WHAT COMPETENCIES SHOULD ENGINEERING PROGRAMS EMPHASIZE? A META-ANALYSIS OF PRACTITIONERS' OPINIONS INFORMS CURRICULAR DESIGN

Honor J. Passow
University of Michigan
Ann Arbor, Michigan, USA

Abstract

Designing a curriculum is a multifaceted challenge that includes questions about learning goals, such as *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* Faculty decisions can be informed by practitioner's opinions, expressed as ratings of importance to professional practice for each of ABET's eleven competencies (Criterion 3a-k). This meta-analysis combines importance ratings by 5978 engineers in ten different studies, published 1992 through 2007. Multiple comparison procedures on the mean ratings for each competency show six distinct levels of importance: 1) (highest importance) problem solving and communication, 2) ethics, 3) life-long learning, 4) experiments, teams, engineering tools, and design, 5) (average importance) "math, science, and engineering knowledge", and 6) (lowest importance) contemporary issues and understanding the impact of one's work. Ratings of two non-ABET competencies fell between the top two levels: "decision-making" and "commitment to achieving goals". Others compared with the third level, including: "able to transition…to the industrial environment", "project management", and "leadership skills". Engineering curricula whose graduates will thrive in practice must develop *competencies* beyond the traditional emphasis on "math, science, and engineering knowledge", and possibly beyond ABET's eleven.

Keywords: competency, engineering curriculum, professional skills, technical skills

Motivation and Research Questions

Designing a curriculum is a multifaceted challenge. In addition to issues of implementation and assessment of programmatic outcomes, curriculum designers consider questions of purpose, such as "what competencies should students have at graduation?" and "what should the relative emphasis be among those competencies?" 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] In this definition, knowledge includes all the types of knowledge defined by Anderson, et al.'s [8] taxonomy: *factual knowledge* (terminology and details), *conceptual knowledge* (classifications, principles, theories, and 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 the profession of engineering, the concept of designing a curriculum to develop competencies has only recently been formalized. From 1932 to 2001, the U.S. accrediting agency for engineering programs, ABET, required that a detailed list of topics be taught. This focus on inputs (topics taught) has been completely replaced by a focus on outputs (competencies achieved by students). Beginning in 2001-02, the accreditation requirements changed dramatically, requiring accredited undergraduate engineering programs in the U.S. to demonstrate that their graduates achieve, at a minimum, eleven 'program outcomes' [9], or competencies. Complying with the change in accreditation requirements actually requires a culture change among faculty. ABET's former criteria required a science-focused preparation that has characterized engineering education since World War II [e.g., 10, 11]. Reinforced by such requirements, the culture has been one where faculty make curriculum decisions that are "discipline-identified and content-centered and … [they] view their roles as transmitting and replicating knowledge for students" [12, p. 152]. ABET's new requirements, which focus on student competencies, demand a culture where faculty are "less discipline-identified, … [and see] their role as promoting student growth or skill acquisition" [12, p. 152]. ABET's requirement for engineering programs to demonstrate graduates' achievement of specific competencies is spreading worldwide through an international agreement among accreditation-style bodies in 14 countries: Australia, Canada, Germany, Hong Kong, Ireland, Japan, Korea, Malaysia, New Zealand, Singapore, South Africa, Taiwan, the United Kingdom, and the United States [13, 14]. Thus, faculty in engineering programs around the world face a culture change, and with it new questions about relative emphasis among competencies, such as "How important is *the ability to apply mathematics, science, and engineering science* relative to *the ability to communicate effectively*?"

In academic programs that prepare students for a profession, such as engineering, medicine, or law, the curriculum will ideally include development of competencies that are important for professional success [12]. Although faculty members often practice professionally in addition to teaching, their experience rarely reflects the full diversity of the environments in which their graduates will practice. Thus, faculty who are designing curriculum can benefit from practitioner opinions about the relative importance of competencies. 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.

[1] My definition draws on the scholarly description of competency and performance by the faculty of Alverno College [1] and other international leaders in the field of competency-based (also called ability-based) higher education [e.g., 2, 3]. My definition includes language from the field of industrial psychology [e.g., 4, 5, 6] and higher education for the professions [7].

Research Design for the Meta-Analysis

Overview of the Approach to 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 [15]. Hunter and Schmidt [16] review and critique 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. Given the nature of the data reported in the studies in Table A1 (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, with results stated as experimental outcomes or as correlations or as descriptive statistics [16-19]. Although most literature on meta-analysis applies to the statistics required for analyzing experimental and correlational studies, meta-analysis can be performed on studies whose findings are simple rates, such as the percent of the elderly who need assistance for eating [e.g., 20]. Glass, et al. (1981) state that the statistics are straightforward when findings in the studies are already expressed in a common metric, such as a rate or a percentage or a difference between percentages. 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. [17, p. 93]

My approach for the meta-analysis will be a Glassian approach, as described by Hunter and Schmidt (1990). The Glassian elements will be an emphasis on descriptive, rather than inferential, statistics and inclusion of all studies in the analysis, regardless of their quality. A limitation of this classic 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 stages after forming the research questions: 1) identifying the studies to include in the meta-analysis, 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 [18].

Identifying the Studies to Include in the Meta-analysis

An extensive literature review identified eleven studies published since 1990 (plus one soon-to-be published) that seek practicing engineers' ratings of the importance of various competencies [21-34]. Methods are described for each study in Table A1. The results of preliminary searches, based on my own experience in the field of engineering education, identified three of the studies. These three studies pointed to two key concepts for indexing: competencies (or job skills) and engineering (or professions). A research librarian designed the final queries for three data bases, Proquest's Dissertation Abstracts, Engineering Village 2 (Compendex and Inspec), and ERIC (Education Resources Information Center). The relevant studies initiated new search paths. Citations of all relevant or closely-related studies were explored (identified in ISI Web of Science and Google Scholar). Also, the reference list of every relevant or closely-related study was reviewed in detail. The many-faceted search, completed in July 2006, yielded twelve survey studies published since 1990 that asked practicing engineers to rate the importance of assorted competencies in engineering practice. Turley's [21] survey study did not ask for ratings of importance, and this different methodology precludes it from the meta-analysis. Similarly, the ASME study [24] was not included in the meta-analysis because it reported ratings of importance in a manner incompatible with the other studies.

Although great care was taken to make a comprehensive search, there are suspected limitations in coverage. Two of the three initial studies were not additionally 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. From these observations of omission, it can be inferred that additional, related, studies may exist, especially unpublished studies made to inform faculty decision-making. All studies in Table A1 are included in the analysis, regardless of their publication status, except for the two that reported data in an incompatible format (Turley (1992) and ASME (1995)). Thus, studies published in 10 different articles are included. 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 to say:

> 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. [17, p. 64]

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

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" [17, p. 80]. These studies have several interesting characteristics to explore: 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. Due to the features of the data and the resulting implications for the analysis, only one subdivision of the data can be explored statistically, respondents' industry. Each of the other characteristics of the studies merits exploration in future research.

