AC 2011-363: A SURVEY OF ESSENTIAL SKILLS FOR PH.D. ENGINEERS IN INDUSTRY

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A Survey of Essential Skills for Ph.D. Engineers in Industry

Abstract

The broad objective of this study is to contribute to the understanding of the skills needed by engineering Ph.D.s in industry and how well doctoral degree programs prepare graduates in these areas. A survey was administered to Ph.D.s in industry to understand the level of each skill needed in their organization, and the amount of preparation they received as doctoral students. Results indicate that learning and working independently, working in teams, written and oral communication, and solving problems are the most important skills for a Ph.D. engineer in industry. Also found, was that the essential skills for industry and the level of doctoral preparation are in general, well aligned. However, the survey results indicate that there are a few skills for which the needed level of ability is not correlated with the level of preparation that the graduates received. Results suggest that one of the most significant areas for improvements in preparing doctoral students is related to teamwork. These findings and others are discussed in this paper.

Background

Traditionally, engineering doctoral programs largely train doctoral students to conduct research in narrowly defined areas that are selected by the faculty advisors, with the expectation that students will become university faculty members. Such specialization does not explicitly prepare graduates for long-term success in the continuously evolving, multidisciplinary, global research environment[1, 2]. Furthermore, there has been a shift in employment options from academic to non-academic positions: 70% of graduates will not hold positions in academia. Approximately 55% will be employed in the for-profit sector, government (7%), private non-profit institutions and self employed (4%) and other areas of employment (4%) according to National Science Foundation (NSF) Division of Science Resources Statistics[3].

According to Akay and Hogan, it has been stated that that Ph.D.s in industry do not have the leadership skills to organize, manage and establish effective teams of researchers that outperform their competition while appreciating the applied problems, knowledge and culture of other fields[2, 4]. The literature focusing on engineering graduate education is scarce at best[2]. Although there is literature about developing these skills at the master's level[5-9], the literature does not adequately address the preparation of engineering doctoral students who pursue careers in industry. This study will thereby assist in determining the knowledge, attributes and skills (KAS) industry desires in Ph.D.s in order to develop Ph.D. programs that include effective strategies to align student preparation with industry needs.

Methodology

A survey was designed to determine the skills and the level of expertise needed by engineering Ph.D.s in industry. The survey was based upon a list of skills that were determined through a review of advertised job solicitations in industry, as described in Watson et al[10]. These job solicitations were for industry positions requiring a Ph.D. in engineering. The list of skills included technical skills, such as solving problems and designing experiments, and transferable skills (often referred to as soft skills) such as communication, teamwork and professional ethics.

The initial draft of the survey was reviewed by a content review panel, which consisted of a mechanical engineering and a chemical engineering faculty member. The modified survey was next reviewed by eight professors in mechanical and chemical engineering. The wording of some questions was clarified and additional questions were added at the request of the department faculty. The final survey was created with Class Climate®, an online survey tool. It included Likert questions about specific skills listed in Table 1, demographic information and open-response questions.

This survey includes two sets of questions related to the skills listed in Table 1. The root for the first set of questions was:

> *Listed below are abilities that may be essential for an entry-level engineering Ph.D. position. For each ability, please mark one answer to indicate the level that is essential for a typical entry-level engineering Ph.D. in your place of employment.*

This root was followed by the list of skills. A four-pole Likert scale was provided for responding about each skill. The term "Basic" was at the low end of the scale (numeric value of 1) and the term "Expert" at the high (4). The option to select "Not Essential" (0) was also provided. The participants were also asked an open-ended question, "What other abilities are essential?" at the end of the first set of questions.

A second set of survey questions that used the skills listed in Table 1 was based on the root:

> *The abilities that may be essential for Ph.D.s are listed again below. Now, think back to when you just completed your engineering Ph.D. program. Please mark one answer to indicate how well your Ph.D. program prepared you in each area.*

Again, a four-pole Likert scale was provided for responses. The term "Not Prepared" were used at the low end (1) and the term "Well prepared" at the high (4). The option to select "Not Applicable" (0) was also provided. The second section concluded with two open-ended questions, "What other abilities did you develop during your Ph.D. program?" and "What do you wish your Ph.D. program had better prepared you to do?"

