Business Objects) query of the University of Michigan's Donor-Alumni-Constituents (DAC) database. DAC contains records for *all* graduates of UM. The query supplied name, degree title, year of graduation, current mailing address, and current email address for all CoE undergraduate alumni who graduated 2, 6, and 10 years prior to the academic year of the survey in College of Engineering majors (Aerospace Engineering, Atmospheric, Oceanic, and Space Sciences, Biomedical Engineering, Chemical Engineering, Civil Engineering, Civil and Environmental Engineering, Computer Engineering, Computer Science (granted by the College of Engineering as opposed to the College of Literature, Science, and the Arts), Electrical Engineering, Engineering Physics, Interdisciplinary

Engineering, Industrial and Operations Engineering, Materials Science and Engineering, Mechanical Engineering, Naval Architecture and Marine Engineering, Nuclear Engineering and Radiological Sciences, and Nuclear Engineering).

Mailing lists of survey recipients contained *only* living graduates who had addresses tagged as active in the CoE alumni database. I investigated the fraction of the population omitted from the mailing list (Figure F1). Restricting our mailing list to active addresses eliminated about 4% of the alumni of interest. (Note: An address is changed to "inactive" after two mailings marked undeliverable are returned to the University in a single year.) Surveys were returned to us by the U.S. Postal Service for about 4% of the alumni of interest in 2004-05. Thus, it appears that the paper surveys reached over 90% of the alumni population of interest.

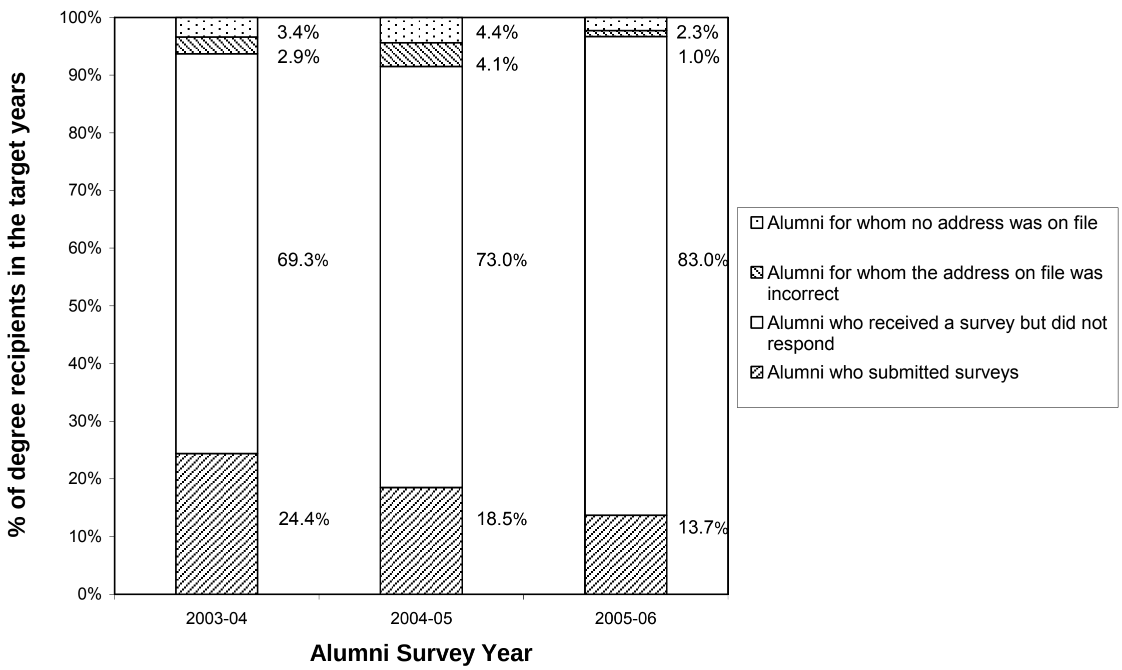
Instrument

The most recent survey is in Appendix E. Each year, the survey was modified slightly based on feedback from faculty and respondents. The only substantial modifications were made for the 2002-03 survey. Jeanne Murabito at the College of Engineering and I had three reasons for the modifications: to co-ordinate the questions on the alumni and senior surveys, to restructure both surveys to make web administration possible, and to clarify scales. Nancy Birk, a researcher at U-M's School of Education, reviewed the revisions I proposed for adherence to the principles of survey design. The final survey incorporated her suggestions.