The 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 *alumni* group consists of 2393 respondents (4.0% from Sweden, 27.7% from the Netherlands, and 68.3% from the U.S.). There is an irregularity in this group. Shea [26] sampled alumni separately from industry engineers, but for his analysis, he combined the two groups. Thus, the alumni group includes 40 industry representatives. The *faculty* group consists of 223 respondents (28.6% from Sweden and 71.3% from the U.S.). The *practicing engineers* group includes 3362 respondents (0.8% from Sweden, 0.5% from the Netherlands, and 98.7% from the U.S.). There is an irregularity in this group. Note that 200 of the 298 industry respondents in the Benefield, et al. (1997) study did not hold the title of "engineer" or "engineering manager", but had titles such as human resources manager. I chose to include this population in the practicing engineers group because, as recruiters in engineering organizations, I assume that their ratings of the importance were highly influenced by engineers in their organization for whom they were hiring. Composition of these groups is detailed in Table A2.

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. [35, p. 262]

Creating common constructs for the competencies

Although the studies selected for the meta-analysis are closely related, only one of the studies replicated the wording of competencies from a previous study. Therefore, common wordings, or constructs, were required for direct comparison. Because ABET's eleven competencies have become familiar constructs among engineering faculty worldwide, they were selected as the set of common constructs for the meta-analysis. Then the competencies from each of the ten studies were mapped onto ABET's. The wording of the survey questions in each study was carefully examined, in context, to determine what ideas the survey respondent might have had in mind while answering the survey. For mapping the surveyed competencies onto ABET's competencies, I relied on my experience as an engineer, engineering educator, and specialist in assessment in engineering education. I finalized the mapping prior to any numeric analysis, to reduce sources of bias.

The appendix contains a table for each of the ABET competencies (Tables A3-A13). Each table displays all of the competencies from the studies in the meta-analysis that I deemed as comparable. When more than one competency in a study mapped onto an ABET competency, the ratings were averaged into a single rating for that study. Note that the study commissioned by ABET [32] actually used the eleven ABET competencies, verbatim. Lang, et al. (1999) explicitly mapped between eight and thirty-two competencies onto each ABET competency. Their study asked respondents to rate each of the 172 competencies individually. Due to the format for reporting the study, it was logical to include only the top-rated competency under each ABET competency in the meta-analysis. All competencies that were not deemed comparable to the ABET competencies are listed in Table A14, and they are discussed in the results section.

Creating a common metric for the ratings

The central challenge of meta-analysis is creating a common metric. "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" [17, p. 93]. Although all ten 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 [36] 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 will be 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 would allow such rank ordering would involve comparing the rating for a specific competency to the "typical" rating for all the competencies in that study, with consideration of the dispersion of the ratings for all the competencies.

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 a widely-held view of a comprehensive basket of competencies. The *ABET mean* and its corresponding standard deviation eliminate the problem of extraneous competencies. However, there is a limitation to this metric: 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. 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. Because the *overall mean* includes some extraneous competencies that have no counterparts in other studies, it was rejected. A third metric, the *common mean*, was also considered and rejected. The common mean is based on the three competencies included in all but one of the studies (problem solving, communication, and life-long learning). Although this metric has more face validity because it is truly common among the studies, the standard deviations for the common competencies were so small that the effect sizes were unstable, 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" [17, 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. Figure 1 shows the standardized data with the competencies in order of descending mean importance.

Meta-Analysis: Combining Findings in an Analysis

The research questions are: *Which competencies are important?* and *What should the relative emphasis be among them*? These questions do not require an absolute scale because relative importance is the heart of the matter. Although there are some limitations in this common metric (described above), the standardized importance ratings based on the *ABET mean* were used in the analysis.

Calculating the overall mean ratings for ABET-mapped competencies

Altogether, the 10 studies in this meta-analysis surveyed 19 populations and had a total of 5978 respondents. The mean ratings for each competency were standardized for each population in each study as described in the section for creating a common metric. Then these were further combined. For each competency, the 19 mean ratings for each population in the 10 studies were averaged to create an *overall mean*, representing all 5978 respondents. The overall mean for each competency and the means for sub-groups of the overall population are shown in Figure 2. The graph in Figure 2 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 of the graph show the groups of competencies which are *not* significantly different. Interpreting the graph, there are six distinct levels of importance ratings. In the *overall means*, the top level of importance consists of two competencies: problem solving and communication. The next two lower levels of importance are ethics followed by life-long learning. Then there are four competencies at the same level of importance: experiments, teams, engineering tools, and design. At the fifth level of importance from the top is the competency "math, science, and engineering knowledge". The competencies deemed of least importance by the respondents are contemporary issues and impact. The simple "tie lines" display the six statistically distinct levels of importance.

Determining the statistically distinct levels of importance

The statistics required 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 below, which I refined based on the recommendations of

Notes. For ***each study***: standardized rating = (mean rating for a competency - grand mean rating for all competencies in the ABET basket)/ (standard deviation of mean ratings in ABET basket)
Thus, a standardized rating = 0 indicates the average importance rating for the ABET-mapped competencies in that study, positive values are above average importance while negative values are below average importance.

