



Preparing Today's Engineering Graduate: An Empirical Study of Professional Skills Required by Employers

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**The Surprisingly Broad Range of Professional Skills
Required for Engineers**

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Abstract

Ensuring engineering program graduates possess the skillset sought by employers is critical to the success of colleges and universities offering these degrees. Accrediting bodies are demanding that engineering programs better integrate professional skills in their curriculum. The IET Accreditation of Higher Education Programmes (AHEP) requires academic programs to include non-technical competencies such as working with information ambiguity, communication, innovation, project management, teamwork, and ethics (AHEP, 2014). The American Society of Engineering Education (ASEE), the American Society of Mechanical Engineers (ASME) and the National Academy of Engineering (NAE) want graduates from engineering programs to possess both technical and non-technical skills (Dukhan and Rayess, 2014). A study of engineering graduates' perspectives on the importance of various ABET technical and non-technical competencies, found the non-technical skills of working in teams, data analysis, problem solving, and communication were critical to graduates' professional success (Passow, 2012).

Missing from extant literature is a comprehensive understanding of which competencies make up the broad classification generically known as "professional" or "non-technical skills." To address this gap, the authors undertake a rigorous literature review to develop a complete list of the competencies that comprise professional skills (e.g. Ahn et al., 2014; Borrego et al., 2013; Colby & Sullivan, 2008; Johnson et al., 2015; Ling, 2002).

The 51 competencies identified from the literature are then validated using a database of online employment advertisements seeking engineers. The dataset of job advertisements includes professional opportunities across engineering disciplines. The rigorous methodology of Software-Assisted Content Analysis is used to identify professional skills required of engineering job applicants.

Results affirm that employers want engineering graduates to possess a portfolio of professional skills. Job advertisements predominantly required multiple professional skills. Furthermore, results show a positive relationship between the years of experience and number of professional skills required. Results also validate the literature-based list of professional skills, with 65% of those professional skills found in the job advertisements.

This study supports that employers seeking to fill engineering positions are requiring a wide range of professional skills, suggesting that the breadth of professional skills needed by engineering program graduates is much greater than what is currently required by accrediting bodies and addressed in most engineering curriculum.

Introduction

Academic programs for students seeking careers in fields with strong discipline-based knowledge requirements traditionally focus heavily on technical expertise. "Engineers have been valued for their technical expertise for centuries. This expertise has often distinguished engineers' role as civil servants who design and create goods, infrastructure, and processes for

the needs of humanity” [1]. But employers are making a new set of demands on the workers they hire; they are seeking competency in both technical and professional skills.

The need for technical employees to possess professional skills has been discussed over the last 40 years. Awareness of the need for employees to possess both technical and professional skills (coined “hard skills” and “soft skills”) dates to leadership research conducted for the U.S. Army in 1975 [2].

Accrediting bodies demand that engineering programs develop professional skills in their curriculum. ABET’s General Requirement 3 for Student Outcomes includes skills related to teamwork, communication, professional and ethical responsibility, and engaging in lifelong learning [3]. The American Society of Engineering Education (ASEE), the American Society of Mechanical Engineers (ASME) and the National Academy of Engineering (NAE) all support that graduates from engineering programs need both technical and professional skills, thus ensuring that colleges and universities integrate these skills in their curriculum [4]. To determine which professional skills are important for career success, researchers have queried academics, students, and practitioners in a range of engineering disciplines and country contexts. Chan et al. identify 38 skills including critical thinking, conflict management, and time management [5]. A study of practicing engineers in New Zealand maintained the importance of communication and ethics but added career planning, leadership, and project management [6].

In addition to confusion over what makes up this professional skill set, no consensus exists on what to call this group of skills. Some research uses a single term, while others use multiple terms interchangeably. Table 1 illustrates the various terms used to describe professional skills needed beyond the technical engineering discipline. Various terms are used to describe individual and groups of additional skills needed by engineering students.