Ph.D.s in engineering who were not working in academia were the target population for the survey. The participant pool was initially populated with known contacts and subsequently expanded though a snowballing technique. The known contacts consisted of alumni from mechanical and chemical engineering Ph.D. programs at University of South Carolina, Georgia Institute of Technology, Florida State/Florida Agriculture and Mechanical University and the University of Tennessee. It also included company contacts from the American Society of Engineering Education/National Science Foundation (ASEE/NSF) Corporate Research Postdoctoral Fellowship for Engineers program[11]. Additional contacts were identified by searching NSF Fastlane for NSF Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) awards related to engineering[12]. The initial contacts totaled 906 people. Each alumnus and company contact received an email asking them to complete the survey if they had a Ph.D. in engineering and to forward it to colleagues with Ph.D.

degrees. All participants had access to the survey from one to two months in the first half of 2010.

The total number of participants who submitted the survey was 188. For data analysis the responses of 15 participants were eliminated because they did not hold a Ph.D. in engineering or an engineering doctorate. Of the 173 remaining participants, the participants who did not work in a "For-Profit Company" (referred to as "Industry" hereafter) were eliminated from the study. An additional 28 participants were eliminated because their surveys were incomplete. The remaining 109 participants are considered in the results presented here with 54 (49%) of participants from the Small Business group and 56 (51%) participants from the Corporate group.

Results

To determine the skills valued by industry, participants were asked to rate the essential level of potentially important skills (seen in Table 1). The distribution of responses and mean value of the Likert Scale for each skill are shown in Table 2. Results suggest that the most important skills are learning independently, working in teams, written and oral communication, solving problems, and working independently. All respondents rated these as essential, with over 50% indicating that an expert skill level is needed as seen in Table 2. These findings are similar to Sekhon's survey of Ph.D.s working in industry with mathematically-intensive disciplines including engineering[13]. In the current study, practicing professional ethics, designing experiments, giving presentations, writing reports and reviewing literature are also considered important. At least 40% of participants indicated an expert skill level was needed in these areas and less than 5% rated these skills as non-essential.

Results suggest that marketing products/processes, managing others, identifying customer needs and writing peer reviewed papers are some of the least important skills for entry-level engineering Ph.D.s in industry. Less than 2% of participants felt that it was essential to have an expert skill level in marketing. Over 20% of participants responded that marketing products/processes was not an essential skill for Ph.D.s in industry. Managing others, identifying customer needs and writing peer reviewed papers had over 10% of participants indicating it was not an essential skill.

Participants were solicited for additional essential skills to industry through an open-ended question, "What other abilities are essential?" Adapting and understanding the industry environment was mentioned by over 18% of the participants. Comments included working towards the company's goals and "not investigating in detail an area of interest related to the problem." They also included understanding cost, quality, and project planning or project management. These comments suggest that the more successful Ph.D.s in industry are able to adapt and understand the industry environment quickly.

Leadership, including interpersonal leadership, visionary leadership and lifelong learning leadership, as described in Watson and Lyons [14], was another theme mentioned by 10% of the participants. Comments included "the desire to learn from non-Ph.D. engineers", collaborating, good interpersonal skills and ability to "define sub-tasks with a project and prioritize". One participant stated that most Ph.D.s in engineering have good technical skills as evidenced by their publications and education. The people who (s)he wants to employee possess good communication and leadership skills in addition to the technical skills. (S)He then pointed out that for people with advanced technical degrees, "It is far easier to train them [Ph.D. engineers] to become technically competent in a position of interest than to have them develop these more socially oriented skills."

The survey also investigated the participants' perceptions of how well their Ph.D. programs prepared them in skills listed in Table 1. Over 50% of participants indicated that they were "well prepared" in the areas of learning independently, written and oral communication, solving problems and working independently as seen in Table 3. Only 40% of participants indicated they were "well prepared" to work in teams. These findings are also similar to the results in Sekhon's study. In that work, less than 50% of his participants indicated the highest level of development in reference to the skills of working in teams, written and oral communication, analyzing a problem in new ways, and working independently with only 6.9% of his population indicating their teamwork skills were developed [13]. The difference between the current study and Sekhon's study may suggest one or more of the following: that there has been an improvement in developing Ph.D.s ability to work in teams in the last twenty years, that the United States and Australia have different approaches to doctoral education, or that not all participants of Sekhon's study were engineers.