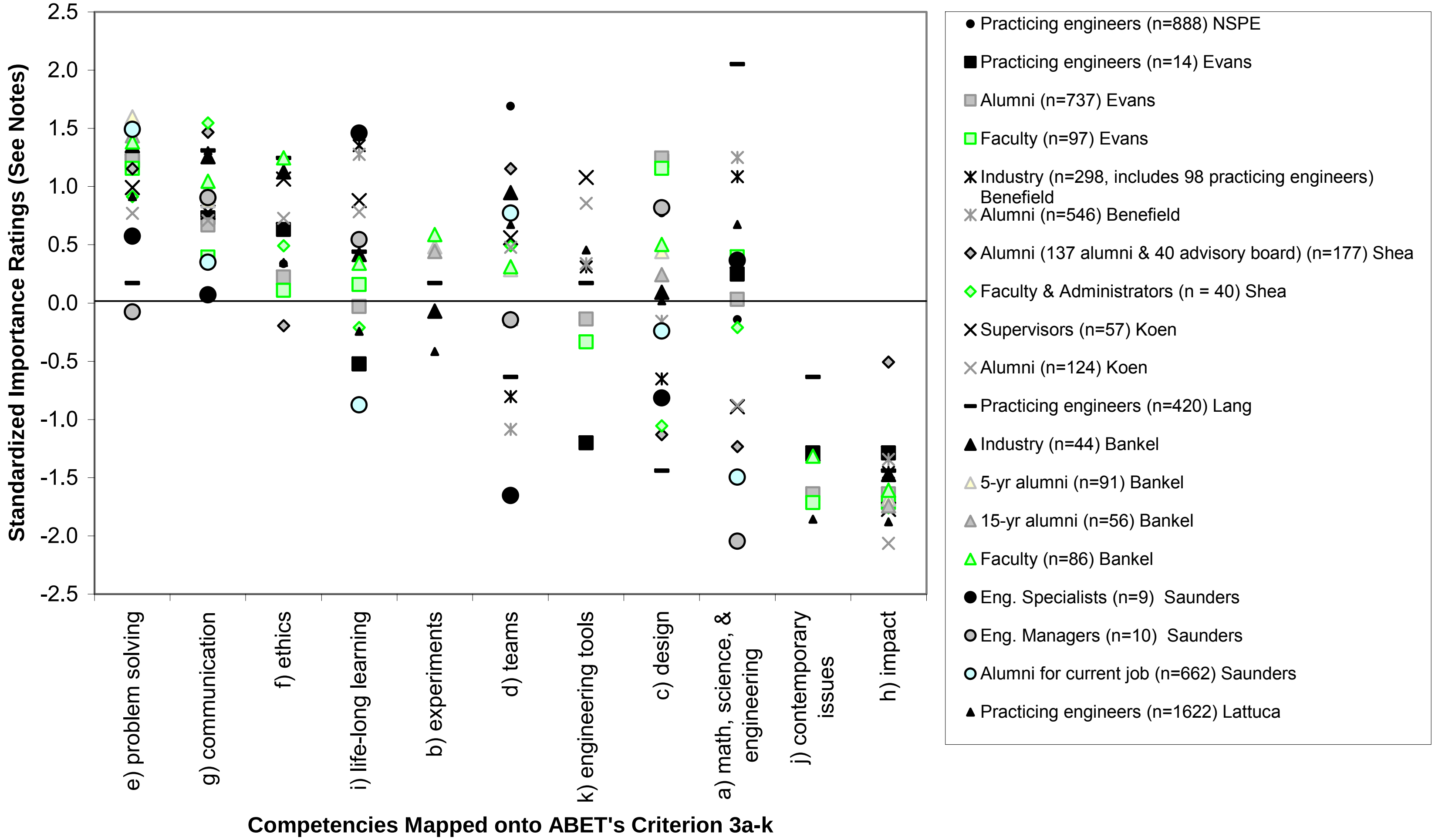

Figure 1. Importance ratings of competencies for recent engineering graduates. Ratings from 5978 respondents in ten separate studies of practicing engineers, engineering alumni, and engineering faculty.

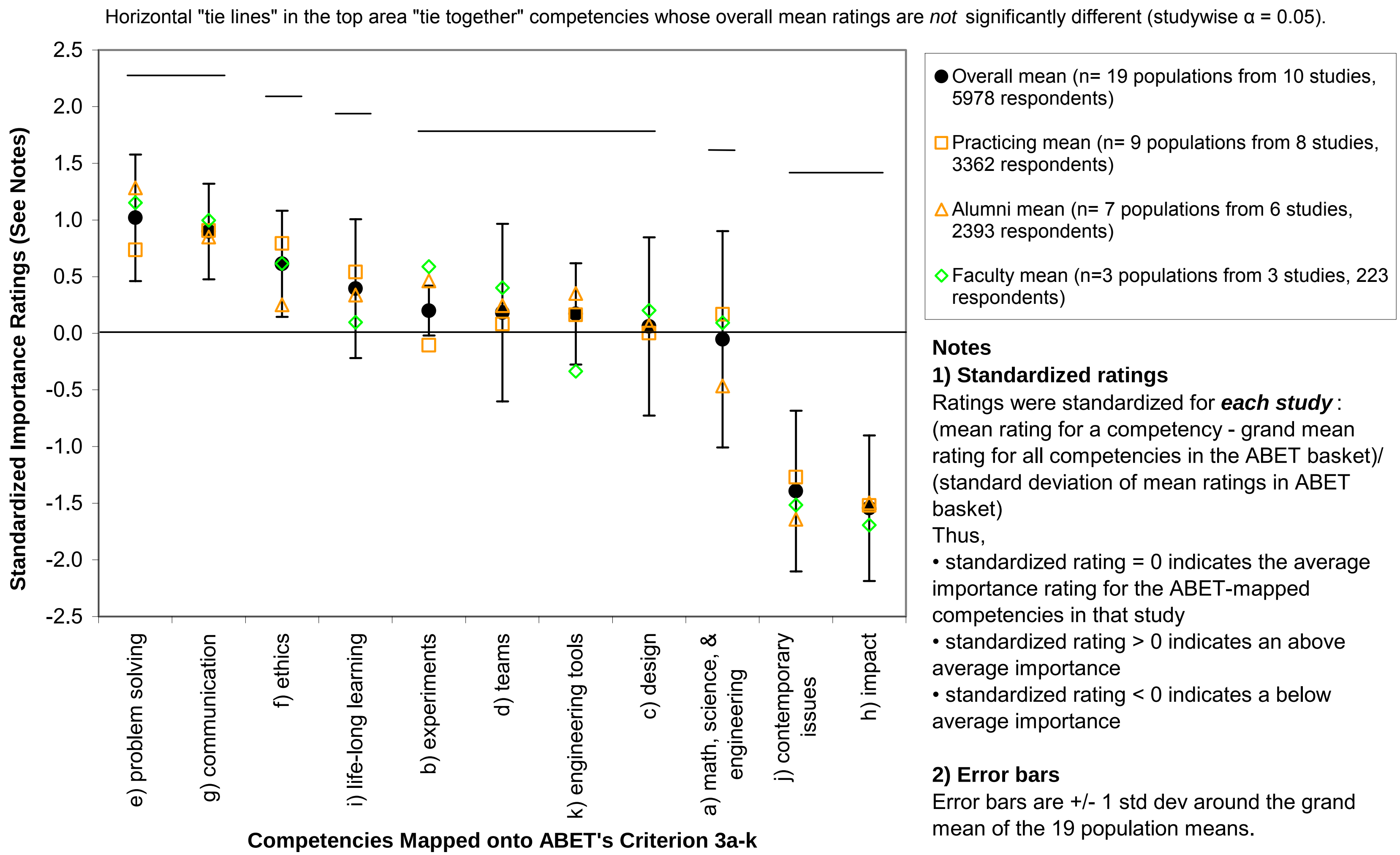

Figure 2 Importance ratings of competencies for recent engineering graduates, ratings by practicing engineers, engineering alumni, and engineering faculty.

Brady West, Lead Statistician at the Center for Statistical Consultation and Research (CSCAR) at the University of Michigan.