Distribution and Collection

Every year, a paper survey has been mailed to each alumnus in our target lists with a pre-paid return envelope. The surveys have been mailed at different times of the year. By 2002-03, a late winter or early spring mailing was the norm. In 2002-03, the mailing was in late March. The response rates were low (possibly due to a conflict with tax season). In an attempt to increase response rates, email follow-ups were sent to those alumni who had email addresses in their records (approximately one third of the total mailing list). In 2004-05, an attempt was made to transition the alumni survey to an entirely web-based survey. In early November, a postcard invitation with the URL was mailed. After receiving only a handful of web responses, the concept of an entirely web-based survey was abandoned. In January 2005, the typical paper survey was mailed to the entire mailing list. Note that except for 2002-03 and 2004-05, no survey follow-ups have been sent. Also note that alumni at foreign mailing addresses have been included consistently since 2004-05.

Figure F1. Alumni population breakdown for selected survey years.



Since 2002-03, the paper survey has contained an optional URL for a web version of the survey hosted by Zoomerang. (The wording and sequence of the questions have always been identical in each format.) In other words, since 2002-03, alumni survey responses are received either on paper or on the web survey. Many alumni have completed the online version: 2002-03 (22% of the respondents completed the web version), 2003-04 (40%), 2004-05 (46%), and 2005-06 (45%). Alumni who complete the web survey do their own data entry, but data entry for the paper surveys is done by staff at the College of Engineering.

Response Rates

The response rates have been calculated conservatively. The common formula (# of surveys received/# of surveys sent) cannot be used directly because of complexities in the data set. To enable accurate departmental response rates, the *number of surveys received* is estimated by the *number of degrees reported*, which is slightly inflated because of double majors. For example, in 2005-06, 419 surveys were received but 425 degrees were reported.

Records for the *number of surveys sent* were not kept in all years, so this number is estimated using the *number of degrees granted* for the calendar years involved. This estimate seems justified because this is a survey of a *population* (the entire list of degree recipients for specific calendar years), not a random sample. Figure F1 is an example of this calculation method. There are three sources of error inherent in using this second estimate. First, alumni who have no address on file, are deceased, or have inactive addresses in the DAC database are included in the denominator Figure F1. Second, surveys returned by the U.S. post office are included in the denominator (Figure F1). Comprehensive records pertaining to these first two sources of error were kept only during the 2003-04, 2004-05, and 2005-06 survey administrations. Third, the number of *degrees granted* (the denominator) is slightly higher than the number of *degree recipients* because between 8 and 40 degree recipients have received dual degrees in each graduating year. Yet, despite having two degrees granted, a dual degree alumnus either submits one survey or does not respond. The complexity of the dataset is a substantial obstacle to correcting for the third source of error. Overall, the three sources of error in the denominator understate the traditional response rate slightly. Specifically, the minimum response rate of 13.3 % (calculated based on degrees granted) is estimated to be as much as 15% response rate if it were calculated based on surveys sent. Similarly, the maximum response rate of 31.6% (calculated based on degrees granted) is estimated to be as much as 36% if it were calculated based on surveys sent. For the 2005-06 survey, the true, overall response rate was calculable: 14.1% (419 responses/2981 surveys sent). This can be compared with estimates. The response rate based on the true number of responses received and the actual number of alumni is 13.7%, as reported in

Figure F1. Contrast this with the 13.3% based on the estimates that employ degrees reported and degrees granted.

Response rates can be examined by multiple approaches. Overall, lumping together the seven administrations of the alumni survey (1999-00 to 2005-06), the response rate is 20.9%, with 4195 total responses from 20,081 degrees granted in the target years. (Note that an additional 30 responses from outside the target years makes a total of 4225 responses.) The response rates are not affected by the number of years since graduation or the specific graduation year. It is still not clear if the time of year that the survey is sent affects the response rate (Figure F2). Also, it appears that response rates are affected by the department from which the alumnus graduated. The details of these analyses are explained below (Figure F3).