Results suggest that participants were not prepared to identify customer needs and market products/processes. More than 40% of participants indicated that their doctoral program did not prepare them in these areas. Optimizing products/processes, scaling-up systems, understanding intellectual property processes, following safety and environmental regulations, leading teams, managing others and resources are skills where less than 20% of participants indicated they were "well prepared" to do, but participants did indicate some degree of preparation.

Participants were also asked what they wished their Ph.D. program had better prepared them to do in an open ended format. Responses focused on understanding the corporate environment. Over 25% of participants wished their doctoral program had better prepared them in their understanding of the industrial environment. This understanding includes project management training, entrepreneurial skills and "selling" an idea to management, marketing and sales teams. These comments reinforce the suggestion that more successful Ph.D.s in industry quickly adapt and gain an understanding of the industrial environment.

Discussion

The design of this survey allows for a comparison between industry needs and doctoral degree preparation. To make this comparison, the mean value of the Likert scale responses were calculated for each of the skill levels needed by industry and for the preparation level the participants received in their doctoral program. These mean values are shown in Table 2 and Table 3. Higher mean values correspond to either better overall preparedness or higher skill levels needed. The means of the essential skill levels needed by industry and the preparation level the participants received in their doctoral program are plotted in Figure 1. The essential skill level is on the X-axis, the essential skill preparation level is on the Y-axis, and the numbers near various data points correspond to the skills listed in Table 1. An analysis of the results suggests a linear correlation between the responses to this question and the responses to the previous question on level of skill needed. Spearman's correlation was used to determine the measure of a linear relationship between the essential skill level and the skill preparation level[15]. Overall, the results indicate a linear correlation between level of preparation and skill level needed. This relationship is shown in Figure 1 by a best fit line with a Spearman's correlation coefficient of 0.852, which according to Cohen's guidelines indicates a strong correlation[16].

Responses indicate that Ph.D. programs prepare graduates well for most areas where a high level of skill is needed and do not prepare them well for areas which are less essential. In order to determine skills where doctoral preparation level is mismatched with the needs of industry, upper and lower tolerance lines were plotted ±0.25 units from the best fit line. A data point below the lower tolerance line is interpreted as representing a skill level where the participants' preparation levels were lower than the level needed by an entry level Ph.D. engineer in industry. A data point above the upper tolerance line then represents skill level where the preparation level is above the level needed by an entry Ph.D. in industry.

The analysis suggests several areas for improvement. Perhaps the most important is teamwork because it requires a high skill level yet the furthest below lower tolerance line. Other skills that fall below the lower tolerance line include: following environmental and safety regulations, understanding intellectual property processes and indentifying customer needs. However, the skill levels required for these skills are not as high as required for teamwork.

Also noteworthy are the results for writing peer reviewed papers. This point is farthest from the upper tolerance line. This skill is associated with a high preparation level, but the survey responses indicate that a high skill level is less essential. Other skills above the upper tolerance line include: working independently, reviewing literature, mentoring others and finding problems. Skills that are associated with points above the upper tolerance line can be considered as potential areas to assess when evaluating the components of Ph.D. programs that prepare students for industry.

Conclusion

Results indicate that learning independently, working in teams, written and oral communication, solving problems and working independently are the most important skills for a Ph.D. engineer in industry. The essential skills for industry and doctoral preparation are positively correlated. Results suggest that one of the most significant areas for improvements in preparing doctoral students is related to teamwork. Improving teamwork skills of graduates from Ph.D. programs that emphasize independent work and individual accomplishments will require careful consideration. Results from this study may be used to enhance future efforts to further align engineering Ph.D. preparation with industry needs.

