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Aligning Academic Preparation of Engineering Ph.D. Programs with the Needs of Industry*

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Engineering doctoral programs in the United States are frequently designed to prepare graduates to become original researchers and work in academia. However, the majority of engineering Ph.D. graduates are being employed in industry, this leads to the question of how well doctoral programs are preparing students to meet the needs of industry. The purpose of this exploratory study discussed in this paper is to determine the skills and skill levels needed by engineering Ph.D.s working in industry so that effective strategies may be developed to align student preparation with industry needs. A review of a sample of job solicitations was performed to create a list of possible skills that are essential for engineering Ph.D.s working in industry. A survey was administered to a sample of Ph.D.s in industry to understand the level of different skills needed in their organization and the amount of preparation they received as doctoral students. Survey results indicated that learning and working independently, working in teams, written and oral communication, and solving problems are the most important skills for Ph.D. engineers in industry. 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. The essential skills for industry and the level of doctoral preparation are, in general, well aligned. Results suggest that one of the most significant areas for improvement in preparing doctoral students is related to teamwork.

Keywords: Ph.D.; industry; skills; survey; teamwork

1. Introduction

Doctoral programs have their roots in the 'master–apprentice' model developed during medieval times [1, 2]. The first Ph.D. in the United States was awarded at Yale in 1861. Two years later, Josiah Gibbs received the first Ph.D. in engineering in the U.S. [3, 4]. Doctoral education continued in the early half of the 20th century, but grew rapidly after World War II and after the launching of Sputnik in 1957. During the Cold War, funding for basic research grew along with the number of graduate engineering students. Upon degree completion, these Ph.D.s typically worked for an academic or national lab conducting basic research [2, 5]. A change in the funding began to occur in the 1970s and 1980s with less federal and private funding going toward basic research and thus fewer academic positions created. The focus of engineering doctoral research also shifted from basic to applied research during this time [5].

Historically, Ph.D. programs within the United States have done a superb job of preparing doctoral students in engineering to become original researchers in narrowly defined areas that are selected by the faculty advisors. Such specialization does not explicitly prepared graduates for long-term success in the continuously evolving, multidisciplinary, global research environment. Furthermore, there has been a shift in employment options from academic to non-academic positions: 70% of graduates will not hold positions in academia. According to the National Science Foundation (NSF) Division of Science Resources Statistics, approximately 55% of engineering Ph.D.s were employed in the for-profit sector, 30% were in educational institutions, 7% were in government, 4% were in private non-profit institutions, and 4% were self employed [6]. The shift in places of employment and type of work has lead to questions of whether or not doctoral programs adequately prepare students for careers that do not center on basic research [5, 7–11].

Even with the historical excellence in engineering doctoral education, there are indicators that show a change is needed [5]. According to Akay, Hogan and the Council for Chemical Research, 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 [7, 12, 13]. Ph.D.s are seen as researchers, and they are increasingly seen as possessing advanced problem solving and reasoning skills. It has been stated by Camporesi and Metcalfe that employers want to hire people with these skills [2, 14]. Other skills desired in Ph.D. graduates include communication, economic awareness and technical skills [2, 7, 10, 14–18]. Rigorous research focusing on engineering graduate education is scarce at best [7]. Although there is literature on developing essential skills of graduate students for industry, it is focused at the master's level [19–23].

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This literature does not adequately address the preparation of engineering doctoral students for careers in industry. This exploratory study will thereby assist in determining the skills and skill level industry desires in engineering Ph.D.s in order to develop Ph.D. programs that include effective strategies to align student preparation with industry needs.

2. Theoretical framework

In this study, the essential skills that non-academic engineering Ph.D. positions require are explored using grounded theory. Grounded theory is the 'building of a substantive theory' by allowing a theory to emerge from the data. In other words, the proposition or hypothesis is tentative and suggested by the data rather than tested by the data. Research guided by grounded theory consists of three phases: research design, data collection, and data analysis. In the research design phase, research questions are clearly defined. The questions are focused, but flexible enough to allow for 'accidental' discoveries. In order to answer the research questions, cases are selected to facilitate the data collection process. Cases are principal units of data. In this study, a case is a job solicitation or a survey response. In grounded theory, cases are chosen in order to refine concepts and theoretical constructs by finding gaps in the data or holes in the developing theories. By sampling specific cases a theory emerges [24–26]. Data are then collected from individual cases during the data collection phase. By constructing a database of multiple cases converging on the same phenomenon, the construct validity, internal validity and reliability is enhanced. The data are then analyzed through coding, where concepts, categories and propositions are generated. The emerging theory is then compared with existing literature, improving the construct definitions, internal validity and ability to be generalized.

3. Job solicitation review

3.1 Job solicitation review methodology

The first phase of this study was the collection and analysis of publicly available job solicitations in chemical and mechanical engineering. The disciplines of chemical and mechanical engineering were chosen because of the researchers' familiarity with these disciplines. These job solicitations were collected and analyzed to create a sense of the skills that may be essential for engineering Ph.D.s working in non-academic positions, including positions at national labs. During a two week period in September 2009, job descriptions were collected from career links on the web sites of the American Institute of Chemical Engineering, American Chemical Society, American Society of Mechanical Engineers and monster.com. The solicitations were filtered using Boolean operators to meet the following criteria: required a Ph.D. in chemical or mechanical engineering, performed research, and were non-academic positions. This process yielded 77 job descriptions.

The job descriptions were analyzed using content analysis (or coding), which is 'a research technique for making replicable and valid inferences from text (or other meaningful matter) to the context of their use' [27]. Content analysis is firmly established as a methodological tool for reviewing job descriptions in other disciplines to determine skills needed in the workplace [28–31]. An initial coding scheme was created from a literature analysis [32] and from reviewing three job descriptions chosen arbitrarily. Approximately half of the job descriptions were coded with the initial coding scheme. During the initial coding, additional constructs were needed and were added to the coding scheme. These additional constructs are identified with asterisks in Table 1. Solicitations coded with the initial coding scheme were recoded with the new coding scheme. All job solicitations were coded by two reviewers to ensure validity and reliability with the new coding scheme. The reviewers had a substantial agreement (97.8% agreement with a Cohen's κ of 0.729) according to interpretations of Cohen's κ by Ladis and Koch [33].

3.2 Results of job solicitation review

The review of job solicitations indicates that Ph.D. employers desire their employees to possess knowledge and skills including engineering and leadership. Each one of these items is discussed in more detail in the following sections and can be seen in Table 1.

3.2.1 Engineering skills

Engineering skills include research skills as well as technical knowledge. These skills were required in all of the analyzed job solicitations. The types of research conducted by Ph.D.s were broken down into three categories: experimental research, computational research and general research.

