AC 2010-2010: GLOBAL ENGINEERING ATTRIBUTES AND ATTAINMENT PATHWAYS: A STUDY OF STUDENT PERCEPTIONS

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Keywords: attainment pathways, attributes, competencies, engineer of 2020, global engineering, global engineering education, student perceptions, survey

Abstract

Many engineering schools are proactively responding to the challenges of globalization, including by enhancing their international profiles and developing global educational programs and initiatives. Some schools are placing particular emphasis on preparing engineers for practice in dynamic, global workplaces. Yet what abilities and qualities define the globally competent engineer, and what types of experiences help support attainment of such attributes? This paper reports on the results of a survey of undergraduate and graduate students at Purdue University (n=231) that was designed to elicit: a) perceptions of desirable qualities and abilities for global engineers, b) self-evaluation of abilities in each of the identified areas, and c) awareness of possible pathways for enhancing one's own competence in each of the identified areas. The survey instrument is unique in that it presents students with a realistic global engineering scenario, and then prompts them to pick the specific abilities and qualities they think would be most essential for completing the described assignment. The list of 15 attributes presented to respondents is focused on the professional and global dimensions of engineering practice, and is based on relevant attributes from Purdue University's Engineer of 2020 initiative. In addition to presenting aggregate results from the survey, we use demographic data to discuss some similarities and differences across different sub-populations. We conclude with a discussion of ongoing and future work, including similar surveys planned for faculty and industry populations.

Introduction

Many universities are encouraging global awareness, education, and citizenship among students and staff, including through cross-national research collaborations, partnerships with foreign institutions, study abroad programs, recruitment of international students and teaching staff, distance education initiatives, and international conferences and workshops.[1,2] In addition, many influential stakeholders have been urging universities to cultivate a new generation of "global engineers" who are prepared to practice effectively in an increasingly diverse, interconnected, and rapidly changing world.[3,4,5,6] ABET's EC2000 accreditation criteria, established in 1997, lends further support to this movement by requiring that graduates "understand the impact of engineering solutions in a global and societal context."[7]

Schools like Purdue University are now embracing this global agenda. For example, specific objectives noted in the university's latest strategic plan include: "expand[ing] pathways to global education," "developing successful global citizens and leaders," "prepar[ing] graduates for a dynamic global workplace," and "graduating students with global credentials."[8] The plan also calls for increasing student participation in "transformational learning opportunities," including those with global dimensions. Purdue's College of Engineering has similarly indicated that producing "graduates [who are] effective in global context" is one of its three strategic goals for

2009-2013.[9] And as discussed in more detail below, the College's Engineer of 2020 initiative features a number of target graduate attributes with an explicit global dimension.

Many kinds of strategies and programs have emerged to help prepare engineering students for global professional trajectories.[6,10-11] At Purdue, for example, the Global Engineering Program (GEP) and Global Engineering Alliance for Research and Education (GEARE) give students opportunities to study, work, volunteer, and intern abroad, and participate in multi-national design projects.[12,13] Many students receive other kinds of global education through coursework, interactions with faculty and peers, team projects, student organizations, and independent travel.

Yet even as such programs and experiences gain traction against the backdrop of ambitious global visions, challenges remain. To begin, there is the problem of scaling up. Even generous estimates suggest that only about 5% of American engineering students have a substantial global experience during their undergraduate years, while others assert that only 10-15% of U.S. engineering schools are taking global education seriously.[11,14] Persistent barriers to expanding global engineering education – ranging from financial considerations and inflexible curricula to a lack of institutional support and language issues – are well documented.[6] But even as these kinds of issues are addressed, there remain important unanswered questions about how students perceive global engineering and global engineering education, including appropriate pathways for attaining the kinds of competencies they will need to practice as global professionals.

This paper is part of a larger study designed to examine how global educational experiences can provide students with opportunities for transformative learning, thereby supporting attainment of desirable graduate attributes. Here we more specifically report on student perceptions of global engineering attributes and related educational pathways. Our primary research questions include:

- What global and professional attributes do engineering students perceive as desirable for practicing as global engineers?
- How do students evaluate their own ability for each of these attributes?
- How do students improve, or expect to improve, their ability for each of these attributes?

As further grounding for our analysis, we begin by reviewing existing literature on identifying and assessing desirable learning outcomes for global engineering education.