Table 1: Terms used to describe professional skills

Term Used	Example Studies
21 st Century skills	[7]
Communication skills	[8] [9]
Critical skills	[10]
Employability skills	[11]
Generic competencies	[12]
Generic engineering competencies	[13]
Generic skills	[5]
Human skills	[14]
Interpersonal skills	[15]
Key competencies	[16]
Non-technical skills	[17]
Personal attributes	[18]
Personal skills	[19]
Personal competence	[20]
Practical skills	[21]
Practical competencies	[22]
Presentation skills	[23]
Professional attributes	[24] [25]
Professional competencies	[26]
Professional skills	[27]
Professionalism	[24]
Social competence	[21]
Social skills	[28]
Soft skills	[6]

Teamwork skills	[29]
Transferible skills	[23] [7]
Transversal competencies	[30]

To encourage consistency and clarity, this study will use the term *professional skills*. However, the decision did not come about easily. Inconsistency in naming these skills is not new. In the 1970s, Whitmore and Fry referred collectively to the skills that are not technical mechanical skills as *soft skills* [2]. Since then, as shown in Table 1, various names have been used. Even calling them *professional skills* creates problems. This moniker captures merely a small portion of the overall breadth of these skills and their effect on careers and organizations, especially when blended with strong technical skills. Second, *professional skills* suggests that technical skills are something else (certainly not unprofessional skills); any career success requires a strong foundation of technical skills. Third, this moniker seems to impose a limit – only professional situations -- on where these skills can benefit someone, when their application can enrich all aspects of life, including say a marriage or friendship. Other names create similar or additional concerns.

In addition to the inconsistency around what to call these skills, determining which skills are necessary varies by study, respondent perspective, and professional organization. To address this gap, the authors undertake a rigorous review of engineering education literature to identify the full range of competencies that encompass professional skills. This expanded list of competencies is then validated using a dataset of engineering job advertisements.

Methodology

Researchers must determine the frame of articles to include and the source. Gomez-Jauregui et al. provide a critical review of the Web of Science (WoS), Scopus, and Google Scholar databases as potential sources for comprehensive literature reviews [31]. The authors chose Scopus as the source for this study because it provides complete information for cited articles and extensive functionality to filter the articles selected.

The authors based the Scopus database search on the title, abstract, and keywords to identify peer-reviewed research articles related to soft skills. The Boolean search then considered a wide range of terms used to describe this set of skills: communication skills, critical skills, employability skills, employment skills, generic competencies, generic skills, human skills, interpersonal skills, job skills, professional skills, professional competencies, professional skills, practical skills, social skills, soft skills, and transferable skills.

Scopus filters limited the search to document type (doctype) = articles, publication year (pubyear) inclusive of the five years 2012-2017, journal subject area (subjarea) = engineering, and language = English. The extract included 708 articles. An additional filter was used to include only articles in engineering journals that included “education” in their titles. The remaining sample includes 175 articles.

The content of the title, abstract, and author keywords were reviewed to identify specific soft skills used in the study. When the initial analysis identified extended lists of skills which were not provided in the extracted data, the full article was downloaded to extract the specific soft skills.

Results

Articles from 12 academic engineering education journals spanned coverage across the 5-year period (Table 2).

Journal Title	2013	2014	2015	2016	2017	Total
Advances in Engineering Education			1	1	3	5
Computer Applications in Engineering Education	2	2	1	1		6
Engineering Education	1					1
European Journal of Engineering Education	6	7	2	4	7	26
IEEE Transactions on Education	3	2	1	3	3	12
International Journal of Continuing Engineering Education and Life-Long Learning				1		1
International Journal of Electrical Engineering Education		3	1			4
International Journal of Engineering Education	15	22	22	5	8	72
International Journal of Mechanical Engineering Education		1			1	2
Journal of Engineering Education			2	3	8	13
Journal of Professional Issues in Engineering Education and Practice	2		3	2	1	8
World Transactions on Engineering and Technology Education	2	5	7	4	7	25
Grand Total	31	42	40	24	39	175

Describing professional skillsets

Articles in the sample use many different terms to describe the skillsets being evaluated. The number of articles using each term (title, abstract, or keywords) are summarized in Table 3. Several articles used multiple terms; however, the most frequently used term is *professional skills* (60), followed by *soft skills* (23), and *practical skills* (19). These 28 labels for the skillsets range from being focused (teamwork skills and communication skills) to being very general or ambiguous (21st century skills, critical skills, generic skills).