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 [37]. The population of engineering graduates is much larger than the sample size of 5978, with an estimated 2.2 million employed U.S. residents with a degree in engineering in 1998 [38]. 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" (19 populations reported in the 10 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 A2). 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 seven population means from the six 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 Figure 2, these three "subjects" were the means for the following sub-groups: the practicing mean (weight = 9), the alumni mean (weight = 7), 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 displayed in Figure 2 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 [$F(10, 198) = 306.97$, $p < .001$] 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 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.

Third, after the ANOVA confirmed that the ratings did differ significantly, the question became, "Which ones differ?" A multiple comparison test was used to answer this question. That is, multiple comparison was used to identify 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 can be classified as a balanced, one-way model, and my question is about practical equivalence as opposed to confidence intervals [39]. The parametric tests for post-hoc, balanced, all-pairwise comparison for practical equivalence are: Tukey's Honestly Significant Difference (HSD) test, Newman-Keuls, Duncan, and the Least Significant Difference test [40]. All these tests assume normality, independence, and homoscedasticity. Miller (1981) states that effects of departures from these assumptions have not been explored in the literature. 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 Least Significant Difference [40]. 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" [41, p. 44], I chose the Student-Newman-Keuls test, which is 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. Results are displayed in the "tie lines" in Figure 2. A confirmatory Duncan test (studywise $\alpha = .05$) yielded the same results, except that it split the large group of four competencies into two overlapping groups.

Meta-analysis of non-ABET competencies

All competencies that were not deemed comparable to the ABET competencies are listed in Table A14. These are organized by descending mean rating for the combination of practicing engineers and engineering alumni. Competencies with high standardized ratings are of particular interest because they are rated as important when compared to the ABET competencies. Such competencies bear consideration for further study and possible inclusion in the ABET list. If a competency has a standardized importance rating at or above 0.5, I deemed it highly important and worthy of discussion.

Three skills were deemed highly important, with standardized importance ratings above 0.5 by at least one population. All three were in Koen and Kohli's (1998) survey [27]: "effective decision-making" (.88 and .86), "able to transition from the academic environment to the industrial environment" (.59 and .50), and "effective project management skills" (.50 and .06). In light of my experience with connections between competencies as revealed in employer interviews, I hypothesize that these three competencies are related concepts. The unifying idea is that academic environments typically do not tap decision-making or project management skills, yet in industrial environments, decisions and projects are the context for all engineering analysis. New hires will flounder if they cannot make decisions and manage projects knowing when to strategically apply their analytical skills. These three competencies warrant further study to determine if they are widely deemed important. All three of these competencies are skills, not attitudes, and therefore would be fairly straightforward to include in the curriculum, although it would require a paradigm shift to a project-based curriculum to develop the competencies.

Another skill rated highly is worthy of mention "effective leadership skills" [22]. This competency was rated substantially above the ABET mean within its study (0.43), which indicates that it may be worthy of further study.

Three attitudes were deemed highly important, with standardized importance ratings above 0.5 by at least one population. *Strong commitment to achieving goals* was the top-rated, non-ABET competency. Two different studies surveyed this concept, with different wordings. Koen & Kohli [27] observed mean ratings exceeding one standard deviation above the mean for "exert high levels of effort, strives to achieve goals" (1.17 and 0.87), while Shea [26] observed ratings by alumni and practicing engineers 0.53 standard deviations above the mean for "Commitment to achieve objectives which requires high expectations, a positive attitude, and an open mind to new ideas and ways of doing things". Having two separate studies rating this competency very highly is a strong indication that it may be deemed highly important.

Bankel et al. [29] had another competency rated highly (0.95 and 0.43) , "personal skills and attributes (Initiative and willingness to take risks, perseverance and flexibility, creative thinking critical thinking awareness of one's personal knowledge, skills, and attitudes, curiosity and lifelong learning, time and resource management)". This survey item represents a large basket of competencies and merits further study to determine the importance of each component attribute.

"Mature, responsible, and open minded with a positive attitude toward life" was surveyed by Evans et al. [23] (0.63 and 0.20) and by Koen and Kohli [27] (0.59 and 0.54). Again, such high ratings in two separate studies are a strong indication that it may be highly important. Further study is warranted.

Many non-ABET competencies had importance ratings below average in their studies. One of these competencies is of note because it was surveyed in three different studies. Five business-related skills were surveyed, and all of them were rated well below the ABET mean in their respective studies. The overall mean for "business skills" was -1.02 standardized importance units, which places it well below “math, science, and engineering knowledge”, but above the lowest importance level for “contemporary issues” and “impact”.

Results

This study is a meta-analysis of ten published studies, which surveyed a total of 5978 practicing engineers, engineering alumni, and engineering faculty. Each original survey asked respondents to rate the importance to professional practice of a variety of competencies. Most of the competencies could be mapped onto ABET’s eleven competencies, as detailed in Tables A3-A13. Ratings for the ABET-mapped competencies were analyzed first. Then the non-ABET competencies were analyzed in relation to the ABET-mapped competencies (Table A14). Finally, patterns were observed among these results.

For the ABET-mapped competencies, multiple comparison procedures on the mean ratings for each competency show six distinct levels of importance (Figure 3): 1) (highest importance) problem solving and communication, 2) ethics, 3) life-long learning, 4) experiments, teams, engineering tools, and design, 5) (approximately average importance) “math, science, and engineering knowledge”, and 6) (lowest importance) contemporary issues and understanding the impact of one’s work. Please note that the absolute ratings in the original studies for contemporary issues and impact were between 2 and 4 on five point scales, indicating that they are deemed of notable importance by respondents. These absolute ratings affirm that the two competencies in the lowest level of importance are still important for professional practice, according to practitioners.

Ratings of two non-ABET competencies fell between the top two levels: “decision-making” and “commitment to achieving goals”. Others compared with the third level, some skill-related and some attitude related. Three skill-related competencies compared with the third level: “able to transition…to the industrial environment”, “project management”, and “leadership skills”. Two attitude competencies also compared with the third level: 1) “personal skills and attributes (Initiative and willingness to take risks, perseverance and flexibility, creative thinking critical thinking awareness of one's personal knowledge, skills, and attitudes, curiosity and lifelong learning, time and resource management)” and 2) “mature, responsible, and open minded with a positive attitude toward life”. Because all but one of these non-ABET competencies occurred in only a single study, further research on these competencies will indicate if they are widely deemed of importance for engineers. Many non-ABET competencies had importance ratings that were below average within their studies. One of these competencies, business-related skills, is of note because it was surveyed in three different studies. Five business-related skills were surveyed, and all of them were rated well below the ABET mean within their respective studies. The overall mean for “business skills” was -1.02 standardized importance units, which places it well below “math, science, and engineering knowledge”, but above the importance level (Figure 3) for “contemporary issues” and “impact”.