Comparing Alumni Respondents to the U-M Population

Population data was available for the following alumni survey parameters: gender, race, grade-point-average, undergraduate major, year of graduation, and how the graduate entered the College of Engineering (as a 1st year student, a transfer from another institution, or a transfer from another U-M school or college). For the chi-squared testing, the null hypothesis was that the sample is representative of the CoE population. This hypothesis was rejected at the $\alpha = .05$ level for gender, race, grade-point-average, undergraduate major, and year of graduation. Women, multi-racials and whites, and higher grade-point averages were reported at significantly higher frequencies than expected in the population. Certain majors (chemical engineering, civil engineering, and materials science and engineering) were reported significantly more frequently than expected, while other majors (computer engineering, computer science, electrical engineering, and interdisciplinary engineering) were reported significantly less frequently than expected. The discrepancy in graduation years mirrors the response rates for the seven survey administrations. After weighting to compensate for surveying some graduation years two or three times, graduation year was still not reported with the expected frequencies. Graduation years surveyed with response rates below the overall response rate of 20.9% are reported below the expected frequency while graduation years

Figure F2. Alumni survey response rates by survey year.

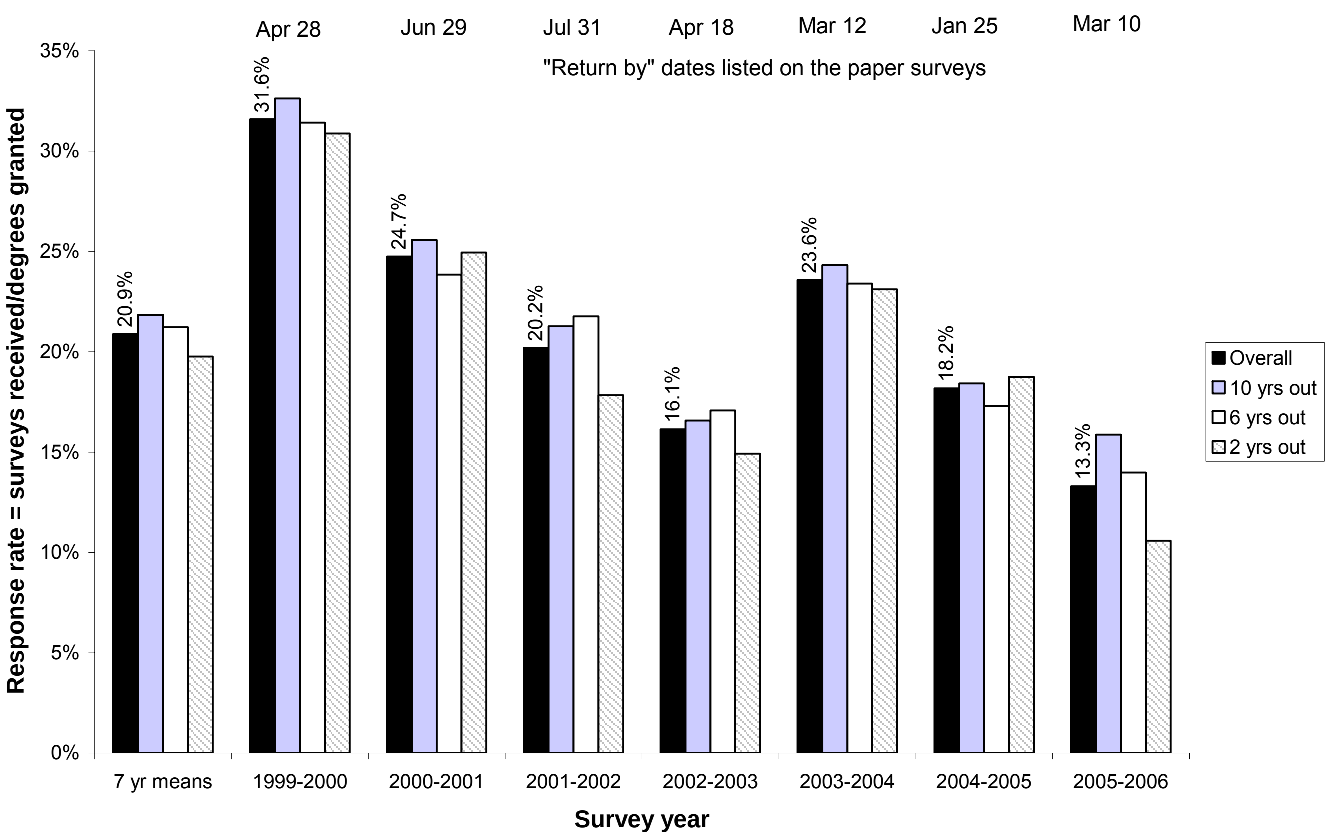
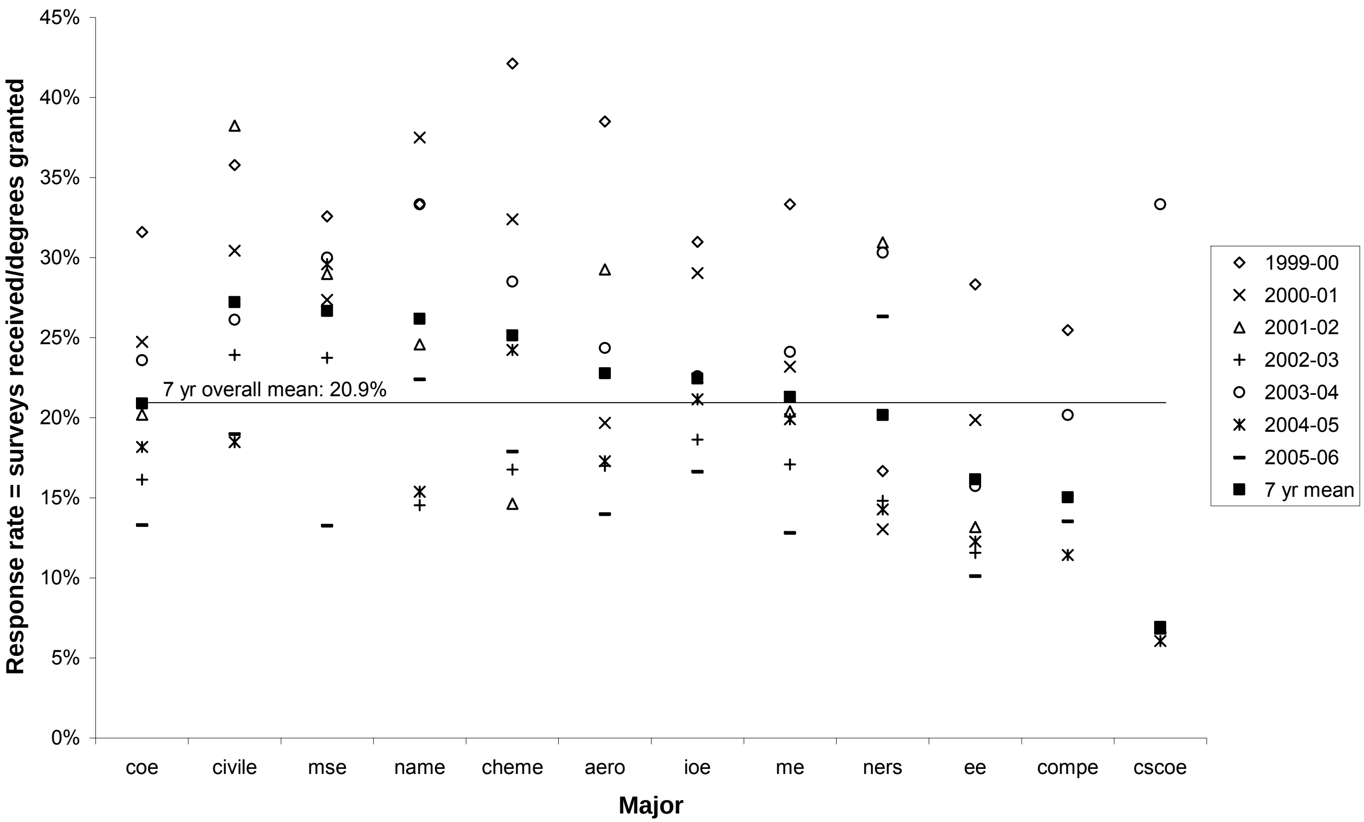