Literature Review

Many studies have focused on identifying competencies required for professional engineering practice, including to support the development of specific criteria and strategies for evaluating the effectiveness of various educational experiences, including degree programs. Yet few researchers have more specifically examined student perceptions of desirable graduate outcomes. Exceptions include Nguyen's examination of essential engineering skills and attributes as perceived by students (n=47) and relevant academic and industry stakeholders.[15]

There has also been a lack of systematic research to establish what specific competencies are required for global engineering practice, although numerous definitions and lists have been proposed. Patil and Codner, for instance, advocate these "essential global competencies":

- Awareness of global political and societal issues;
- Understanding of cross and multicultural issues;
- Understanding of the globalised nature of engineering education;
- Knowledge of the international labor market and workplace imperatives;
- Understanding of the international business, economy and world market;
- Competency in applying engineering solutions/applications in a global context.[16]

The authors have used surveys to identify gaps between employer perceptions of the importance of attributes as compared to their satisfaction with the actual performance of recent graduates.

In the more specific context of global engineering education, Lohmann et al. have noted a continued dearth of research on student learning, career impacts, and intercultural proficiency: "Largely absent are rigorous methods for assessing foreign language ability or competencies specifically related to professional practice within the academic discipline."[17] In response, they are working to develop a comprehensive assessment strategy for Georgia Tech's International Plan, based on four measurable facets of global competence: foreign language proficiency, comparative global knowledge, intercultural assimilation, and disciplinary practice in a global context. Their assessment instruments and strategies are still being developed, and some baseline data from their work has been reported.[18]

Ongoing efforts to study Purdue's GEARE program have similarly emphasized global competency, in part evaluated through student questionnaires, individual interviews, and focus groups.[19-20] This work has largely been based on a "three dimensional" definition for global engineering that consists of a wide array of technical, professional, and global competencies. This list of competencies was in part inspired by the NAE's Engineer of 2020 report, and later informed the list of graduate attributes developed by Purdue's Engineer of 2020 Committee.

Downey et al., on the other hand, have developed a unique scenario-based instrument to evaluate the global competency of students, which they define as the ability to work with others who define and solve problems differently, including across national, cultural, and/or disciplinary boundaries.[10] To date, however, this definition and instrument have not been embraced outside of the undergraduate elective courses developed and taught by the authors at their home institutions.

As this overview suggests, a lack of shared expectations for global educational experiences has begotten a lack of common assessment instruments and strategies. However, there are notable exceptions. For example, administrators at Purdue and many other institutions are using the Intercultural Development Inventory (IDI).[18,21,22,23] The IDI is standardized, validated, and has a long history of use, making it easy to administer and suitable for comparative research. But while IDI may allow measurement of cross-cultural sensitivity in general, this proprietary instrument is costly, not readily modifiable, and not specifically tailored to global practice in technical fields.

Hahn et al. have used multiple assessment methods, including self-reflection writing, oral presentation, and interviews, to assess learning outcomes of a project abroad program.[24] Content analysis of student self-reflection papers revealed that student comments could be mapped onto

many of the graduate attributes from Purdue's Engineer of 2020 initiative.[25] We follow Hahn et al. in avoiding *a priori* definitions of desirable outcomes for global engineering education.

We also do not make any assumptions about what educational pathways might best support attainment of such outcomes. Instead, we hope our research will help us better understand how relevant groups of stakeholders (students, faculty, and industry partners) perceive desirable graduate attributes and associated attainment pathways. The findings can then be compared and contrasted with other definitions. We will also be developing new assessment instruments and strategies that are focused on the specific attributes and outcomes identified through our research, and we hope these will be usable across multiple programs and even institutions.

Methods

Survey Instrument

This paper presents results from a mixed-methods survey instrument. The instrument was iteratively developed and refined by the five authors from June to November of 2009. Before the final version of the survey was released, it was piloted with at least one representative from each target group (undergraduate and graduate students, industry partners, faculty). The results of the pilots were used to improve the final instrument. This paper presents results only from the student version of the survey, which differs slightly from the industry and faculty versions.

Purdue's Engineer of 2020 target attributes helped drive survey development.[24] As indicated in Table 1, competency statements were generated for the indicated attributes. Some attributes were used verbatim, while others were refined to make their meanings more transparent. Because our study is specifically concerned with "global" and "professional" attributes and outcomes, we did not include any of the more technical "Knowledge Areas" in our list of competencies. However, we did include an "Other" option so respondents could add their own competencies to the list.