The most striking result of this meta-analysis is that *competencies* were consistently rated as more important than *bodies of knowledge*. Before examining the results, recall my definition of competencies. 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

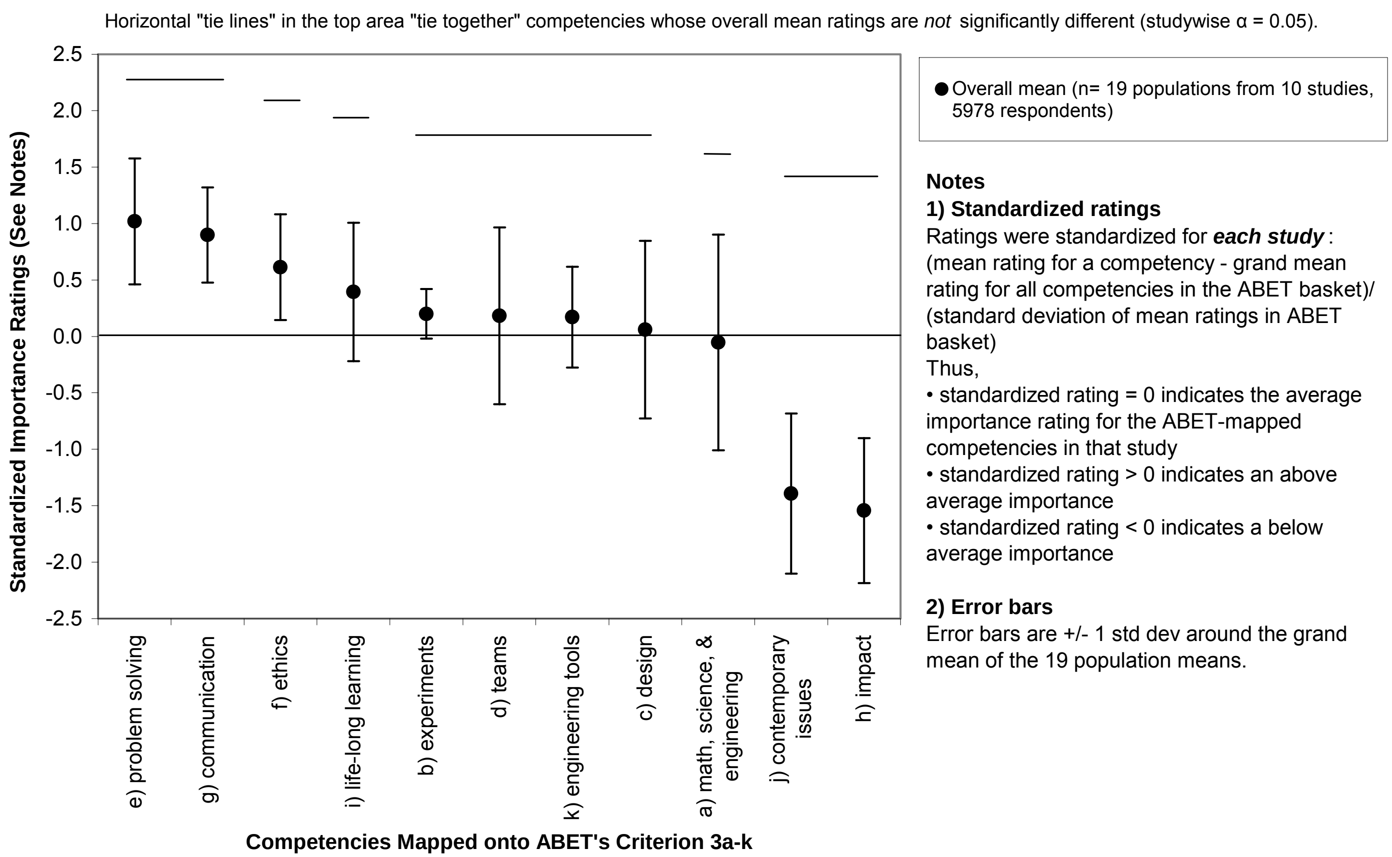

Figure 3. Importance ratings of competencies for recent graduates. Ratings by 5978 engineers in 10 studies.

effective action), in complex and uncertain situations such as professional work, civic engagement, and personal life. Note that the focus of a competency is on skillful performance. In contrast, a body of knowledge may be part of what enables skillful performance, but it is not equivalent. For example, a recent graduate may have a well-organized body of knowledge including principles, theories, and analytical procedures without knowing when or how to apply that knowledge to make decisions and take action in uncertain situations.

Although I have called all of the items in the original surveys “competencies”, three of them are actually worded on the surveys as “bodies of knowledge” because no decisions or action are implied. These three are contemporary issues, impact, and “math, science, and engineering knowledge”. Examining the original wording of the items in Tables A3, A10, and A12 shows the general absence of words implying decisions, action, or application for these three, and the presence of such words for all the other ABET ‘program outcomes’. Note that although the ABET wording of competency “a) an ability to apply knowledge of mathematics, science, and engineering” clearly defines “ability” and “application”, only one of the original surveys [32] included ideas beyond a body of knowledge. Specifically, thirteen of the original survey items were stated as a body of knowledge, such as “fundamental understanding of physical and life sciences” [27] and “in-depth technical knowledge in major engineering discipline” [25]. The original survey items for the other eight “competencies” were stated predominantly in competency language: problem solving, communication, ethics, life-long learning, experiments, teams, engineering tools, and design. All the original survey items can be examined in Tables A3-A13. Several example items worded as competencies, having decision or action language are as follows: “the ability to identify and fix critical problems using sound engineering principles” [26], “experimentation…hypothesis formulation, survey[ing] print and electronic literature, experimental inquiry, hypothesis test and defense” [29], for ethics a “demonstrated understanding of the importance of *honesty* in science and engineering” [28] and finally “effective oral communication” [27]. **The most striking result of this study is that all eight *competencies* worded as competencies were rated above all three competencies worded as *bodies of knowledge*.** The bodies of knowledge were rated at or below average importance.

This result is echoed among the non-ABET competencies, where each of the *bodies of knowledge* was rated at or below average among the *competencies*. First, note that of the 26 unique non-ABET survey items, only three were stated as bodies of knowledge. This is significant because it demonstrates the survey writers’ acknowledgment that competencies would be more important to engineering practice than additional bodies of knowledge. The three non-ABET survey items that do not state or imply decisions, action, or application are “recognition that engineering is an integrative process involving analysis and synthesis” [22], “knowledge of business strategies and management practices” [23, 27], “knowledge of several areas of engineering outside of the student's major discipline” [25]. I classify these three as bodies of knowledge.