Experimental research skills were desired by 60 of the 77 job solicitations (or 78%) and included designing experiments and specific experimental techniques as noted in Table 1. Almost half (48%) of the job descriptions indicated that Ph.D.s need to be able to design experiments. One job solicitation stated, 'Assignments will require the selection of appropriate lab and field test methods, data analysis and procedure development.' The specific techniques required by employers were also discussed in 27 of the 77 positions (35%). Some of these techni-

Table 1. Final coding scheme of knowledge and skills for Ph.D.s in engineering and the frequency of occurrence in job solicitations. During the initial coding, additional constructs were needed and were added to the coding scheme. These additional constructs are identified with asterisks

	Number of job solicitations	Percentage of job solicitations
Engineering skills		
Experimental research	60	78
Use specific experimental techniques	27	35
Design experiments	37	48
Computational research	40	52
Use specific software or computational techniques	18	23
Conduct computational research	26	34
General research	9	12
Specific content area	77	100
Engineering topics	77	100
Environmental or safety regulations*	18	23
Product or process development*	50	65
Specification development*	19	25
Scale-up or pilot plant work*	22	29
Meet customer needs*	24	31
Sales and marketing*	11	14
Process of product optimization*	26	34
Consultant*	35	45
Leadership skills		
Interpersonal leadership skills	69	90
Networking*	12	16
Manage people	26	34
Teamwork skills	68	88
Multidisciplinary teamwork*	51	66
Communication skills	63	82
Oral communication skills	49	64
Written communication skills	48	62
Visionary leadership skills	67	87
Problem solving	53	69
Innovation	45	58
Knowledge of intellectual property process	13	17
Problem finding skills*	32	42
Lifelong Learning Leadership Skills	37	48
Mentoring*	9	12

ques included: atomic force microscopy, surface area analysis, optical microscopy (Raman, infrared, ultraviolet), scanning electron microscopy, nuclear magnetic resonance, gas chromatography, and mass spectrometry.

Computational research consists of using computer models or simulations to perform research with no experiments being performed. Within the computational research skills category, a third of the employers gave examples of specific software or computational techniques desired in Ph.D.s in 18 of 77 (23%) of job descriptions. One such example is:

> Desired qualifications include strong programming skills (C++, python, and Matlab) and experience with one or more of the following: finite-element modeling, numerical methods for mass transport (such as computational fluid dynamics or the large deformation of solids), molecular dynamics for solid materials, and kinetic Monte Carlo simulations.

A third category, which accounted for 9 out of 77 (12%) jobs, was used to identify job descriptions that mentioned research as part of their essential skills, but the description was unclear if the research was computational or experimental. Examples of this general research category are 'design and conduct R&D activities to improve the safety, reliability and operability of hydrogen processing systems' and 'The successful candidate will join a group of researchers currently leading efforts on a major federal R&D contract in collaboration with university partners.'

The job descriptions suggest that employers expect engineers with Ph.D.s to have technical knowledge and skills within their discipline as evidenced by 100% of job solicitations citing specific subjects or technical skills. For example,

> A thorough knowledge of polymer physics, polymer and composite processing techniques, and the thermomechanical behavior of polymer and composite systems is required. Successful candidates will be expected to demonstrate the ability to identify and quantify the physical properties of novel polymer materials, to specify and develop processing technologies for these materials . . .

are desired technical knowledge and research skills for a chemical engineer. For a mechanical engineer, 'Computational fluid dynamics (CFD) and fluid–structure interaction (FSI) models applied to riser VIV, tank sloshing, wave-current coupling, extreme wave run-up and impact analysis' is an example of desired technical knowledge and research skills. Technical knowledge is incorporated into research skills and other engineering skills. This idea is supported in the discussion *Reshaping the Graduate Education of Scientist and Engineers* [5].

Engineering skills also included product or process development, product or process optimization, specification development, consultant, scale-up or pilot plant work, sales and marketing. Employers desired skills in this category in 57 out of 77 (74%) job descriptions. One example is 'The individual will provide technical, rheological and microscopic insight and support for formulation, process development, finished product specifications, advertising claims, competitor product and prototype evaluations.' Product or process development was the most common theme with 50 of the 77 (65%) jobs mentioning this skill. Almost half of the positions (35 of 77) wanted a successful candidate to consult with customers outside or within the company. Other skills for a successful candidate in non-academic positions included the ability to optimize various processes and products (26 of 77) and to be able to work in a pilot plant environment (22 of 77).

3.2.2 Leadership skills

Ph.D.s not only conduct research in industry, but they are leaders in their field. Through this job description analysis and a literature review [35], three interrelated leadership themes emerged: interpersonal leadership, visionary leadership, and lifelong learning leadership. Interpersonal leadership skills were found in 90% of job solicitations and included team building, motivating others, and creating a professionally stimulating workplace. Visionary leadership skills incorporated the skills needed to define and solve complex problems with innovative solutions and were found in 87% of the reviewed job solicitations [7, 34, 35]. Lifelong learning leadership was defined as the ability of a leader to determine what knowledge the team, including the leader, needed in order to implement a solution to a problem and develop a plan so the team gains the needed knowledge [36–38]. Lifelong learning leadership was found in 48% of the job solicitations. These categories of leadership are explained in more detail in the following paragraphs.

Interpersonal leadership skills included teamwork, specifically multidisciplinary teamwork, communication, and supervising others. Teamwork skills were mentioned the most frequently (88%) in job solicitations, with 66% of solicitations specifying multidisciplinary teamwork skills. A typical example of teamwork was, 'The candidate will be a member of a multi-disciplinary team that will focus on the development of new heterogeneous catalysts or improving the catalytic process.' Communication was mentioned in 82% of the job solicitations. Supervising others was a theme found in 34% of the job solicitations. The results support the idea that research and development take place by nature in a multidisciplinary team environment where the leader is able to communicate effectively among team members and across organization lines [39].

The skills categorized as visionary leadership skills included: the ability to find a problem, and solving the problem with not only a solution, but an innovative solution. Problem solving was the most common theme categorized as a visionary leadership skill and was found in 69% of the job solicitations. Innovation was found in 58% of job solicitations and was the second most common theme of visionary leadership skills. The ability to define a problem was found in 42% of the job descriptions. These findings suggest that Ph.D.s need the ability to define and solve problems with innovative solutions, which is in agreement with Akay, Basadur and Jablokow [7, 34, 35].