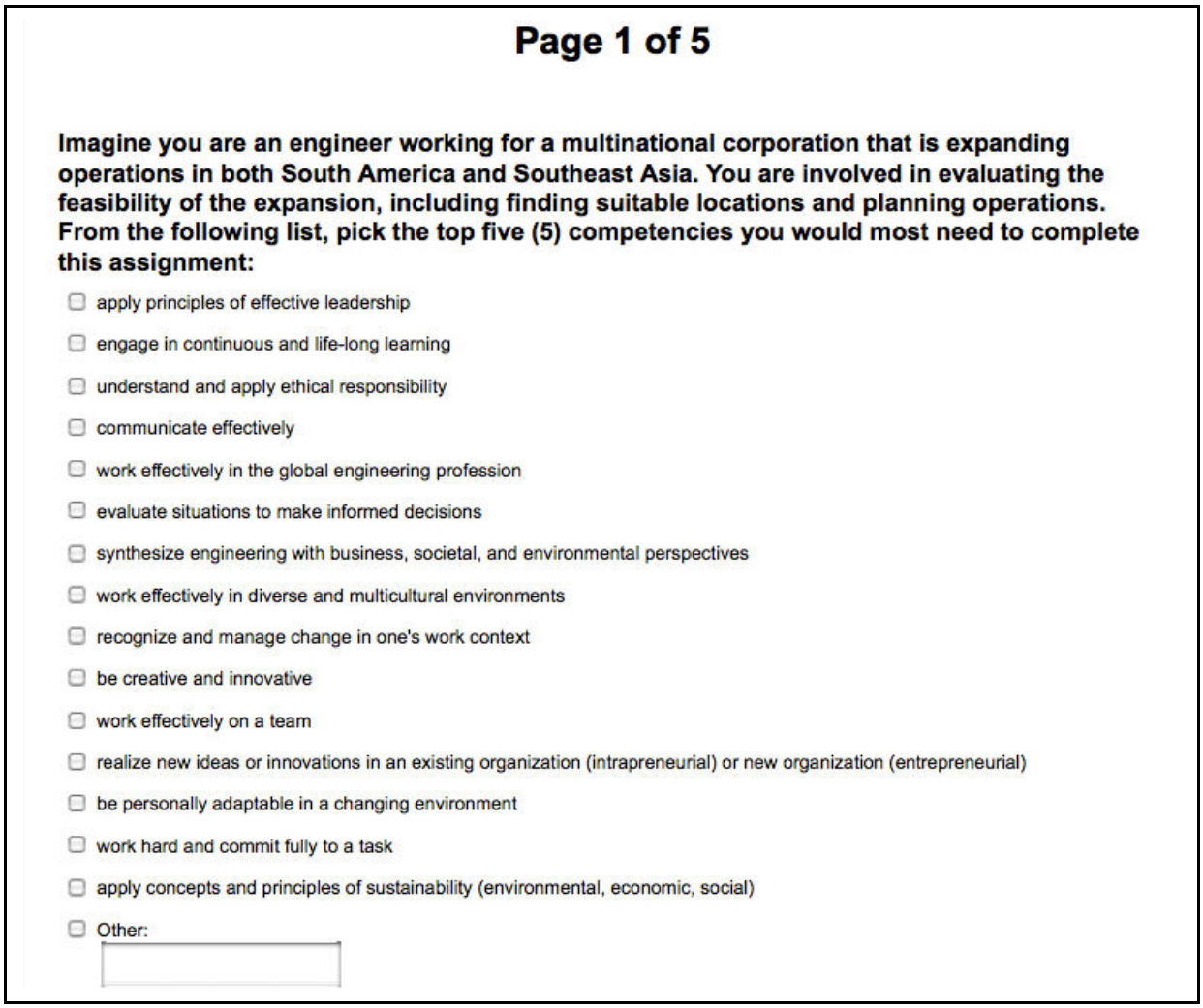
The final survey consists of six sections, and was administered online using the Qualtrics application. As indicated in Figure 1, the first section combines the statements listed above with a scenario-based question inspired by the work of Downey et al.[10] The scenario was specifically intended as a realistic engineering work situation that is generalizable across both engineering disciplines and regions.