Figure F3. Alumni survey response rates by major.



surveyed with response rates above the overall mean are reported above the expected frequency.

For the alumni survey data, the null hypothesis that the sample is representative of the CoE population was not rejected for how the student entered the CoE. Respondents' reported frequencies of entering the college as 1st year students, transfer students from 2- and 4- year colleges, and transfers from another UM school or college match the expected frequencies at the $\alpha = .05$ level. For this one variable, the population data was not available before the 2003 graduation year, so only the 2003 graduation year sample was compared to the 2003 population for the chi-squared test. Altogether for the alumni data, *weighting to reduce non-response bias may be advisable for the variables: gender, race, grade-point-average, undergraduate major, and year of graduation*.

The Senior Survey

The exit survey of graduating seniors gathers 1) opinions about high school and first-year preparation for the major, 2) opinions about their undergraduate program including advising and the quality of preparation in specific curricular outcomes, 3) information about co-curricular involvement, and 4) opinions about how important specific curricular outcomes will be in the workplace. Starting with the 2003-04 senior survey (the first to include the questions about the *predicted* importance of ABET's eleven learning outcomes), this survey has been administered entirely through email invitations, an online survey, and repeated email follow-ups. Thus, respondents perform all their own data entry. Survey recipients who respond immediately receive no email follow-ups. Those who are slow to respond receive follow-ups about every two weeks for the remainder of the semester until graduation.

Response Rates

Because the senior survey can be viewed in multiple ways, response rates can be examined two ways. Overall, if all nine of the senior survey administrations (August 2003 to May 2006) are lumped together, the response rate is 50.8%, with 1671 degrees counted on surveys submitted from 3288 degree applications in the target semesters.

Analysis of the response rates shows several trends. First, the response rates seem to be affected by the semester of graduation (Figure F4). Second, it appears that response rates are affected by the department from which the respondent graduated (Figure F5).

Figure F4. Senior survey response rates by survey year.