Lifelong leadership included mentoring and encouraging others as well as oneself to grow technically and professionally. Employers also wanted successful candidates to be able to mentor less experienced engineers and scientists in 12 of 77 (15%) jobs. For instance, employers desired Ph.D. engineers to have the 'ability to coach, assess, evaluate, develop, motivate, and empower team members.' Other aspects of life long leadership, such as continuing to gain depth and breadth of knowledge throughout a person's career, was mentioned in approximately 50% of the job descriptions. The low percentage of employers mentioning mentoring was unexpected. According to Gratton and Hunt, collaborations in teams and leadership skills have been proven to increase with mentoring, and almost 90% of the job solicitations mentioned teamwork [40, 41].

4. Survey

4.1 Survey methodology

A survey was designed to determine the skills and level of expertise needed by engineering Ph.D.s in for-profit positions (industry). The survey was based upon the list of skills that were frequently cited in job solicitation review discussed in the previous section. The initial survey listed skills including engineering skills, such as solving problems and designing experiments, and transferable skills (often referred to as soft skills) such as communication, teamwork and professional ethics. Technical knowledge was integrated into various engineering skills in the survey, though specific areas of technical knowledge were not included in the survey.

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 and a mechanical engineering doctoral student. The survey was modified and reviewed by eight professors in the mechanical and chemical engineering departments. The wording of some questions was clarified and additional skills were added at the request of the department faculty, such as 'write peer-reviewed papers' and 'demonstrate business etiquette.' The final survey was created with Class Climate®, an online survey tool. It included 32 skills, demographic information and two open-response questions related to these skills. The final list of skills can be seen in Table 2.

This survey includes two sets of questions related to the skills listed in Table 2. 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 two-pole, four-choice 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-response 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 2 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 two-pole, four-choice Likert scale was provided for responses. The terms 'Not Prepared' were used at the low end (1) and the terms 'Well prepared' at the high (4). The option to select 'Not Applicable' (0) was also provided. The second section concluded with an open-response question, 'What do you wish your Ph.D. program had better prepared you to do?'

Table 2. Percentage distribution of essential skill level needed for the total population (* denotes question added by faculty)

Question number		Not essential (0)	Basic (1)	(2)	(3)	Expert (4)	Average	Standard deviation
1	Learn independently	0	1	11	25	64	3.5	0.7
2	Work in teams	0	0	7	37	55	3.5	0.6
3	Communicate in writing	0	1	9	34	56	3.5	0.7
4	Communicate orally	0	1	9	37	53	3.4	0.7
5	Solve problems	0	3	7	37	53	3.4	0.7
6	Work independently	0	5	15	26	55	3.3	0.9
7	Design experiments	1	6	11	35	46	3.2	0.9
8	Practice professional ethics	0	11	6	35	48	3.2	1.0
9	Give presentations	1	3	17	35	44	3.2	0.9
10	Review literature	4	4	15	32	46	3.1	1.0
11	Write reports*	2	4	17	37	40	3.1	0.9
12	Work across disciplines	1	5	19	40	34	3.0	0.9
13	Innovate	2	5	23	37	34	3.0	1.0
14	Find problems	3	9	25	31	33	2.8	1.1
15	Manage multiple projects	2	8	27	36	26	2.8	1.0
16	Demonstrate business etiquette*	4	11	23	35	27	2.7	1.1
17	Create proposals*	2	16	24	35	24	2.6	1.1
18	Follow safety regulations	5	16	20	31	27	2.6	1.2
19	Provide technical support	5	15	25	35	22	2.5	1.1
20	Optimize products/processes	5	9	30	41	15	2.5	1.0
21	Lead teams	6	15	30	32	17	2.4	1.1
22	Follow environmental regulations	6	23	22	27	22	2.4	1.2
23	Design computational studies	7	11	34	37	11	2.3	1.1
24	Manage resources	5	18	31	33	14	2.3	1.1
25	Develop specifications	4	17	38	30	11	2.3	1.0
26	Write peer-reviewed papers*	12	15	29	25	18	2.2	1.3
27	Understand intellectual property processes	5	25	27	30	13	2.2	1.1
28	Mentor others	8	24	25	25	17	2.2	1.2
29	Scale-up systems	8	20	32	29	11	2.1	1.1
30	Identify customer needs	13	16	35	25	12	2.1	1.2
31	Manage others	11	25	35	22	8	1.9	1.1
32	Market products/processes	20	36	25	15	3	1.4	1.1

Engineering Ph.D.s not working in academia were the target population for the survey. The participant pool was initially populated with known contacts. It was subsequently expanded though a snowballing technique, where the initial members of the participant pool were asked to forward the survey to colleagues with Ph.D. degrees. The participant pool can be described as two groups: a Corporate group and a Small Business group. The Corporate group included alumni from mechanical and chemical engineering Ph.D. programs at four universities in the Southeastern United States. It also included company contacts from the American Society of Engineering Education/National Science Foundation (ASEE/NSF) Corporate Research Postdoctoral Fellowship for Engineers program [42]. These groups comprised 212 initial contacts. The Small Business group was identified by searching NSF Fastlane for NSF Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) awards related to engineering [43]. The Small Business group consisted of an initial 694 contacts. Each alumnus and company contact received an e-mail asking them to complete the survey if they had a Ph.D. in engineering and to forward it to colleagues with engineering Ph.D. degrees. One caveat of the snowballing technique is that it could result in unknown demographics or cross-over populations. All participants had access to the survey for one to two months in the first half of 2010.

4.2 Survey data

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 an engineering Ph.D. or an engineering doctorate degree. 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 responses of the remaining 109 participants were analyzed in this study. The Corporate group consisted of 56 (51%) of the participants, and the Small Business group consisted of 54 (49%) of the participants. Demographic information about these participants is presented in Table 3.

Participants were asked to identify their engineering discipline. The percentage of participants in chemical engineering was 25%, mechanical engineering was 22%, electrical engineering was 21%, and materials science was 20% (See Table 3). The remaining participants were broadly distributed across agricultural, biomedical, biological, civil, computer, environmental, industrial, manufacturing, nuclear, petroleum, software and systems engineering. More than one engineering field was selected by 25% of participants; 16% of participants selected two areas of expertise; 5% of participants selected three areas of expertise; and 3% of participants selected four areas of expertise.

According to the survey, all of the participants completed their Ph.D. between 1954 and 2010. To explore how graduation dates affected the survey responses, participants were grouped by time since completing their Ph.D. The number of participants completing their Ph.D. less than 5 years ago was 43, between 5 and 15 years ago was 39 and more than 15 years ago was 28. Responses to a question on gender indicate that 16% of the respondents were female. This proportion is close to the national ratio (21%) of females obtaining their engineering Ph.D. in 2007 [44].