Table 1. Purdue Engineer of 2020 Attributes and Equivalent Survey Statements

Purdue Engineer of 2020 Attribute[24]	**Equivalent Survey Statement**
Abilities	
Leadership	apply principles of effective leadership
Teamwork	work effectively on a team
Communication	communicate effectively
Decision-making	evaluate situations to make informed decisions
Recognize and manage change	recognize and manage change in one's work context
Work effectively in diverse and multicultural environments	work effectively in diverse and multicultural environments
Work effectively in the global engineering profession	work effectively in the global engineering profession
Synthesize engineering, business, and societal perspectives	synthesize engineering with business, societal, and environmental perspectives
Knowledge Areas	
Science & math	N/A
Engineering fundamentals	N/A
Analytical skills	N/A
Open-ended design and problem solving skills	N/A
Multidisciplinarity within and beyond engineering	N/A
Integration of analytical, problem solving, and design skills	N/A
Qualities	
Innovative	be creative and innovative
Strong work ethic	work hard and commit fully to a task
Ethically responsible in a global, social, intellectual, and technological context	understand and apply ethical responsibility
Adaptable in a changing environment	be personally adaptable in a changing environment
Entrepreneurial and intrapreneurial	realize new ideas or innovations in an existing organization (intrapreneurial) or new organization (entrepreneurial)
Curious and persistent learners	engage in continuous and lifelong learning
Other (not featured in original list of Engineer of 2020 attributes)	
N/A	Apply concepts and principles of sustainability (environmental, economic, social)*
N/A	Other

* Sustainability was not among the original list of attributes developed by Purdue's Engineer of 2020 committee. However, it has been featured prominently in a number of related events and publications.

Figure 1. Survey Section 1 – Global Engineering Scenario and Competencies



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Imagine you are an engineer working for a multinational corporation that is expanding operations in both South America and Southeast Asia. You are involved in evaluating the feasibility of the expansion, including finding suitable locations and planning operations. From the following list, pick the top five (5) competencies you would most need to complete this assignment:

- ☐ apply principles of effective leadership
- ☐ engage in continuous and life-long learning
- ☐ understand and apply ethical responsibility
- ☐ communicate effectively
- ☐ work effectively in the global engineering profession
- ☐ evaluate situations to make informed decisions
- ☐ synthesize engineering with business, societal, and environmental perspectives
- ☐ work effectively in diverse and multicultural environments
- ☐ recognize and manage change in one's work context
- ☐ be creative and innovative
- ☐ work effectively on a team
- ☐ realize new ideas or innovations in an existing organization (intrapreneurial) or new organization (entrepreneurial)
- ☐ be personally adaptable in a changing environment
- ☐ work hard and commit fully to a task
- ☐ apply concepts and principles of sustainability (environmental, economic, social)
- ☐ Other:

Table 2 provides sample questions for the other major survey sections. In Section 2, respondents were asked to rank order the relative importance of the five competencies selected in Section 1. In Section 3, respondents ranked their own ability for each of the selected competencies, and in Section 4 they were asked to describe how they had developed, or would expect to develop, each of the five selected competencies. Section 5 was designed to elicit respondent understandings of transformative learning experiences. A final section of the survey collected relevant demographic information (e.g. educational level, age, ethnicity, global characteristics and experiences, etc.). A question related to amount of time spent living in another culture was adapted from the IDI instrument. This paper mainly reports results from Sections 1-4 of the survey.

Table 2. Overview of Survey Instrument Sections 2-5

Section 2 – *Rank order all five (5) of the selected competencies*

By clicking and dragging, rank order the competencies you selected on the previous page from most important (1) to least important (5):

Section 3 – *Self-assess own ability for each selected competency*

Please rate your own ability to do each of the following:

	No Ability		Adequate Ability		High Ability
» apply principles of effective leadership	○	○	○	○	○

Section 4 – *Describe possible attainment pathways for each selected competency*

How have you developed, or how would you expect to develop, your ability to **apply principles of effective leadership**?

Section 5 – *Reflect on transformative learning experiences*

Reflecting on the learning experiences you identified in the previous section, describe the experience that would have the most significant impact on your behavior, lifestyle, beliefs, values, and/or understanding of your self.

Participant Characteristics

Our target population for this survey was students enrolled at all levels (first year through graduate) in Purdue University's College of Engineering. To obtain data from students with a wide range of global experience (from minimal to extensive), the survey was promoted heavily among students affiliated with various global programs (e.g. study abroad, GEARE, GEP, etc.). The study received appropriate human subjects clearance (Purdue IRB approval #0911008658).