Taken all together, the results of this study create a larger picture. In short, engineering curricula whose graduates will thrive in practice must develop *competencies* beyond the traditional emphasis on “math, science, and engineering knowledge”. The ideal competencies may go beyond ABET’s eleven ‘program outcomes’. Through synthesis of all the competencies deemed important in this meta-analysis, an integrated description of a highly effective engineering graduate might be as follows. Outstanding engineering graduates will be able to 1) Solve problems, make decisions, and manage projects knowing when to apply analytical skills, experimental skills, engineering tools, design skills, and technical knowledge. 2) Communicate effectively and work well in teams. Lead others. 3) Maintain high ethical standards. 4) Commit to life-long learning. 5) Take responsibility for achieving organizational goals in the industrial environment. Take initiative. Be flexible and open-minded. Persevere. 6) Effectively manage time and resources. 7) Understand contemporary issues and the impact of engineering work.

Discussion and Implications

Considering the results in context

The research questions in this study are: *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* The results of the study should be interpreted in light of theory. Stark and Lattuca [12] call their curriculum model 'the academic plan model'. "The academic plan model is a 'small t' theory. It is not intended to predict or explain student learning; rather, it serves as an analytical tool that directs attention to the many elements of a given [program's] curriculum, and the many influences on what students learn, how they learn it, and why they learn" [42, para. 11]. The academic plan model describes eight elements of the academic plan: purpose, content, sequence, learners, instructional resources, instructional processes, evaluation, and adjustment. Questions of *which competencies* and *what …relative emphasis* directly address the purpose and content aspects of the academic plan. The academic plan model also describes three categories of influences on the curriculum: external influences, organizational influences, and internal influences. The external influences include disciplinary associations, the marketplace, and alumni. Organizational influences pertain to governance and mission at the academic institution, and internal influences are within the academic program, such as faculty, students, the discipline, and the program's mission [12]. The opinions synthesized in this meta-analysis represent the external influences of disciplinary associations, the marketplace, and alumni. In summary, this meta-analysis offers the synthesized opinions of external influences pertinent to the purpose and content of the curriculum.

Such a quantitative synthesis of opinions of external interest groups is rarely available for faculty to consider when making curricular decisions. "Toombs and Tierney [43] correctly point out that faculty members often work alone in designing courses without being sufficiently concerned about the various external interest groups" [12, p. 18]. However, engineering programs do have two mechanisms in place for bringing the voice of external interest groups to the faculty. Through the program outcomes, or competencies, in ABET's new criteria, engineering programs have heard a clear and specific call for a broader purpose beyond the traditional disciplinary sciences. And for programs with industry advisory boards, there is an additional mechanism in place to explore issues of purpose and content, if the faculty chooses to engage the board in such discussions. As a supplement to these two mechanisms, faculty now have this meta-analysis, which offers ratings of relative importance to professional practice for a variety of competencies, including ABET's eleven program outcomes. Unfortunately, the nature of the original studies prevents exploration of deviations from the overall trends in Figure 3. Further research is needed to determine how importance ratings vary by engineering discipline, by field of practice, and by the demographics of the respondent.

Nonetheless, faculty can consider these overall ratings in light of other curricular aims when they design a curriculum. For example, an undergraduate curriculum in engineering is more than simply preparation for a profession. It is also a student's only undergraduate experience. As a result, preparation for the profession of engineering is only one facet of the undergraduate program. Other facets typically include other traditional aims of undergraduate education, such as liberal learning. Leading thinkers in higher education since the late 1800's have conceived of the purpose of undergraduate education as liberal learning, that is "developing intellectual habits of mind that can be applied to all areas of human endeavor and that form the basis for lifelong intellectual pursuit" [44, p 89]. With respect to the aim of liberal learning, ABET's competencies "h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context" and "j) a knowledge of contemporary issues" may be the most important. Thus, when a program's mission includes liberal learning, faculty would wisely emphasize these two competencies above their "level six" importance rating (Figure 3) with respect to professional practice.

Implications: A call for a paradigm shift

Since WWII, engineering education has emphasized a body of mathematical and scientific knowledge [e.g., 10, 11]. This emphasis is part of a trend in professional education. Since the early 1900's professional education has been dominated by the impact of the Flexner Report.

> The Flexner legacy…[is] based on the presumption that learning must be hierarchical [and] that scientific theory must precede application. As Rice and Richlin [45] note, "Normative for almost all career-oriented programs are the assumptions that learning precedes doing and that practice is the application of theory" (p. 81). Such a view, which Schon [46] calls "technical rationality," is reinforced by the dominant academic culture of our universities, a culture that prizes basic research, the pursuit of knowledge for its own sake, above all other forms of scholarship. Generally speaking, the more its faculty are able to conform to this culture, the higher the professional school's status in the institutional pecking order. This is why technical rationality continues to hold sway in most professional schools, even in the face of mounting criticism that much of the professional curriculum is irrelevant to practice [for example, 47, 48], and that other more powerful pedagogical models are available [49]. [7, p. 344]

The result is a "discontinuity" [7, p. 351] between a scientific body of knowledge and practical competencies.

Despite the advent of ABET's new competency-based criteria, it appears that typical engineering curricula have not much altered their focus on "math, science, and engineering knowledge." A recent study dissected all 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 at 19.4% and a large fraction of the engineering workforce, 16.3% [50]. The authors tallied detailed 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 of the syllabus topics mapped onto the most traditional ABET competencies: "math, science, and engineering knowledge", experiments, design, and problem solving. They also found that there was little to no instructional emphasis on teams, communication, impact, and contemporary issues.

This finding about how listed topics can be mapped indicates a primary emphasis on bodies of knowledge. 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” [50, p. 246]. The authors also 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”. 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: the researchers and the nine departments all view the purpose of the curriculum as transmitting a body of knowledge, as opposed to developing student competencies. Thus, a prominent feature of this study is that the curriculum perspective has not yet changed, despite ABET’s new requirements of competencies. The curriculum emphasis is still on transmitting a body of knowledge, not on developing abilities or competencies.

With respect to preparing students for the profession of engineering, the results of this meta-analysis clearly call for strong emphasis in areas beyond the central curricular emphasis since World War II on math, science, and engineering knowledge. The most striking result of this study is that all eight *competencies* worded as competencies were rated above all three competencies worded as *bodies of knowledge*. The bodies of knowledge were rated at or below average importance. This result is echoed among the non-ABET competencies, where each of the *bodies of knowledge* was rated at or below average among the *competencies*. In short, engineering curricula whose graduates will thrive in practice must develop *competencies* beyond the traditional emphasis on “math, science, and engineering knowledge”. The ideal competencies may go beyond ABET’s eleven ‘program outcomes’. Through synthesis of all the competencies deemed important in this meta-analysis, an integrated description of a highly effective engineering graduate might include the following competencies. Outstanding engineering graduates will be able to 1) Solve problems, make decisions, and manage projects knowing when to apply analytical skills, experimental skills, engineering tools, design skills, and technical knowledge. 2) Communicate effectively and work well in teams. Lead others. 3) Maintain high ethical standards. 4) Commit to life-long learning. 5) Take responsibility for achieving organizational goals in the industrial environment. Take initiative. Be flexible and open-minded. Persevere. 6) Effectively manage time and resources. 7) Understand contemporary issues and the impact of engineering work.