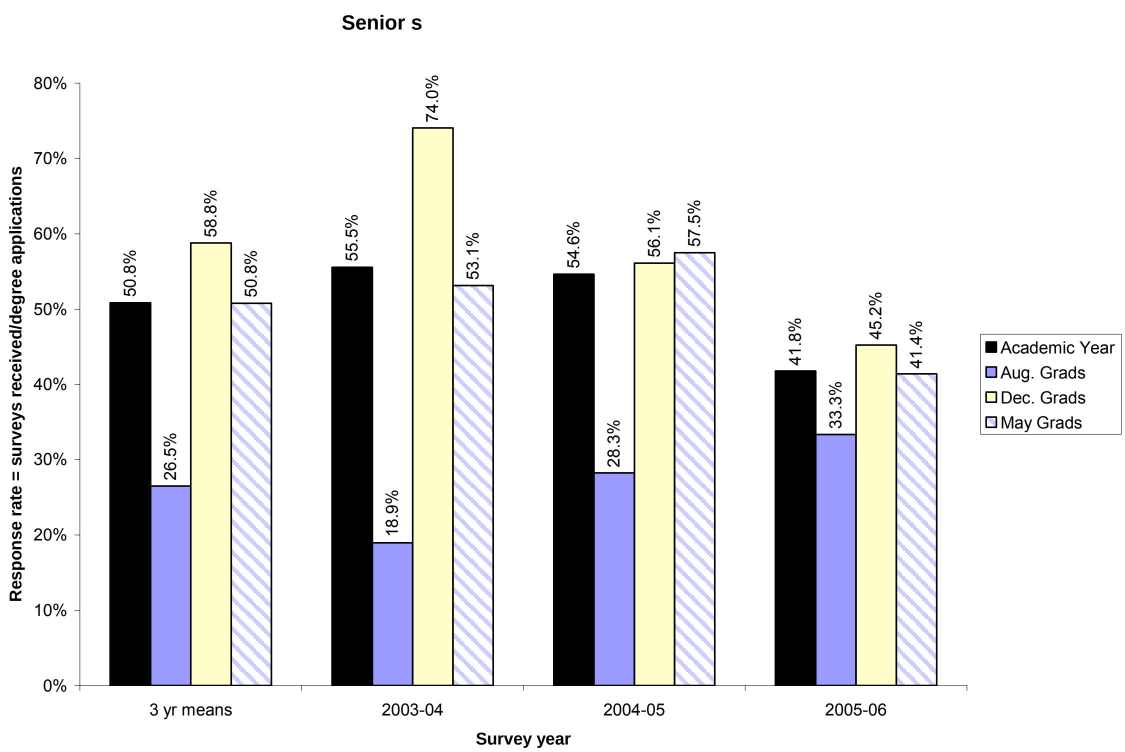
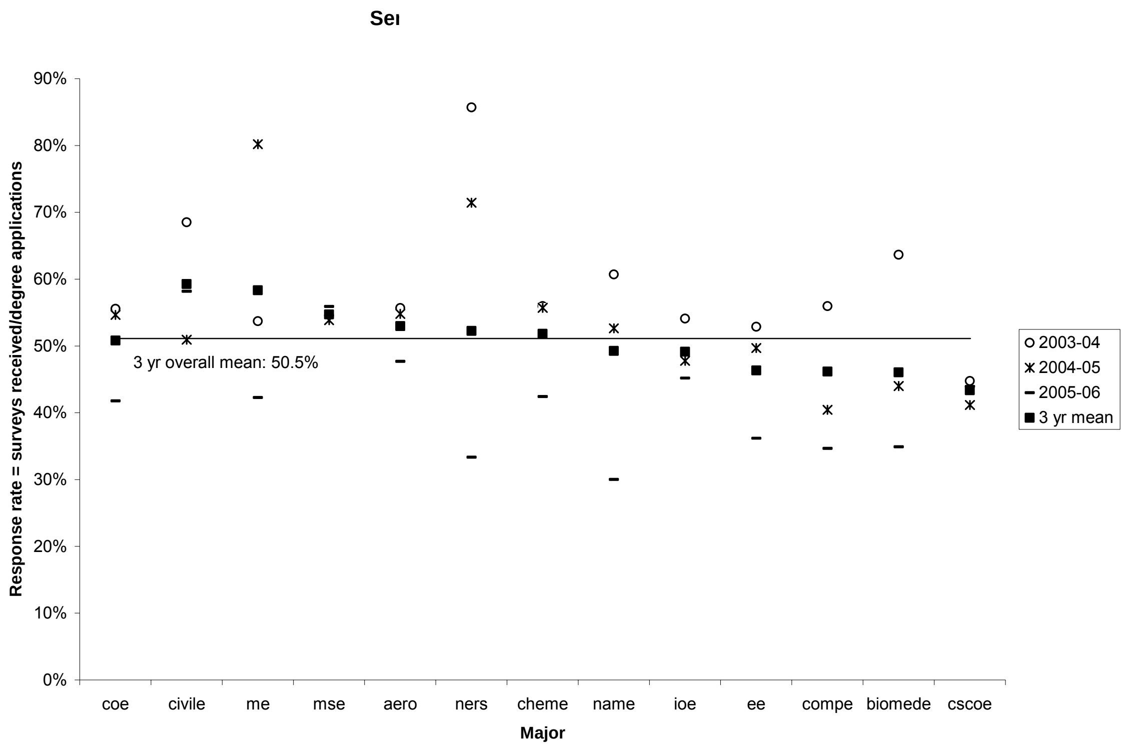


Figure F5. Senior survey response rates by major.