Table 3. General Demographic Characteristics of Study Survey Respondents, n=231

Level		Gender		English Language		Ethnicity/Culture*	
23	First year	160	Male	179	Native Speaker	33	International Student
72	Sophomore	68	Female	50	Non-Native Speaker		
41	Junior	3	Not Specified	2	Not Specified	1	Native American
69	Senior					42	Asian
23	Graduate					3	African American
1	Postdoc					8	Hispanic/Latino
2	Not Specified					158	White/Caucasian
						2	Multiracial
						9	Not Specified

* Ethnicity/Culture does not total 231 because respondents could pick multiple categories.

From December 2-23, 2009 we received 278 survey responses, with 231 usable in whole or part (e.g. mostly complete, but some questions with partial or missing responses). General participant characteristics are summarized in Table 3. A reasonably diverse demographic was obtained, including in terms of student level, gender, native language, and ethnicity/culture. The top three departments represented in our respondent pool were Mechanical Engineering (94 responses), Electrical and Computer Engineering (50 responses), and First-Year Engineering (32 responses). The high response rates in these units were likely due to our targeted promotional efforts.

Table 4. Global/International Characteristics of Survey Respondents, n=231

Global/international characteristic (select all that apply)		Total amount of time spent living in another culture	
103	I am proficient in a language other than English	89	Never
24	I have interned/co-oped abroad (outside the US)	53	Less than 3 months
54	I have worked in a multi-national company (in US or outside) and collaborated with co-workers abroad	15	3-6 months
		11	7-11 months
36	I have traveled abroad for volunteering/mission/relief work (any duration)	12	1-2 years
		21	3-5 years
42	I have studied abroad (less than eight weeks)	7	6-10 years
46	I have studied abroad (eight weeks or more)	21	Over 10 years
79	I have traveled extensively on my own as a tourist	2	Not Specified
26	Other global/international experiences or characteristic		

Table 4 summarizes the global/international characteristics reported by survey respondents. Again, this information indicates a reasonably diverse sample, with significant numbers of respondents having anywhere from very minimal to very extensive experience living and

working across countries and cultures. In future analysis we intend to group respondents into a smaller number of discrete clusters or levels of global/international experience.

Data Analysis

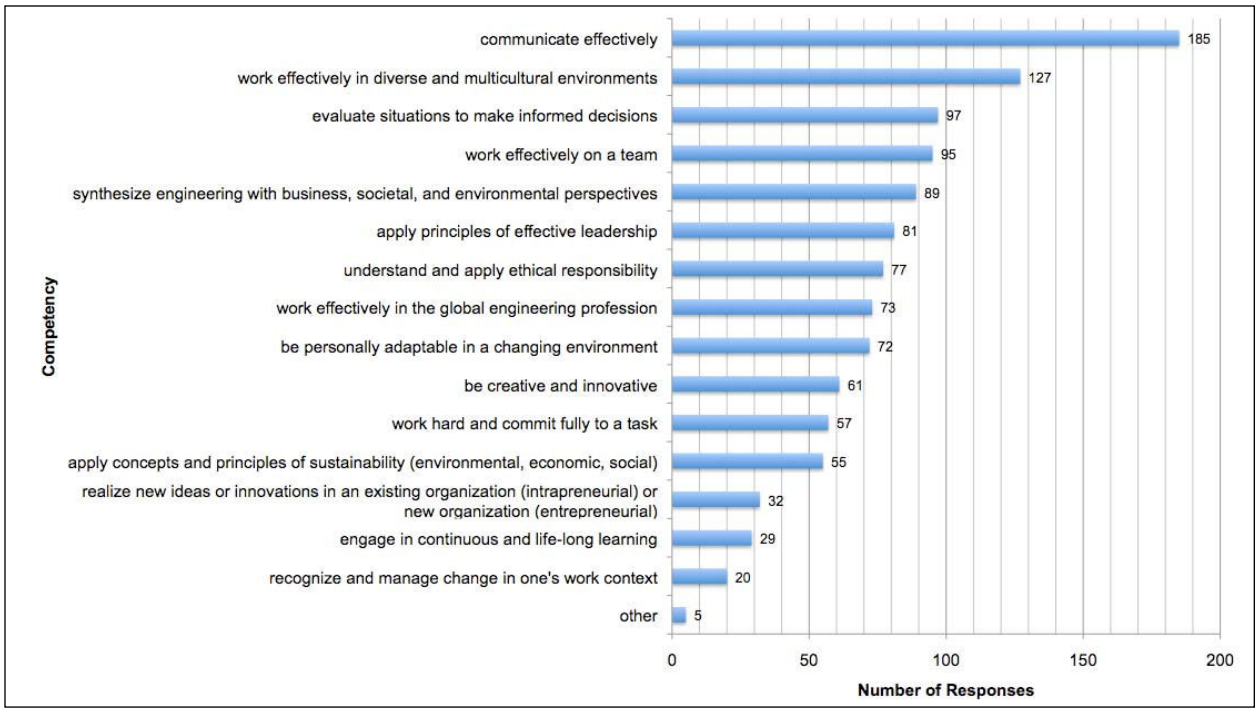
All data was exported from the Qualtrics survey application in CSV format, then imported into Microsoft Excel for preliminary analysis. Some simple results verification was performed by comparing tabulations of data in Qualtrics and Excel. The lead author used an open coding procedure to perform preliminary analysis of qualitative responses from survey Section 4.[26]