Table 1: Skills Included in Order on the Survey of Ph.D.s in Industry

Skills Identified from Position Review			
1	Innovate	17	Create proposals
2	Find problems	18	Give presentations
3	Solve problems	19	Review literature
4	Design experiments	20	Write peer-reviewed papers
5	Design computational studies	21	Write reports
6	Optimize products/processes	22	Develop specifications
7	Market products/processes	23	Learn independently
8	Identify customer needs	24	Work independently
9	Provide technical support	25	Work in teams
10	Scale-up systems	26	Lead teams
11	Understand intellectual property processes	27	Manage others
12	Follow safety regulations	28	Mentor others
13	Follow environmental regulations	29	Manage resources
14	Work across disciplines	30	Manage multiple projects
15	Communicate orally	31	Practice professional ethics
16	Communicate in writing	32	Demonstrate business etiquette

Table 2: Percentage Distribution of Essential Skill Level Needed for Ph.D.s in Industry

Question Number	Skill Needed Percentage	Not Essential 0	Basic 1	2	3	Expert 4	Average	Standard Deviation
1	Innovate	1.8	4.5	22.7	37.3	33.6	2.7	0.9
2	Find problems	2.7	9.1	24.5	30.9	32.7	2.6	1.0
3	Solve problems	0.0	2.7	7.3	37.3	52.7	3.1	0.7
4	Design experiments	0.9	6.4	10.9	35.5	46.4	2.9	0.9
5	Design computational studies	7.3	10.9	33.6	37.3	10.9	2.1	1.0
6	Optimize products/processes	4.5	9.1	30.0	40.9	15.5	2.3	0.9
7	Market products/processes	20.0	36.4	25.5	15.5	2.7	1.3	1.0
8	Identify customer needs	12.7	16.4	34.5	24.5	11.8	1.9	1.1
9	Provide technical support	4.5	14.5	24.5	34.5	21.8	2.3	1.0
10	Scale-up systems	8.2	20.0	31.8	29.1	10.9	2.0	1.0
11	Understand intellectual property processes	4.5	25.5	27.3	30.0	12.7	2.0	1.0
12	Follow safety regulations	5.5	16.4	20.0	30.9	27.3	2.3	1.1
13	Follow environmental regulations	6.4	22.7	21.8	27.3	21.8	2.1	1.1
14	Work across disciplines	0.9	5.5	19.1	40.0	33.6	2.7	0.8
15	Communicate orally	0.0	0.9	9.1	37.3	52.7	3.1	0.6
16	Communicate in writing	0.0	0.9	9.1	33.6	56.4	3.1	0.6
17	Create proposals	1.8	16.4	23.6	34.5	23.6	2.4	1.0
18	Give presentations	0.9	2.7	17.3	35.5	43.6	2.9	0.8
19	Review literature	3.6	3.6	14.5	31.8	46.4	2.9	0.9
20	Write peer-reviewed papers	11.8	15.5	29.1	25.5	18.2	2.0	1.1
21	Write reports	1.8	3.6	17.3	37.3	40.0	2.8	0.9
22	Develop specifications	3.6	17.3	38.2	30.0	10.9	2.1	0.9
23	Learn independently	0.0	0.9	10.9	24.5	63.6	3.2	0.7
24	Work independently	0.0	4.5	14.5	26.4	54.5	3.0	0.8
25	Work in teams	0.0	0.0	7.3	37.3	55.5	3.2	0.6
26	Lead teams	6.4	14.5	30.0	31.8	17.3	2.2	1.0
27	Manage others	10.9	24.5	34.5	21.8	8.2	1.7	1.0
28	Mentor others	8.2	23.6	25.5	25.5	17.3	2.0	1.1
29	Manage resources	4.5	18.2	30.9	32.7	13.6	2.1	1.0
30	Manage multiple projects	1.8	8.2	27.3	36.4	26.4	2.5	0.9
31	Practice professional ethics	0.0	10.9	6.4	34.5	48.2	2.9	0.9
32	Demonstrate business etiquette	3.6	10.9	22.7	35.5	27.3	2.5	1.0

Table 3: Percentage Distribution of Preparation of Essential Skills for Ph.D.s in Industry