To determine the skills valued by industry, parti-

Table 3. Demographics of participants in percentages

	Total	Male	Female	Less than 5 years experience	5–15 years experience	More than 15 years experience	Small business	Corporate
Participants	100	84	16	39	35	25	49	51
Chemical	25	19	5	10	10	5	6	18
Mechanical	22	21	1	8	7	6	11	11
Electrical	21	18	3	8	8	5	15	5
Materials	20	15	5	5	9	5	12	8
Aerospace	7	7		2	3	3	3	5
Computer	5	5		4		2	5	1
Environmental	5	3	3	2	2	2	4	2
Software	5	5	1	3	1	2	1	5
Systems	5	5		5		1	2	4
Biomedical	5	5		2	3		5	
Other	5	3	2	3		2	2	3
Manufacturing	3	3		1	2		3	
Biological	2	2		1	1		2	
Industrial	2	2			1	1	1	1
Nuclear	2	2				2	1	1
Civil	1		1	1				1

cipants were asked to rate the skill level of the 32 potentially important skills (as seen in Table 2) that were essential for an entry-level Ph.D. engineer in their organization. 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. At least 40% of participants indicated an expert skill level was needed in practicing professional ethics, designing experiments, giving presentations, writing reports and reviewing literatures; 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 for industry through an open-response question, 'What other abilities are essential?' with 19% of the participants responding. Adapting and understanding the industrial environment was mentioned by over 18% of the respondents. This concept includes working towards the company's goals and 'not investigating in detail an area of interest related to the problem.' It also includes understanding cost, quality, and project planning. The more successful Ph.D.s in industry are able to adapt and understand the industry environment quickly according to participants.

Leadership, including interpersonal leadership, visionary leadership, and lifelong learning leadership, as described by Watson and Lyons [32], 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 he wants to employ possess good communication and leadership skills in addition to the technical skills. 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 the skills listed in Table 4. 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 (see Table 4). Only 40% of participants indicated they were 'well prepared' to work in teams and to design experiments.

Results suggest that participants were not well 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, were areas where less than 20% of participants indicated they were 'well prepared', 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-response format to which 44% of participants responded. The responses focused on understanding the corporate environment. Over 25% of respondents wished their doctoral program had better prepared them in understanding the industrial environment. Comments indicated that this understanding includes project management training, entrepreneurial skills and 'selling' an idea to management, marketing and sales teams. It was also suggested that more successful Ph.D.s in industry quickly adapt and gain an understanding of the industrial environment.

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 skills needed by industry and for the preparation level that the participants received in their doctoral program as seen in Tables 2 and 4. Higher mean values correspond to either better preparedness or higher skill level needed. The means of the essential skill levels needed by industry and the preparation level the participants received in their doctoral program were plotted to determine if there was a correlation. In Fig. 1 the essential skill level is on the x-axis, the essential skill preparation level is on the y-axis, and the numbers within the figure correspond to numbered skills listed in Tables 2 and 4. An analysis of the results suggests a correlation between the responses to the questions about preparation level and skill level needed. Spearman's correlation was used to determine the measure of a linear relationship between the essential skill level and the skill preparation level [45].

Table 4. Percentage distribution of preparation of essential skills for total population

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

Overall, the results indicate a linear correlation between level of preparation and skill level needed. This relationship is shown in Fig. 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 [46].

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 within the upper and lower tolerance lines is interpreted as a skill where the preparation level is appropriate for the skill level needed by an entry level Ph.D. in industry. 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.

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 that are less essential. Some of the skills where industry indicates a high skill level needed and participants indicated they were appropriately prepared include learning and working independently, communicating both orally and in written format, solving problems, designing experiments and working across disciplines. Several skills required a lower skill level and corresponded to a lower preparation. These include developing specifications, leading teams and optimizing processes or products. The interpretation is that, although less important, these are skills where the preparation level is in general appropriate for the entry level engineering Ph.D. employee.

Not all of the skills were within the two tolerance lines, and the analysis suggests several areas for improvement. Perhaps the most important is teamwork, because the survey results indicate teamwork as requiring a high skill level, yet it is associated with the greatest distance below the 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. Although the skill levels required for these skills are not as high as for teamwork, these are also areas to consider in attempts to better align Ph.D. preparation with the needs of industry.

If it can be assumed that doctoral preparation tends to emphasize skills important to the academic

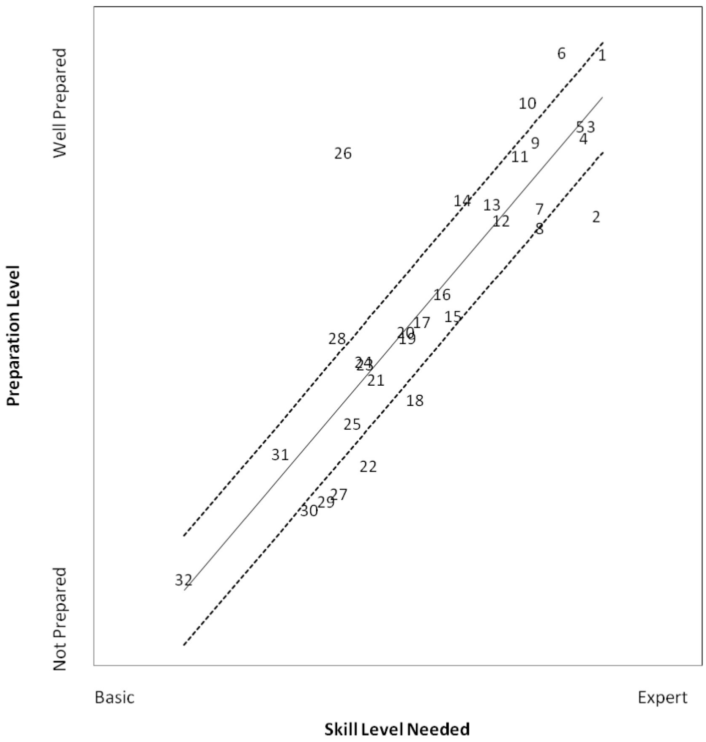

Fig. 1. Alignment of doctoral preparation with industry needs. (The numbers correspond to the question numbers in Table 2.)

work environment, then skills above the line may be interpreted as more important to academia. Likewise, skills below the line are more important to industry. For example in Fig. 1, a point (26) is associated with 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 results indicate that a relatively low skill level is needed. 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 areas in which Ph.D. programs more than adequately prepare graduates. They might also be potential areas to assess when evaluating the components of Ph.D. programs that prepare students for industry.