Findings

Global Engineering Competencies

As noted above, the first survey section asked respondents to select the five competencies most needed for the hypothetical global engineering scenario. As indicated in Figure 2, by far the most common competencies selected by respondents were *communicate effectively* (selected by 185 of 231 or 80% of respondents) and *work effectively in diverse and multicultural environments* (selected by 127 of 231 or 55% of respondents). *Decision-making*, *teamwork*, and *synthesis of engineering with business, societal and environmental perspectives* were respectively ranked third, fourth, and fifth. Leadership and ethics were respectively ranked sixth and seventh.

Figure 2. Number of Responses by Competency



Interestingly, *work effectively in the global engineering profession* was ranked eighth. Based on observations from our survey pilots, we hypothesize that many respondents favored specific statements over broader or more ambiguous alternatives. It is also notable that only five

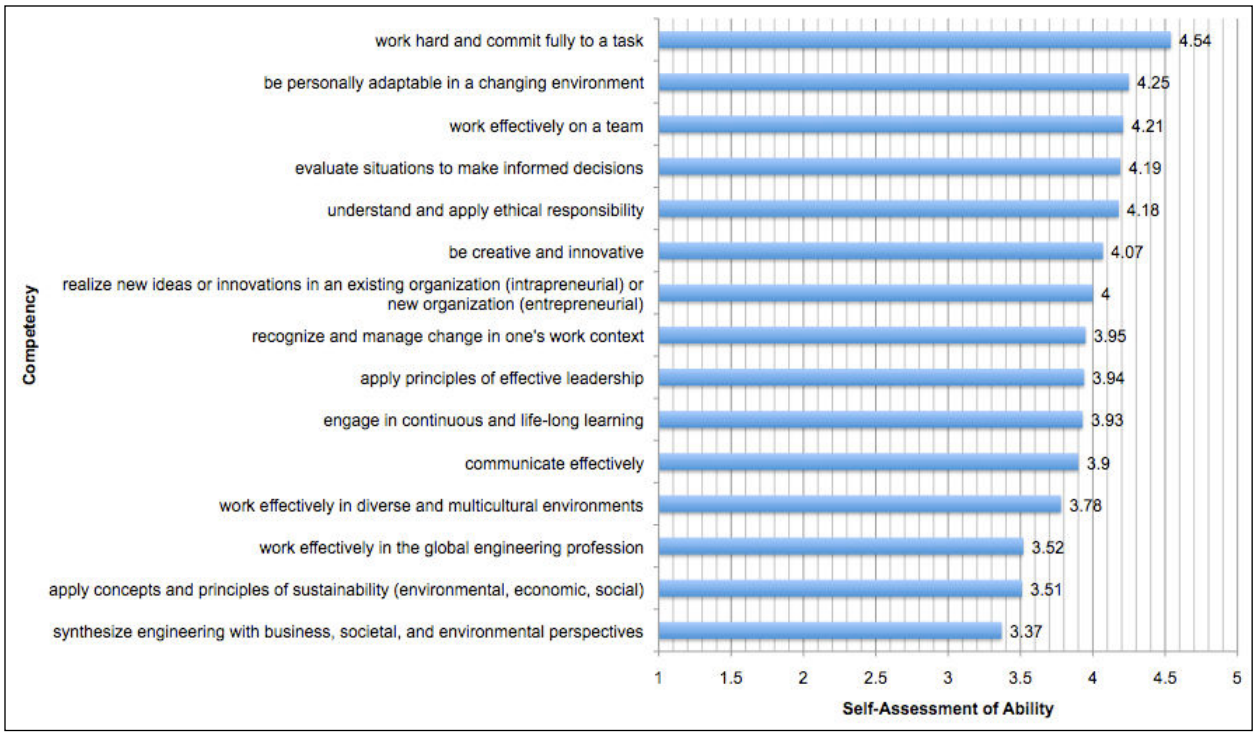
respondents utilized the *Other* option. Responses for those who selected *Other* included "all of the above" and "achieve at least basic foreign language competence." Two additional responses discussed economic or cost analysis. It is notable that no students identified technical knowledge or skills in their responses. While the given competencies implicitly suggested that the survey was focused on global and professional attributes, we hypothesize that many respondents assumed an engineer in this kind of global scenario would have appropriate technical skills.