Comparing Senior Respondents to the U-M Population

Population data was available for the following senior survey variables: gender, race, grade-point-average, undergraduate major, semester of graduation, and how the graduate entered the College of Engineering (as a 1st year student, a transfer from another institution, or a transfer from another U-M school or college). For the chi-squared testing, the null hypothesis was that the sample is representative of the CoE population. This hypothesis was rejected at the $\alpha = .05$ level for gender, race, how the graduate entered the CoE, and semester of graduation. Women responded more frequently than expected. Asian, Hispanic, and multi-racial were reported more frequently than expected, all other races (including the censored observation of *no response*) were reported less frequently than expected. The observed frequency of transfer students from other UM colleges were higher than expected, while those for freshmen and transfers from other institutions were lower than expected. The observed frequency of graduation semester was higher than expected for Fall 2003, Winter 2004, Fall 2004, Winter 2005, and lower than expected for Summer 2003, Summer 2004, Summer 2005, Fall 2005, and Winter 2006. This pattern mirrors the pattern in response rates: semesters with response rates above the overall average of 50.8% are observed with higher than the expected frequency, while semesters with response rates below the average are observed with lower than the expected frequency.

For the senior survey data, the null hypothesis that the sample is representative of the CoE population was not rejected for grade-point average and major. For both grade-point-average and major, the observed frequencies match the expected frequencies at the alpha = .005 level. For the senior data, weighting to reduce non-response bias may be advisable for the variables: gender, race, how the graduate entered the CoE, and semester of graduation.

APPENDIX G. SURVEY QUESTIONS FOR FUTURE RESEARCH

The example survey questions in Tables G1, G2, and G3 meet the four criteria described in "Implications for Competency-Based Surveys". These questions 1) define the work environment, work role, and career stage to be considered, 2) fully define each competency in relevant action language, 3) use frequency ratings and proficiency ratings, 4) use importance rankings. To be fully useful, these questions should be followed by questions that gather information about the respondent's work environment, work role, and career stage.

Table G1. Example survey question about frequency of using each competency.

	How **often is this competency <u>significant</u>** in your job?				
	Never	Yearly	Monthly	Weekly	Daily
Apply knowledge of math, science and engineering					
Use the techniques, skills, and modern engineering tools necessary for engineering practice					
Design and conduct experiments					
Analyze and interpret data and symptoms					
Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability					
Work in teams					
Identify, formulate and solve engineering problems					
Act ethically and with professional responsibility					
Communicate by speaking and listening					
Communicate in writing					
Consider the impact of engineering solutions in a global, economic, environmental, and societal context					
Initiate and maintain learning as needed					
Apply knowledge of contemporary issues to engineering problems					

Table G2. Example survey question about the minimum proficiency needed for each competency.

	What is the **<u>minimum</u> necessary level of performance** for each competency in your job?		
	Marginal	Proficient	Exemplary
Apply knowledge of math, science and engineering			
Use the techniques, skills, and modern engineering tools necessary for engineering practice			
Design and conduct experiments			
Analyze and interpret data and symptoms			
Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability			
Work in teams			
Identify, formulate and solve engineering problems			
Act ethically and with professional responsibility			
Communicate by speaking and listening			
Communicate in writing			
Consider the impact of engineering solutions in a global, economic, environmental, and societal context			
Initiate and maintain learning as needed			
Apply knowledge of contemporary issues to engineering problems			

Table G3. Example survey question for ranking the importance of each competency.

	Rank the top <u>five most important</u> competencies for your job? 1 = most important 5 = least important
Apply knowledge of math, science and engineering	
Use the techniques, skills, and modern engineering tools necessary for engineering practice	
Design and conduct experiments	
Analyze and interpret data and symptoms	
Design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability	
Work in teams	
Identify, formulate and solve engineering problems	
Act ethically and with professional responsibility	
Communicate by speaking and listening	
Communicate in writing	
Consider the impact of engineering solutions in a global, economic, environmental, and societal context	
Initiate and maintain learning as needed	
Apply knowledge of contemporary issues to engineering problems	

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