Term	Freq.	Term	Freq.
21 st Century skills	1	Personal competence	1
Communication skills	17	Practical skills	19
Critical skills	1	Practical competencies	1
Employability skills	2	Professional attributes	1
Generic competencies	7	Professional competencies	12
Generic engineering competencies	1	Professional engineering competencies	1
Generic skills	12	Professional skills	60
Human skills	1	Professionalism	1
Interpersonal skills	9	Social competence	1
Job skills	1	Social skills	4
Key competencies	1	Soft skills	23
Non-technical skills	12	Teamwork skills	3
Personal attributes	1	Transferable skills	4
Personal skills	1	Transversal competencies	1

Identification of specific skills

A content analysis of the titles, abstracts, and keywords identified the specific skills studied. In several cases, the specific skills were not identified. Whenever possible, the authors downloaded and reviewed articles if specific skills were not identified in the initial review of the title, abstract, and keywords. Table 4 provides the individual skills grouped by general category. Terms identifying the skills vary in their specificity so broader categories were used to logically categorize synonymous and similar terms. An example is the *creativity* group, which includes artistic and creative skills, artistic and aesthetic considerations, creative thinking, creativity, innovation, and generate new ideas.

Similarly, *communication* as a category aggregates similar skills from individual studies including an ability to communicate effectively, communicate effectively with customers, communicate across cultures and disciplines, report writing, language ability, express and receive ideas clearly, foreign language, graphical communication skills, oral communication, presentation skills, visual communication, write concisely, written communication, documenting, interpersonal communication, public speaking, speak clearly and present ideas clearly, and visualization.

Table 4 - Terms from Literature	
Skill Category	Specific Skills from Literature
Analytical	reviewing evidence; analyze data; analyze a problem; problem analysis; reasoning
Career planning	career planning
Change management	adapting to change; adaptability to organizational and technological changes; change management
Character	ambition; assertiveness; noble character; wisdom and charisma; confidence; empathy; flexibility; mature; persuasive; proactive; understand and respect other professionals; influence others; think and act independently
Communication	an ability to communicate effectively; communicate effectively with customers; communicate across cultures and disciplines; report writing; language ability; express and receive ideas clearly; foreign language; graphical communication skills; oral communication; presentation skills; visual communication; write concisely; written communication; documenting; interpersonal communication; public speaking; speak clearly and present ideas clearly; visualization
Comply with standards	complete objectives within organizational guidelines
Conflict management	handle conflict; manage conflict
Creativity	artistic and creative skills; creative thinking; creativity; innovation; generate new ideas
Critical thinking	critical thinking
Cultural awareness	work in a cross-cultural team; cultural adaptation; cultural awareness; cultural issues; cultural differences;
Deal with ambiguity	dealing with uncertainty
Decision making	ability to make decisions; make judgements based on relevant information; decision making
Ethical and professional responsibility	an understanding of professional and ethical responsibility; ethical; ethics; ethics and equity; ethics and professional responsibility; morals
Flexibility	quick adjustment to work environment abilities
Give and receive feedback and criticism	ask for feedback and criticism from students from other disciplines or cultures; constructive criticism; evaluate performance of others; accept constructive feedback; give constructive feedback
Goal-oriented	goal development
Information management	identify relevant information; ability to apply information
interpersonal skills	interpersonal skills; social skills; ability to interact with others
Leadership	leadership; motivational leadership; lead a team; motivate and supervise others; build team cohesion; develop and manage teams; coordinate groups
Lifelong learning	acquire new skills and knowledge continually; desire to continuously learn; learning; lifelong learning; life-long learning; study skills; independent learning; self-learning; set personal learning targets; motivate further learning; self-assessment; self-directed learning; self-reflection
Listening	listening skills; listening
Manage information	research information
Negotiate	negotiate to reach a decision
Plan work	action planning; coordinate and plan tasks; organize things effectively
Problem solving	adapt knowledge to solve problem; problem solving; creative problem solving
Professional and ethical responsibility	regulators and the needs of society; social issues and responsibilities; be aware of political issues; act with awareness of global issues; be aware of economic and environmental issues; act with integrity; personal responsibility; professional and ethical responsibility; professional rights and responsibilities; understand roles and responsibilities; values; possess sound engineering ethics; social responsibility; understand the impact of engineering solutions on society; uphold norms; act with professionalism
Project management	project management; project planning and monitoring
Relationship management	build and maintain working relationships; interpersonal relations; trust building; work with individuals from other fields or disciplines
Resource management	resource management
Self-management	self management and development; manage themselves