Student Self Evaluation of Abilities

For each of the five competencies they selected, respondents were asked to rate their own ability on a five-point scale, from no ability (1) to adequate ability (3) to high ability (5). Overall, self-assessment ratings were high, with an average across all competencies of 3.95. In summary, students evaluated their abilities highest in the areas of *work ethic* (4.54 out of 5), *personally adaptive* (4.25), *teamwork* (4.21), *decision-making* (4.19), and *ethical responsibility* (4.18).

Respondents ranked themselves lower in a number of areas that were perceived as important for the practice of global engineering. Most notably, the lowest ranking attributes were *global engineering* (3.52), *sustainability* (3.51), and *synthesize engineering with business, societal, and environmental perspectives* (3.37). Respectively ranked eleventh and twelfth, the competencies *work effectively in diverse and multicultural environments* and *communicate effectively* were also identified as relatively weaker area across the entire survey population.

Figure 3. Self Evaluation of Ability by Competency



It is especially striking that three of the top five competencies that respondents identified as important (*communicate effectively*, *work effectively in diverse and multicultural environments*,

and *synthesize engineering with business, societal, and environmental perspectives*) were among the lowest five competencies in terms of self-evaluation of abilities. These findings tentatively suggest gaps between student perceptions of desirable competencies for global engineering as compared to their own levels of confidence and ability in many of these same areas.

Demographic information allows further comparative analysis of results. For instance, we found no significant difference in self-assessment ratings by gender. Across educational levels, ratings were slightly lower than average (3.875) for sophomores, near average for first year, junior year, and graduate students, and slightly above average for seniors (4.04). Ratings were also slightly higher for students who had spent some amount of time living in another culture.

Table 5. Self-evaluation of Competency With and Without Intern/Study Abroad

	No Intern and/or Study Abroad		Intern and/or Study Abroad	
Competency (overall rank)	**n**	**Average Self-Evaluation**	**n**	**Average Self-Evaluation**
communicate effectively (1)	143	3.89	42	3.95
work effectively in diverse and multicultural environments (2)	92	3.61	34	4.28 ($p < 0.001$)
evaluate situations to make informed decisions (3)	77	4.13	20	4.40
work effectively on a team (4)	72	4.22	23	4.17
synthesize engineering with business, societal, environmental perspectives (5)	68	3.25	21	3.76 ($p < 0.05$)
work effectively in the global engineering profession (8)	57	3.37	16	4.07 ($p < 0.05$)

Perhaps most suggestive, respondents who studied abroad (eight weeks or more) and/or interned abroad evaluated their own abilities higher for many of the competencies frequently associated with global engineering. Statistically significant differences are indicated as shaded rows in Table 5. These results suggest that intern and/or study abroad experiences improve student confidence in many areas of ability frequently associated with global engineering practice. However, there were no statistically significant differences between the two groups in the competency areas of *communication skills*, *decision-making*, and *teamwork*. As we note below, one possible explanation for this trend is that most students do not readily identify intern or study abroad experiences as necessary pathways for attainment of these two competencies. "Domestic" coursework and work experiences may adequately support development of these abilities, resulting in similar self-evaluations for both of these groups.

Competency Definitions and Attainment Pathways: Communicate Effectively

Qualitative responses from Section 4 of the survey help show how respondents understand: a) the scope and definition of each competency, including related skills they view as important, and b)

possible pathways for developing each competency. For this preliminary analysis we focus on *communicate effectively* since respondents selected it most often as an important attribute.