Summary

The research questions in this study are: *Which competencies are important for professional practice?* and *What should the relative emphasis be among them?* Results should be considered in context. This meta-analysis offers the synthesized opinions of practicing engineers and engineering alumni, who are external influences on an academic program. Their opinions are pertinent to the purpose and content of the curriculum. Such a quantitative synthesis of opinions of external interest groups is rarely available for faculty to consider when making curricular decisions. Engineering faculty typically hear the voice of external influences through ABET accreditation, and through industrial advisory boards, where applicable. As a supplement to these two mechanisms, faculty now have this meta-analysis, which offers ratings of relative importance to professional practice for a variety of competencies, including ABET's eleven program outcomes. Clearly, an undergraduate curriculum in engineering is more than simply preparation for a profession. It is also a student's only undergraduate experience. Consequently, faculty can consider these ratings, which pertain to preparation for a profession, in light of other curricular aims such as liberal learning when they design an engineering curriculum. The relative ratings of the various competencies can inform which competencies will be included in the purpose and content of the curriculum and what the relative emphasis will be among them.

However, the most striking result calls for a change of perspective on the larger purpose of the curriculum to developing *competencies* beyond the traditional emphasis on "math, science, and engineering knowledge". Since WWII, engineering education has emphasized a body of mathematical and scientific knowledge. The result is a culturally entrenched "discontinuity" [7, p. 351] between a scientific body of knowledge and practical competencies. A recent study [50] demonstrates that the curriculum perspective in engineering education has not yet changed, despite ABET's new requirements of competencies. The curriculum emphasis is still on transmitting a body of knowledge, not on developing abilities or competencies. Thus, this meta-analysis calls for a paradigm shift regarding the purpose of the curriculum.

To bring about this paradigm shift, faculty would need to see "their role as promoting student growth or skill acquisition" [12, p. 152] as opposed to the traditional view where faculty make curriculum decisions that are "discipline-identified and content-centered and … [they] view their roles as transmitting and replicating knowledge for students" [12, p. 152]. With such a shift, the curriculum would naturally be viewed as a multi-year experience for each student, as opposed to a sequence of often disconnected courses. This would be a culture shift from course-level planning for knowledge transmission to *design* of integrated curricula composed of complementary courses that, as a program, 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 the relative emphasis should 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" [51].

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A. Appendix – Supporting Tables

Table A1. Overview of the methods employed in the twelve closely related studies that gather practicing engineers' opinions about the relative importance of a full basket of competencies.

Study	Purposes of the Study			Description of Data
	What Competencies	Relative Importance	Competency Gaps	
Turley (1992)	38 competencies from 20 interviews	Software engineers stated on a survey whether or not specific behaviors characterized their work. *Importance ratings were obtained through analysis* involving the confidential classification of each respondent as an exceptional performer or non-exceptional performer by his or her manager. Respondents never learned of their classification.	-	Responses from 129 professional *software engineers* of all ages (.6 to 20 years experience) at a single U.S. company (47% response rate).
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".	Survey	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).

Study	Purposes of the Study			Description of Data
	What Competencies	**Relative Importance**	**Competency Gaps**	
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.	Survey	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.
ASME (1995)	56 "Best Practices" in the Product Realization Process (PRP), grouped into skill categories: team, design, analysis, testing, and manufacturing	Industry & academic surveys. Industry survey asked about both "entry level engineers (new B.S. graduates)" and "experienced engineers (5+ yrs)" The questions were "How important is it for [entry level OR experienced] mechanical engineers to have a working knowledge of the following 'Best Practices'?" (p. B-3) Ratings were on a 5-point scale. The "Best Practices" were worded as topics, such as "communication" and "design for environment".	Follow-up survey for industry only	Responses from 66 targeted individuals (40.5% response rate) within 33 targeted companies in a range of industries (aerospace, automotive, chemicals, communications, computers/ peripherals, consumer/industry products, electronics, packaged goods, and textiles). Surveys asking for importance ratings for entry-level engineers were sent to all *mechanical engineering* department chairs in the U.S. Responses from 92 mechanical engineering programs (38% response rate).
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.	Survey	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).

Study	Purposes of the Study			Description of Data
	What Competencies	**Relative Importance**	**Competency Gaps**	
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).	Survey	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).
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.

Study	Purposes of the Study			Description of Data
	What Competencies	Relative Importance	Competency Gaps	
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 (not yet published)	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.	Survey	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.
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".

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

Table A2. Example calculations of overall mean and sub-group means for two competencies, problem-solving and experiments †.

Population	n	e) problem solving	b) experiments
Practicing mean (n= 9 populations from 8 studies, 3362 respondents)	**3362**	**0.74**	**-0.10**
Practicing engineers (n=888) *NSPE*	888		
Practicing engineers (n=14) *Evans*	14	1.22	
Industry (n=298, includes 98 practicing engineers)	298		
Supervisors (n=57) *Koen*	57	0.99	
Practicing engineers (n=420) *Lang*	420	0.17	0.17
Industry (n=44) *Bankel*	44	1.35	-0.07
Eng. Specialists (n=9) *Saunders*	9	0.57	
Eng. Managers (n=10) *Saunders*	10	-0.08	
Practicing engineers (n=1622) *Lattuca*	1622	0.91	-0.42
Alumni mean (n= 7 populations from 6 studies, 2393 respondents)	**2393**	**1.28**	**0.46**
Alumni (n=737) *Evans*	737	1.25	
Alumni (n=546) *Benefield*	546		
Alumni (137 alumni & 40 advisory board) (n=177)	177	1.15	
Alumni (n=124) *Koen*	124	0.77	
5-yr alumni (n=91) *Bankel*	91	1.60	0.48
15-yr alumni (n=56) *Bankel*	56	1.44	0.44
Alumni for current job (n=662) *Saunders*	662	1.49	
Faculty mean (n=3 populations from 3 studies, 223 respondents)	**223**	**1.15**	**0.59**
Faculty (n=97) *Evans*	97	1.16	
Faculty & Administrators (n = 40) *Shea*	40	0.91	
Faculty (n=86) *Bankel*	86	1.38	0.59
Overall mean (n= 19 populations from 10 studies,	**5978**	**1.02**	**0.20**
Overall std dev		0.56	0.22

† For each competency, the *practicing engineers mean* is the mean for all nine populations classified as practicing engineers, i.e. the grand mean of the nine population ratings listed below it in the table. The *engineering alumni mean* and the *engineering faculty mean* were each calculated in the same way. For each competency, the *overall mean* is the grand mean of the nineteen separate population means as reported in the various studies, i.e. the mean of all the values in the column that are not in boldface type.