Industry validation of specific skills

The intersection of key components of the hiring process occurs in the job advertisement, where employers list their demands; job prospects scour for matches to their skill sets and desires; and marketplace realities influence advertisement content. For many companies, job advertisements are the primary means for recruitment, an important tool for “personnel searching for potential job orders, private employment agency counselors..., employers checking on what the competition is offering, school counselors attempting to get a feel for the local labor markets, and labor market analysts” [32].

Employers must pay to post Help Wanted advertisements, thus suggesting a financial commitment to finding an employee. The per-word cost of these advertisements inherently limits what employers can include; generally, employers focus on the important keywords, phrases and qualifications to contain costs. This limiting factor means words appearing in a job advertisement are deemed “worth the expense;” therefore, excess words and unessential qualifications are excised. Meanwhile, job applicants rely on advertisements to learn of opportunities. Through scrolling or keyword searching, applicants seek opportunities that match both their technical and professional skills. As a result, employers post their advertisements for jobs on platforms like Indeed.com and others. This intersection of employer needs and applicant’s desires provides a robust environment to explore whether professional skills truly matter in the hiring process.

Content analysis of job advertisements was used to research recruitment effectiveness [33] and to identify gaps between skills needed on the job and skills advertised [34].

For this study, the development of a list of terms from the existing literature (Table 4) provides a framework to support the identification of soft skills being sought by employers. The list of specific skills in Table 4 represents an aggregation across 5 years of academic research into engineering education, based on responses from students, alumni, professionals, and academics. This additional validation step checks the skills identified in the literature against what is currently being requested by industry in the hiring process.

Advanced features of computer assisted qualitative data analysis software (CAQDAS) identified the relevant terms in the job advertisements [35]. This method leverages the auto-coding features of Atlas.ti to identify pre-specified terms in the documents, allowing the researchers to focus on the analysis of the coded results [36] [37].

Several websites provide searchable databases of online job advertisements. Indeed.com was selected as the source for this study because of its established information currency, large number of postings, and ease of use [38]. Additionally, Indeed.com provides functionality to access large volumes of advertisements using an application programming interface (API) that extracts the sample data as a single comma-delimited text file. To ensure focus on technically oriented jobs and set a reasonable frame for the sample, jobs for engineering positions in the Chicago area during a one-month period were collected through the API.

The API extracted 82 job advertisements for engineering positions in the Chicago area. The Indeed.com database requires that the company posting the advertisement enter an *Engineering Type*. A frequency distribution of the engineering types supports that a broad range

of engineering disciplines are included in the sample (Table 5). Table 5 provides the frequency of the engineering types exactly as they were provided by the posting firm, meaning overlaps in the disciplines (e.g. *Mechanical*, *Mechanical or BioMed*, and *Industrial/Mechanical*) occurred.

Table 5 Engineering Disciplines Advertised		
Engineering Discipline	Count	Percent
Architectural or Mechanical	2	2%
Chemical	1	1%
Civil	5	6%
Electrical	5	6%
Environmental	1	1%
Industrial/Manufacturing	20	24%
Mechanical	11	13%
Mechanical or BioMed	1	1%
Mechanical or Chemical or Electrical	2	2%
Mechanical or Electrical	3	4%
Product	2	2%
Production	2	2%
Quality	10	12%
Other	17	21%
n = 82		

The content of the job advertisements was analyzed using a two-step process, whereby specialized software completed the laborious task of identifying terms in the advertisements and a researcher validated the context in which each term was used [39]. The auto-coding function of ATLAS.ti software allows for the efficient scanning of large volumes of content based on pre-identified terms [35]. Auto-coding was executed at the word level and then verified based on a review of the context in which the word is used in a specific job advertisement. Preliminary results of the content analysis of skills the literature found in engineering job advertisements are provided in Table 6.