As summarized in Table 6, presentation skills and public speaking were frequently mentioned by respondents when asked how they had improved, or would expect to improve, their ability to *communicate effectively*. Diversity/multicultural skills and language skills were also noted often, sometimes with direct reference to the global engineering scenario presented in the first part of the survey. Various aspects of writing – including technical communication, memo and e-mail writing, etc. – were mentioned 16 times. Six respondents referenced listening skills and just one explained that reading skills were important. These results help reveal the perceived breadth of this particular competency area. In fact, many responses mentioned multiple skills.

Table 6. Definitions and Attainment Pathways for *Communicate Effectively*

Definitions	*Attainment Pathways*
34 Presentations, Public Speaking	56 Coursework
18 Diversity/Multicultural Skills	42 Teamwork
16 Writing	40 Experience/Practice
13 Language Skills	35 Work
6 Listening	16 Projects
1 Reading	8 Extracurricular
	4 Informal Social Interactions
	3 Teaching/Tutoring
	3 Interviewing for Jobs
	2 Leadership Roles
	1 Study Abroad

A total of 40 individuals indicated that practice and/or experience (in general) had improved or could improve competency in this area, e.g. “I have developed my communication skills through practice and real world experiences.” While such statements may seem obvious and perhaps even circular, they nonetheless reveal a widespread perception that communication skills are not innate, and can be enhanced through practice and experience.

Among those who identified specific pathways for improving this competency, 56 discussed coursework. Of these, 19 referred to coursework in general, while 27 discussed classes outside of engineering (in communication, English, foreign languages, etc.) and 10 referenced engineering courses. Many individuals identified teamwork (42 responses) and project-related activities (16 responses) as providing opportunities to improve communication skills. Of those who discussed work-related contexts, 26 respondents discussed work in general while 9 referred specifically to co-ops or internships. Surprisingly, only one respondent mentioned study abroad as a possible pathway for improving communication skills. Again, this may suggest that students perceive “domestic” educational and work settings as suitable contexts for improving communication skills. As noted above, participation in study or internship abroad had little impact on how respondents evaluated their own communication skills.

Discussion and Conclusions

Our findings show that many engineering students perceive "generic" or "transferable" competencies like *communication*, *teamwork*, and *decision-making* as most important for global practice. They also frequently identified as important some more specialized competencies, such as *work effectively in diverse and multicultural environments* and *synthesize engineering with business, societal, and environmental perspectives*. Our results reinforce the idea that "global competency" might best be defined as a cluster of global and professional skills, some of which might shift in importance depending on the particular context or scenario of practice.

We also observe that many students rated their own abilities relatively low in some of the areas most often associated with global competence, which suggests they are not especially well-prepared for global practice. However, intern and study abroad experiences appear to have an overall positive impact on student self perceptions of confidence in a number of important competency areas, including *work effectively in diverse and multicultural environments*, *synthesize engineering with business, societal, and environmental perspectives*, and *work effectively in the global engineering profession*.

It is notable that respondents were not especially confident in their ability to *communicate effectively,* despite this being a top-ranked attribute. Further, few students saw study abroad as a pathway for improving this competency, and participation in intern or study abroad was not correlated with higher confidence in one's communication skills. Large numbers of respondents identified courses and work experiences as typical pathways to improved communication skills.

Teamwork is another area worth highlighting, especially since it was both ranked highly as a global engineering attribute and evaluated highly in terms of student ability. We propose that the pervasiveness of teamwork within and beyond engineering education has both reinforced the importance of this concept and enhanced the ability of students to work on teams. Interestingly, our results also show an interdependence of communication and teamwork skills, with large numbers of respondents identifying group interactions or projects as providing opportunities for enhancing communication skills. Many respondents also linked communication to diversity.

We acknowledge the limitations of our results, including some skewed demographics in our respondent pool and a potential lack of reliability in having participants rate their own abilities in select areas. We are also aware that our efforts are to some extent limited by the specific statements presented in this survey, including competency statements that are very broad and/or open to wide interpretation (e.g. *work effectively in the global engineering profession*).

Nonetheless, we feel our results are suggestive of aggregate trends and can be used to make a number of broad comparisons (e.g. contrasting lowest and highest ranking competencies). In future work we intend to analyze and report findings on attainment pathways for more of the competency areas, which will help us better understand how respondents are understanding and interpreting their scope and definition. We are also now using a similar survey to collect data from faculty members and industry partners, which will allow comparisons across all three stakeholder populations.

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