4.3 Similarities between different demographic groups

The industries that hire engineering Ph.D.s produce a wide array of products and processes. The employees are also diverse with different years of experience, disciplines, and gender. With this diversity it is important to understand the similarities and differences of the essential skills among different groups. Therefore, an analysis of participants' responses using the Mann-Whitney test was performed comparing different demographic groups to the general population. The Mann–Whitney test is a non-parametric test comparing two observations [45]. Non-parametric refers to samples that do not have a normal distribution, and opinions of human subjects using a Likert scale survey may not have a normal distribution. The Mann–Whitney test identifies the differences in the medians of two responses. The differences in the two medians are identified when the p-value is less than the alpha value. For this test, an alpha of 0.05 and a p-value equal or less than 0.05 give evidence that the two data samples are not equal.

4.3.1 By years experience

In order to determine if the skills needed in industry were biased by when the participant received his or her Ph.D., the participants responses were broken into three different levels of experience: 0–5 years of experience, 5–15 years of experience, and 15 or more years of experience and compared with the general population using the Mann–Whitney test. The analysis showed no statistical difference between the three different levels of experience, suggesting that the level of experience did not change the perspectives of the respondents on the skill requirements for entry level Ph.D.s in industry.

4.3.2 *By survey distribution groups*

In order to determine if the essential skills needed varied with company size; the participants were divided into two groups based on the likelihood of participants working in a large corporation or a small business: the Corporate group and Small Business group respectively. The levels of essential skills needed by the Corporate and Small Business groups were similar. Creating proposals and writing reports were the only skills that were statistically different between the two groups, and both of these skills seem to be more important in small businesses. Writing reports was considered an important skill for the Small Business group. An expert skill level was indicated as essential for an entry level position by 50% of the Small Business group. Less than 30% of the Corporate group indicated that it was essential be have an expert skill level in writing reports. Both groups indicated that Ph.D.s in industry need some skill in creating proposals, but 35% of the Small Business Group and only 12% of the Corporate Group indicated that an expert level was essential. Results suggest that Ph.D.s working in small businesses need a higher skill level in writing proposals. This phenomenon may be a result of soliciting responses from NSF SBIR awardees, who have to demonstrate success to communicate business plans in order to receive financial support.

4.3.3 *By discipline*

Participants came from various disciplines within engineering, as shown in Table 3. Because a significant number of participants indicated that their engineering discipline was mechanical, chemical, electrical or materials science, the survey responses from these disciplines were explored. In general, there was good agreement between the responses of these disciplines in terms of the skill level needed by entry level Ph.D. engineers. The only statistically significant difference was that chemical engineers indicated that following safety regulations was also an important skill. Following safety regulations had more than 40% of chemical engineering indicating that an expert skill level was needed, and none indicating that it was not essential. These results are significantly different from the total population, where 27.3% indicated that an expert skill level was needed and 5.5% indicated that it was not essential.

Among the different disciplines, the preparation level is generally in good agreement between the responses. Mechanical and chemical engineering had no statistically different responses from the total population. However, in some areas, the preparation that electrical engineers received during their doctoral program was statistically greater than the general population. For example, results from electrical engineering participants indicate 55% were well prepared and 0% were not prepared or indicated that teamwork was not applicable. The preparation level for solving problems and designing computational studies was statistically lower for materials scientists compared with the general population. Over 50% of materials scientists indicated that they were well prepared to solve problems; none indicated that the skill was not applicable, and only 3% indicated that they were not prepared. The preparation level of materials scientists for designing computational studies to be well prepared was indicated by 11%, not applicable by 7% and not prepared by 11% of the participants. The preparation level for following safety regulations was statistically higher for materials scientists compared with the general population. The preparation level to follow safety regulations for materials scientists was indicated to be well prepared by 27%, not applicable by 5% and not prepared by 16% of participants.

The data for chemical engineering, electrical engineering, materials science and mechanical engineering responses were also analyzed to compare the needs of industry with doctoral degree preparation. Similar to the total population, the Likert scale responses for the needed skill level and the preparation level were calculated for each of the skills and plotted. The needed skill level is on the x-axis, and the preparation level is on the y-axis. Each discipline had a positive linear correlation between the essential skills level needed in industry and the preparation level the participants received in their doctoral program (Figs 2–5). The Spearman's rank correlation coefficients ranged from 0.747 to 0.903 (Table 5) indicating a large effect size even though each discipline had several skills outside the tolerance lines [46]. Chemical engineering had the weakest alignment (effect size at 0.747), and electrical engineering had the strongest alignment (effect size of 0.903). The differences in correlation coefficients suggest that the alignment of doctoral education to the needs of industry may be different among disciplines in this study.

All disciplines indicated that teamwork and working independently require a high skill level for work in industry. Teamwork was below the lower tolerance line for mechanical engineering, chemical engineering and materials science, suggesting that these disciplines may not be adequately prepared to work in teams in industry. One the other hand, working independently was above the upper tolerance line for these three disciplines, indicating that doctoral students are more than sufficiently prepared to work independently. Both teamwork and working independently were between the tolerance lines for electrical engineers, suggesting that

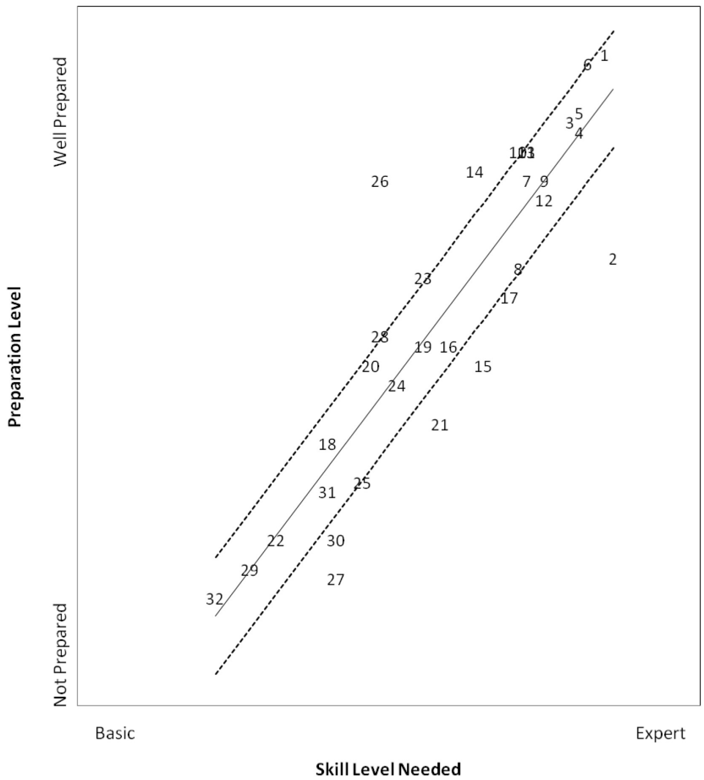

Fig. 2. Alignment of doctoral preparation with industry needs for mechanical engineers. (The numbers correspond to the question numbers in Table 2.)