Table 6: Skills in Job Advertisements					
Skill Category	Ad Count	Pct	Skill Category	Ad Count	Pct
Analytical	4	5%	Comply with standards	3	4%
Career planning	0	0%	Conflict management	0	0%
Change management	0	0%	Creativity	4	5%
Character			Critical thinking	0	0%
ambition	1	1%	Cultural awareness	1	1%
assertive	0	0%	Deal with ambiguity	0	0%
charisma	0	0%	Decision making	2	2%
confidence	0	0%	Ethical and professional responsibility	2	2%
empathy	0	0%	Give and receive feedback and criticism	0	0%
flexibility	1	1%	Goal-oriented	4	5%
maturity	1	1%	Information management	14	17%
noble character	0	0%	Interpersonal skills	3	4%
persuasive	0	0%	Leadership	9	11%
proactive	0	0%	Lifelong learning	16	20%
respect	1	1%	Listening	2	2%
wisdom	0	0%	Manage information	14	17%
Communication			Negotiate	2	2%
customer	0	0%	Planning work	17	21%
documentation	5	6%	Problem solving	29	35%
foreign language	0	0%	Professional and ethical responsibility	2	2%
graphical	0	0%	Project management	28	34%
oral	7	9%	Relationship management	0	0%
presentation	2	2%	Resource management	0	0%
public speaking	0	0%	Self-management	3	4%
report writing	11	13%	Take directions from supervision	0	0%
visual	2	2%	Teamwork	25	30%
written	13	16%	Time management	6	7%

Since the literature provided specific character traits and communication skills, those two categories were disaggregated for the content analysis. Of the 52 job skill categories and their subsequent related skills, 31 (60%) were noted in the job advertisements.

Of greatest demand are *problem solving* (35%), *project management* (34%), *teamwork* (30%), and *planning work* (21%). Eighteen of the categories/skills appeared in 5 or less of the 82 job advertisements.

Discussion of Results

These results support the long-held belief that students in technical fields need to develop professional skills to complement their discipline-based technical skills. When these skills are aggregated across studies, a surprisingly robust list of professional skills emerges.

The current professional skills specified by accrediting agencies and professional organizations are not consistent with the wide range of skills identified in extant engineering education literature.

The inconsistency and lack of definitions of the terms used to describe professional skillsets creates an environment fraught with ambiguity. The additional lack of consistency in

which specific skills are needed in industry creates an environment where academic programs are left to choose which skills to develop. The lack of alignment of professional skills between accreditation standards, academic research, and the hiring process is of great concern.

While the majority of professional skills appear in job advertisements in varying degrees, a portion of the professional skills culled from academic literature do not. A number of possible reasons for this disparity exist. First, academic literature identifies skills from many contexts and perspectives. The list of professional skills was compiled from a variety of journal articles, which in many cases looked at specific fields or industries. The sample coming from job advertisements reflects a singular perspective based on what the employer identifies as important for the position. Conversely the terms gleaned from studies include competencies identified by academics, employers and by career professionals. Additionally, while the list of professional skills was vetted against the authors’ experiences, we do not have a full knowledge of all fields and industries.

Second, employers may be unable to articulate these professional skills in ways academic researchers can, much like the ongoing debate over what these skills should actually be called. Researchers spend time thinking and evaluating, while employers spend time doing. Business people have to act fast so anything that slows them down is cast aside. Another possibility is that employers do not recognize the need for, are not well versed in or know how to properly evaluate candidates for these unmentioned professional skills. These skills also may be the ones they undervalue in their employees and their organization. Managers have blind spots, especially in areas where he or she is not strong. Therefore, regardless of their potential value to the organization, that manager or leader may be unable to see the importance. For instance, a leader who struggles as a listener may not recognize or value the need for that skill in his organization.