Table A3. Original survey wordings for items mapped onto ABET's a) "math, science, and engineering knowledge"

Competency	Study	Standardized importance rating			
(a) an ability to apply knowledge of mathematics, science, and engineering	Meta-analysis	-0.05			
		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
Fundamental understanding of mathematics	Koen 1998		0.06	-0.04	
Fundamental understanding of Physical and Life Sciences	Koen 1998		-1.16	-1.28	
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
A breadth and depth of technical background	Evans 1993	0.05		-0.11	0.62
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 & ?	-1.44	-0.28	-1.93	
Have specialist technical knowledge	Saunders 2005 & ?	1.46	-5.58	-3.75	
In-depth technical knowledge in major engineering discipline	Benefield 1997	1.09		1.25	
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
Analytical skills	Saunders 2005 & ?	1.08	-0.28	1.19	
(a) an ability to apply knowledge of mathematics, science, and engineering	Lattuca 2006	0.67			
Not surveyed by Bankel					

Table A4. Original survey wordings for items mapped onto ABET's b) experiments.

Competency	Study	Standardized importance rating			
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	Meta-analysis	0.20			
		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			
Not surveyed by NSPE, Evans, Benefield, Shea, Koen, & Saunders					

Table A5. Original survey wordings for items mapped onto ABET's c) design.

Competency	Study	Standardized importance rating			
(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	0.06			
		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 (DFX))	Bankel 2003	0.04		1.09	0.87
Ability to synthesize	Saunders 2005 & ?	-0.82	0.82	-0.24	
(c) an ability to design a system, component, or process to meet desired needs	Lattuca 2006	0.02			
Not surveyed by Koen					

Table A6. Original survey wordings for items mapped onto ABET's d) teams.

Competency	Study	Standardized importance rating			
(d) an ability to function on multi-disciplinary teams	Meta-analysis	0.18			
		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 disciplines to solve large scale problems	Benefield 1997	-1.48		-1.62	
People skills. The ability to work effectively with customers, management, and colleagues. Works well in a team structure. [author's emphasis].	Shea 1997	1.15			0.49
Able to function in a multicultural and diverse work environment.	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 & ?	-1.65	-0.14	0.77	
(d) an ability to function on multi-disciplinary teams	Lattuca 2006	0.67			
Not surveyed by Evans					

Table A7. Original survey wordings for items mapped onto ABET's e) problem solving.

Competency	Study	Standardized importance rating			
(e) an ability to identify, formulate, and solve engineering problems	Meta-analysis	1.02			
		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 good engineering methods. [author's emphasis].	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 & ?	0.57	-0.08	1.49	
(e) an ability to identify, formulate, and solve engineering problems	Lattuca 2006	0.91			
Not surveyed by NSPE, Benefield					

Table A8. Original survey wordings for items mapped onto ABET's f) ethics.

Competency	Study	Standardized importance rating			
(f) an understanding of professional and ethical responsibility	Meta-analysis	0.61			
		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			
Not surveyed by Benefield, Saunders					

Table A9. Original survey wordings for items mapped onto ABET's g) communication.

Competency	Study	Standardized importance rating			
(g) an ability to communicate effectively	Meta-analysis	0.90			
		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 & ?	0.69	-0.08	-0.20	
Oral communication skills	Saunders 2005 & ?	-0.55	1.88	0.90	
(g) an ability to communicate effectively	Lattuca 2006	1.31			
Not surveyed by NSPE					

Table A10. Original survey wordings for items mapped onto ABET's h) impact.

Competency	**Study**	**Standardized importance rating**			
(h) the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context	Meta-analysis	-1.54			
		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			
An appreciation and understanding of world affairs and 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			
Not surveyed by Saunders					

Table A11. Original survey wordings for items mapped onto ABET's i) lifelong learning.

Competency	Study	Standardized importance rating			
(i) a recognition of the need for, and an ability to engage in life-long learning	Meta-analysis	0.39			
		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 technologies	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 & ?	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			
Not surveyed by NSPE					

Table A12. Original survey wordings for items mapped onto ABET's j) contemporary issues.

Competency	Study	Standardized importance rating			
(j) a knowledge of contemporary issues	Meta-analysis	-1.39			
		Practicing	*Managers*	*Alumni*	*Faculty*
An appreciation and understanding of world affairs and 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			
Not surveyed by NSPE, Benefield, Shea, Koen, Saunders					

Table A13. Original survey wordings for items mapped onto ABET's k) engineering tools.

Competency	Study	Standardized importance rating			
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	Meta-analysis	0.17			
		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 design.	Koen 1998		1.08	0.86	
Computer literacy in analysis tools used in engineering specialty	Lang 1999	0.17			
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	Lattuca 2006	0.46			
Not surveyed by NSPE, Shea, Bankel, Saunders					

Table A14. Original survey wordings for items that did not map onto ABET competencies.

Competency	Study	Standardized importance rating			
		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 environment	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	-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	-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	-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	

Acknowledgements
This meta-analysis would not have been possible without the help of several people. Two librarians worked with me for many months to locate the published studies: Marija Freeland at the University of Michigan (UM) Libraries and Barbara Prince at the Hanover Town Library, Etna, NH. Two authors of published studies shared unpublished data for use in the meta-analysis, Gillian Saunders-Smits at Delft University of Technology in the Netherlands and Lisa Lattuca at the Pennsylvania State University. Brady West, Lead Statistician at UM's Center for Statistical Consultation and Research (CSCAR), kindly suggested refinements to the details of the meta-analysis. Professor Eric Dey, at UM's School of Education, reviewed the manuscript. I gratefully acknowledge their assistance.

Biographical Information
Honor J. Passow is Research Associate for Assessment for the College of Engineering at the University of Michigan and a doctoral candidate at the University of Michigan's Center for the Study of Higher and Postsecondary Education. Her undergraduate and master's work were in mechanical engineering at MIT. She has worked as a product engineer at Siemens and has taught engineering courses at several colleges and universities. Her current research focuses on applying concepts of engineering design processes and control theory to higher education.

Corresponding author
Honor J. Passow, P.E.
Research Associate for Assessment
Undergraduate Education
College of Engineering
University of Michigan
Mailing address: P.O. Box 113, Etna, NH 03750
Phone: 603-643-3245
Email: hpassow@umich.edu