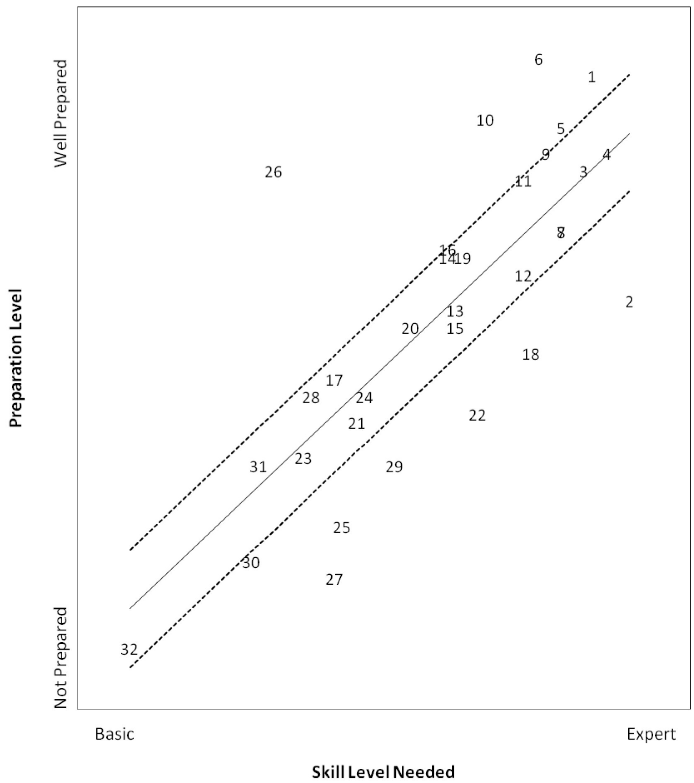

Fig. 3. Alignment of doctoral preparation with industry needs for chemical engineers. (The numbers correspond to the question numbers in Table 2.)

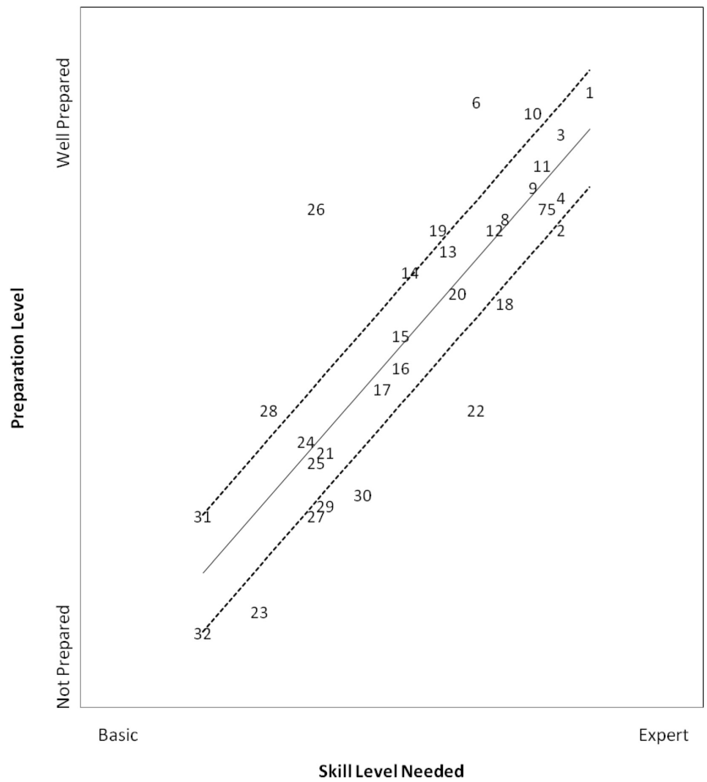

Fig. 4. Alignment of doctoral preparation with industry needs for materials scientist. (The numbers correspond to the question numbers in Table 2.)

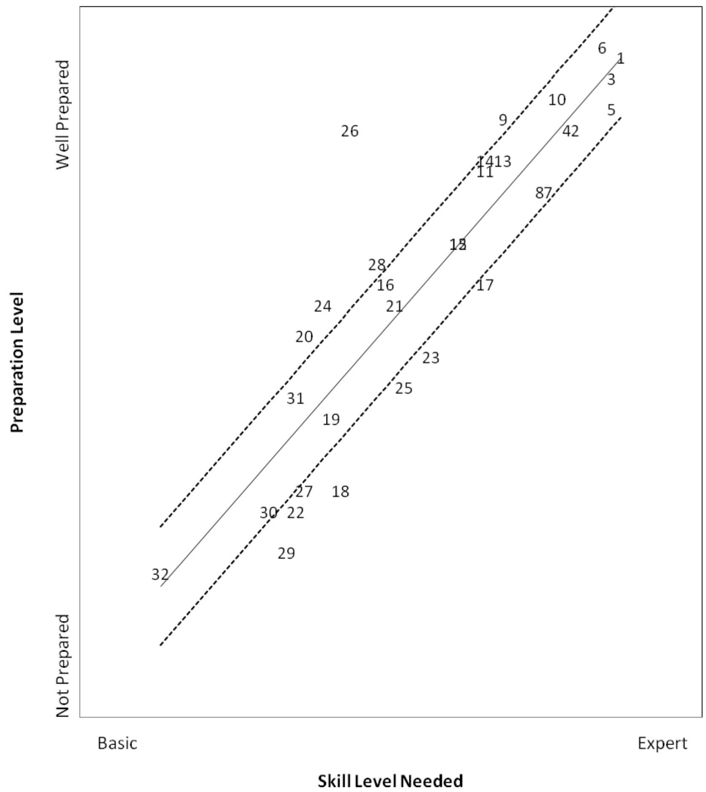

Fig. 5. Alignment of doctoral preparation with industry needs for electrical engineers. (The numbers correspond to the question numbers in Table 2.)

Table 5. Spearman's correlation of essential skill levels needed by industry and preparation level of survey participants received in their doctoral programs

	Spearman's ρ
All participants	0.852
< 5 years' experience	0.809
Small business	0.875
Corporate	0.809
Mechanical engineering	0.882
Chemical engineering	0.747
Materials science	0.836
Electrical engineering	0.903
Males	0.851
Females	0.874

electrical engineers are adequately preparing doctoral students to work in teams and work independently in industry. Thus, mechanical engineering, chemical engineering and materials science programs may want to reevaluate how doctoral students interact with others within their programs.