Another possibility is that the 35% that go unmentioned are truly unmentionable; either they do not meet the standard for inclusion because of cost or they are excised in the process of editing a job announcement because their inclusion would seem too elementary or cause them to be perceived as unprofessional by peer organizations or job seekers.

The list of professional skills we developed aligns in broad terms with ABET requirements, with 8 of the 11 ABET student outcomes focusing on professional skills (Table 7). However, the alignment requires interpretation, both of the ABET requirement and the list of professional skills [3].

Table 7: Mapping to ABET Criteria

ABET Criteria	Professional Skills
(a) an ability to apply knowledge of mathematics, science, and engineering	<input type="checkbox"/> Able to adapt knowledge to new situations
(b) an ability to design and conduct experiments, as well as to analyze and interpret data	<input type="checkbox"/> Analytical <input type="checkbox"/> Confident tackling unfamiliar problems <input type="checkbox"/> Gathers, locates, shares information <input type="checkbox"/> Uses critical thinking

(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	<input type="checkbox"/> Can manage projects (strategically) <input type="checkbox"/> Complies with standards <input type="checkbox"/> Persistent in overcoming obstacles, determined <input type="checkbox"/> Questions accepted wisdom <input type="checkbox"/> Thinks and reasons logically <input type="checkbox"/> Thinks creatively, creative, uses creativity <input type="checkbox"/> Uses critical thinking
(d) an ability to function on multidisciplinary teams	<input type="checkbox"/> Can lead people, direct others, build teams, collaborate (leader role) <input type="checkbox"/> Works in team, team member, team player
(e) an ability to identify, formulate, and solve engineering problems	<input type="checkbox"/> Suggests improvements <input type="checkbox"/> Can identify, analyze, solve problems
(f) an understanding of professional and ethical responsibility	<input type="checkbox"/> Understands ethical implications of decisions
(g) an ability to communicate effectively	<input type="checkbox"/> Possesses communication skills, able to communicate on multiple levels <input type="checkbox"/> Uses strong oral presentation skills, story telling <input type="checkbox"/> Uses strong written communication skills
(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	<input type="checkbox"/> Willing to learn
(j) a knowledge of contemporary issues	
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	

The exact words drawn from academic literature and the ABET outcomes rarely match, forcing one to map the outcomes to specific professional skills. The mapping required interpretation. For this mapping, we took a relatively narrow view; a mapping using greater latitude would probably include twice as many professional skills. In reality, few are likely to undertake that mapping task, creating the possibility that engineering students may be developing these skills but are unaware or unable to articulate them to an employer. Admittedly, the ABET list is probably intentionally broad, for a list as long as the professional skills list would be unwieldy and nearly impossible to evaluate.

Simply put, the academic literature may be ahead of the accreditation standards and the hiring process. This would explain why the academic literature identifies more professional skills than are present in the accreditation standards or the job advertisements. This difference will require further research.

Conclusion

This study provides the first comprehensive analysis of professional skills which captures the inconsistency of terminology and the breadth of skills that may be included. A rigorous and structured literature review is provided which identifies the range of terms used to describe the non-technical skill set. Consistent with the practices of ASEE/LEES, and for the purposes of this paper, the authors adopt the term *professional skills* as it is encompassing of a wide range of competencies - but still has its weaknesses.

The study uniquely used a structured review of the engineering education literature to gather a first of its kind list of competencies not previously gathered. This list reflects the inconsistency in the terms used to describe the competencies. A content analysis of a sample of engineering job advertisements did support that a large portion of the list of competencies were requested by firms hiring engineers.

It is encouraging that academics, accrediting bodies, and practitioners agree on the need for engineering students to possess a robust set of professional and technical skills. Further research is needed in order to develop a consistent language around the topic which will allow educators to develop the specific professional skills that will support engineers continued success in a dynamic work environment. Issues around when specific professional skills are needed and how the skills vary across disciplines must be addressed if academic programs are expected to address professional skills in their curriculum.

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