Question Number	Skill Preparation Level Percentage	Not Applicable 0	Not Prepared 1	2	3	Well Prepared 4	Average	Standard Deviation
1	Innovate	0	4	25	28	43	3.1	0.9
2	Find problems	1	5	20	31	44	3.1	0.9
3	Solve problems	0	1	10	32	57	3.5	0.7
4	Design experiments	0	7	18	34	41	3.1	0.9
5	Design computational studies	7	19	25	25	23	2.4	1.2
6	Optimize products/processes	4	16	24	37	19	2.5	1.1
7	Market products/processes	11	55	22	10	3	1.4	0.9
8	Identify customer needs	7	43	28	15	6	1.7	1.0
9	Provide technical support	7	16	19	35	23	2.5	1.2
10	Scale-up systems	7	35	40	10	7	1.7	1.0
11	Understand intellectual property processes	4	43	30	19	5	1.8	1.0
12	Follow safety regulations	5	26	30	22	17	2.2	1.2
13	Follow environmental regulations	8	35	26	17	13	1.9	1.2
14	Work across disciplines	2	5	18	37	37	3.0	1.0
15	Communicate orally	0	1	8	41	50	3.4	0.7
16	Communicate in writing	0	1	10	32	57	3.5	0.7
17	Create proposals	2	18	26	29	25	2.6	1.1
18	Give presentations	0	3	8	37	52	3.4	0.8
19	Review literature	0	0	5	33	62	3.6	0.6
20	Write peer-reviewed papers	2	3	12	27	56	3.3	0.9
21	Write reports	1	0	14	37	48	3.3	0.8
22	Develop specifications	5	25	34	27	9	2.1	1.0
23	Learn independently	0	0	2	18	80	3.8	0.5
24	Work independently	0	0	5	12	84	3.8	0.5
25	Work in teams	0	8	19	33	40	3.0	1.0
26	Lead teams	2	25	30	26	16	2.3	1.1
27	Manage others	4	34	35	19	9	2.0	1.0
28	Mentor others	2	18	31	27	22	2.5	1.1
29	Manage resources	1	20	35	27	16	2.4	1.0
30	Manage multiple projects	3	15	28	30	25	2.6	1.1
31	Practice professional ethics	2	9	13	41	35	3.0	1.0
32	Demonstrate business etiquette	4	14	24	28	31	2.7	1.2

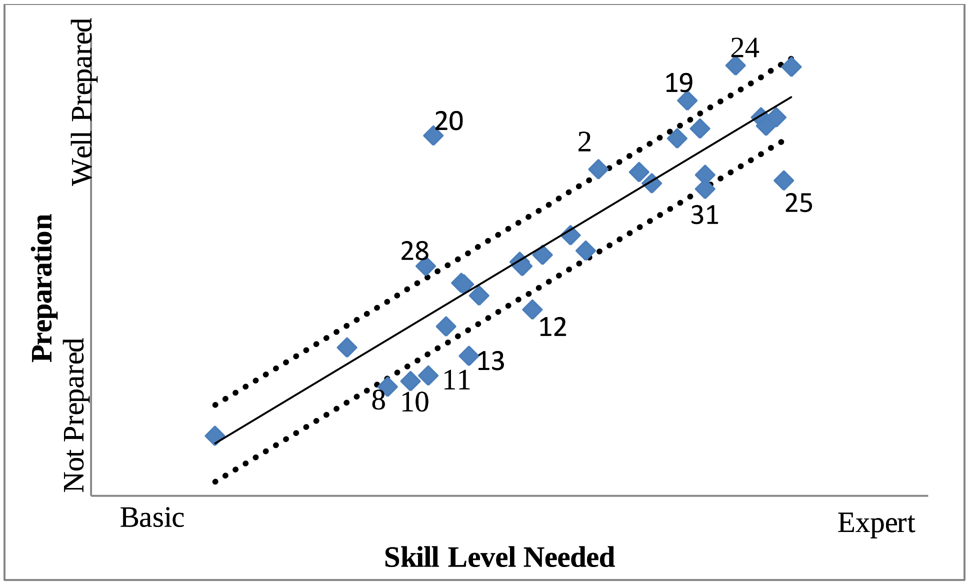

Figure 1: Alignment of Doctoral Preparation with Industry Needs

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