Communication skills are considered important skills for Ph.D.s to possess in industry. General oral and written communication skills were within the tolerance lines for mechanical, chemical and electrical engineering and materials science. The data suggest that engineering Ph.D.s. are more than sufficiently or sufficiently prepared to communicate in both written and oral formats within industry. For example, giving presentations was above the upper tolerance line for electrical engineers, suggesting that electrical engineers possess more than sufficient presentation skills. Meanwhile, giving presentations was between the tolerance lines for mechanical engineers, chemical engineers and materials scientists, indicating adequate preparation for the needs of industry.

For written communication skills, the relationship between the needs of industry and doctoral preparation is similar for mechanical, chemical, electrical engineering and materials science disciplines. Written communication skills, specifically writing reports, are within the tolerance line, indicating that Ph.D.s within these disciplines are adequately prepared to communicate in writing. However, writing peer-reviewed papers is the skill farthest above the upper tolerance line, suggesting that doctoral preparation of writing peer reviewed papers is more than adequate for the needs of industry. It could perhaps be inferred that the skills learned in writing the peer reviewed papers as a Ph.D. student are transferred to writing reports for industry.

Survey results indicate learning independently and solving problems are two of the most important skills for engineering Ph.D.s to possess when working in industry. These two skills were between the tolerance lines for mechanical, electrical engineering and materials science disciplines. Learning independently and solving problems are above the upper tolerance line for chemical engineers, indicating that chemical engineers may be more than adequately prepared in these areas. Other skills that are important for engineering Ph.D.s include designing experiments and innovating. They are also within the tolerance lines for all four disciplines in this study suggesting engineers within these disciplines are adequately prepared to learn independently and solve problems in industry.

Following safety and environmental regulations are two skills that fall below the lower tolerance line for chemical engineering, materials science and electrical engineering. It is important to note that although following safety regulations is below the lower tolerance line for chemical engineering, materials science and electrical engineering, chemical engineering requires a statistically higher skill level than the other disciplines and general population. The data suggests that following environmental and safety regulations are skills where Ph.D.s graduates in chemical engineering, electrical engineering and materials science are not adequately prepared. For chemical engineers, these results are supported by a recent report issued by the Council for Chemical Research stating that 'There is a very poor safety culture in academia relative to industry and government labs . . .' [12] .

4.3.4 By gender

With the many stereotypical differences between males and females, it is important to investigate the essential skills needed by both genders, and the perceived preparation level. Participants' gender did not statistically affect the indicated essential skill level needed by Ph.D.s in industry. Although not statistically significant, it is interesting to note that more than 55% of male participants indicated that an expert skill level was required for solving problems, and only 23% of the female population indicated an expert skill level was required for solving problems (though all females indicated that some problem solving skill level is essential). No females indicated that problem solving was not essential. The lack of statistical significance may be in part because of the small sample size of the female population (18 participants).

An investigation of the male responses indicated that the skill level needed and the preparation level were similar to the total population (Fig. 6). The skills were the same as those that were inside or outside of the tolerance lines for the total population as the male population, which was 84% of the population. A similar investigation of the female responses indicated that the female population reported several skills outside of the 0.25 tolerance

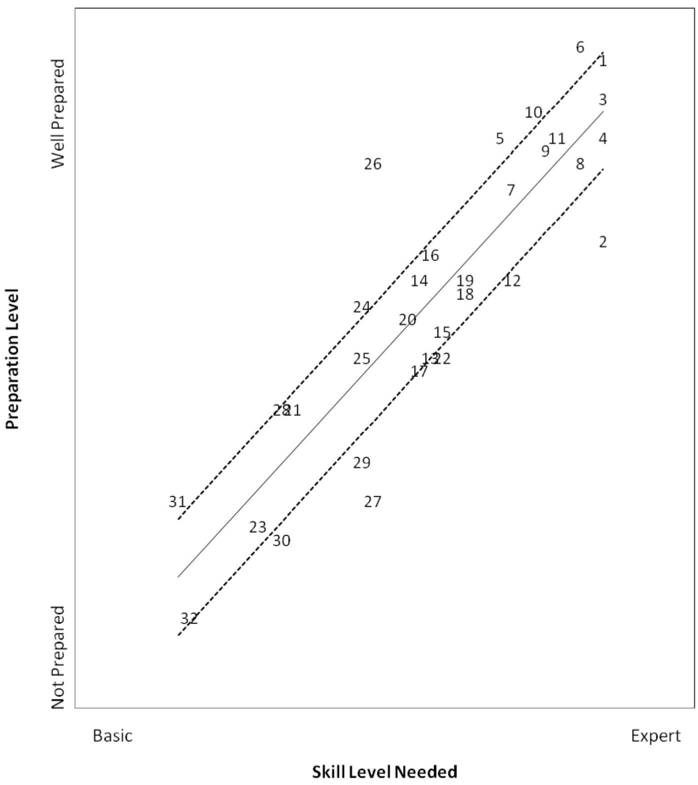

Fig. 6. Alignment of doctoral preparation with industry needs of female participants. (The numbers correspond to the question numbers in Table 2.)

lines that were within the tolerance lines for the general population (Fig. 6). For example, creating proposals and working across disciplines were skills that were below the tolerance lines for the female population but were within the tolerance lines for the total population. Managing others, managing resources and solving problems were skills that were above the tolerance lines for the female population. It is noteworthy that the skill level needed for managing others is less for females than males, which may suggest a difference in the responsibilities for males and females. This difference in the responsibilities for males and females is outside the scope of this study and should be addressed in future studies.

5. Discussion

The current work explored the skills and skill level industry desires in engineering Ph.D.s. Results of this study indicate that teamwork, oral and written communication, solving problems, and working independently are considered essential skills for engineering Ph.D.s working in industry. While these skills are important skills to develop in undergraduate programs, results suggest that they need to be reinforced in doctoral programs. This additional reinforcement may be particularly true for students who completed their undergraduate degree in countries that do not emphasize these skills in their undergraduate engineering programs.

These findings are in agreement with Sekhon's findings. Sekhon conducted a study that measured the importance skills of Ph.D.s working in industry with mathematically-intensive backgrounds, including engineering. His study took place in the late 1980s in Australia [18]. Additionally, the results from the current study indicate that practicing professional ethics, designing experiments, giving presentations, writing reports and reviewing literature are also considered important skills but were not mentioned in Sekhon's study.

Both this study and Sekhon's study explored the preparation level doctoral students receive for working in industry. The results of this study indicate that doctoral students were well prepared in learning independently, written and oral communication, solving problems and working independently. Sekhon's study indicated that written and oral communication, solving problems and working independently were developed only to an extent [18]. Unlike Sekhon's study, this study compared industry needs and doctoral degree preparation. Results indicate that overall doctoral programs prepare doctoral students sufficiently for employment within industry, however, students' preparation for working in teams could be considered a priority for improvement.

5.1 Engineering knowledge

Industry desires its engineering Ph.D.s to possess a high degree of engineering skills, including experimental research, problem solving skills and technical knowledge. Results from this study agree with previous studies and reports indicating that engineering Ph.D.s need to possess research and technical skills [2, 5, 7, 16, 17]. Research and technical skills were mentioned in 100% of the analyzed job descriptions. The specific skills and knowledge will vary among disciplines and jobs, but a high skill level is required as evidenced by the survey results. The results of this study indicate that Ph.D.s in industry are adequately prepared for the technical and research skills required by industry.

Problem solving skills are valued by industrial employers, as evidenced by 69% of the job solicitations mentioning problem solving, and as discussed in the works of Sekhon, Camporesi, Metcalfe and Cumming [2, 10, 14, 18]. Over 50% of the survey participants in this study indicated that engineering Ph.D.s working in industry need an expert problem solving skills, which is also supported by Sekhon [18]. This study suggests the preparation of engineering doctoral students problem solving skills is aligned with the needs of industry.

5.2 Teamwork

Teamwork is one of the major building blocks of research activity [47]. Industry places great importance on teamwork, as evidenced by the 68% of the job solicitations mentioning teamwork, and over 50% of the survey participants indicating that an expert skill level was essential for working in industry. Results suggest that one of the most significant areas for improvements in preparing doctoral students is related to teamwork. The analysis shows for the general population that teamwork was the skill furthest below the tolerance line but requires a high level of skill. The same trend (teamwork being furthest below the tolerance line) was found for mechanical and chemical engineering and materials science disciplines. The analysis also indicated that these three disciplines were more than adequately prepared to work independently. On the other hand, the analysis of electrical engineers suggested that they were appropriately prepared to work in teams and independently. It is suggested that perhaps the types of tasks required of electrical engineers working in a team lend themselves to working on a task individually. This suggestion supports research by Gratton and Erickson indicating that teams are more effective when members can work on separate, individual tasks yet feel that they are working toward a common goal [41].

5.3 Communication skills

Both oral and written communication skills are important for engineering Ph.D.s working in industry to possess. This is evident by 82% of job solicitations discussing communication skills, over 50% of survey participants indicating an expert skill level is required for Ph.D.s working in industry, and the studies of Sekhon, Griffin, Shaw and Griffith, [18, 47–49]. In general, the analysis of the preparation level of communication skills to the skill level needed in industry indicated that academia prepares doctoral students to communicate effectively. It is interesting to note that academia places more emphasis on the writing of peer reviewed articles than is essential for industry positions. While it is important to consider the emphasis placed on writing peer reviewed articles when trying to further align doctoral programs with industry needs, the skills gained by doctoral students that may be used when writing reports in industry cannot be ignored.

5.4 Validity, reliability and limitations of the study

Like any exploratory study, this one has limitations. The design of the job solicitation review is considered broadly indicative, rather than definitive, because it did not include on-campus recruiting, job solicitations posted at company websites, nor did it include those in printed media. Additionally, the United States was in a severe economic downturn during the time period (Fall 2009) when the job solicitations were collected. The skills needed for the posted jobs may have been different during this time from years prior and in the future. The job solicitations also may have described skills using 'buzz' words. The skills described using 'buzz' words may or may not be unique to engineering Ph.D.s in industry, but they may be valued by industrial employers in general. This phenomenon does not affect the reliability of the findings from the survey. It does, however, introduce the possibility, that there may be valuable skills that were not included in the survey items.

Another limitation is that the survey was distributed using the snowballing technique. Thus, the survey response rate is unknown. Another limitation of the snowballing technique is that it may lead to a bias because the initial contacts are known and trusted by the 'snowball group.' The close associations between the initial contacts and the 'snowball group' may cause the sample to be homogenous [50]. Another limitation is that researchers cannot be 100% certain that the survey was taken by the target population. Survey participants were asked their highest degree obtained and their field of engineering, but respondents could have self-reported incorrectly.

In an attempt to address the validity and reliability of the survey findings, phone interviews were conducted with three of the survey respondents. The respondents were identified as follows. A final question on the survey offered the participants who provided contact information a copy of a report of the findings. A two-page report containing Fig. 1 was sent by e-mail to those who requested it. The e-mail contained an invitation to discuss the findings with one of the researchers. Of the three who volunteered, two worked in a large corporation and one in a small business. All were male. The volunteers discussed the skills needed by Ph.D. engineers who work in industry. The volunteers affirmed and elaborated on several of the findings from this study, particularly in the areas of teamwork, regulations, and peer-reviewed papers. A brief summary of each discussion follows.

One volunteer from a large corporation reviewed the report and showed it to another engineering Ph.D. with whom he works. Both men felt the study was an accurate portrayal of their graduate studies, experiences, and current organization. The volunteer stated that his university did not prepare students well to work in teams, follow environmental and safety regulations, or teach them about intellectual property processes. He further stated that industry values documentation, but the Ph.D.'s time is too valuable to spend an excessive number of hours documenting something when they could be working on something else. Also a lot of the research within his company cannot be sent out for peer reviewed papers. They have to protect their intellectual property, and the information may contain company secrets.

A second volunteer from a large company said that he knows many Ph.D.s whose graduation has been delayed because of the school's or advisor's requirement that they write/publish a journal article. He says a lot of emphasis is placed on writing peer reviewed articles in academia. Since completing his Ph.D. in 2003, he has written two peer reviewed papers with his doctoral advisor and no other papers. In his current position, most of his research cannot be released to the public, though writing peer reviewed articles is not frowned upon.

The volunteer from the small business felt that academic work is always important, but industry is more interested in creating products based on the learning in academia. Research in academia is learning things for the sake of knowledge and understanding the problem. Academic papers are important in doctoral programs because students develop basic reasoning and knowledge. He stated that peer reviewed papers are not emphasized in industry because industry does not need the external opinions to validate ideas. He predicted that, in the future, the data point for writing peer reviewed papers in Fig. 1 will move farther from the best fit line.

This exploratory study's results indicate that, overall, academia adequately prepares doctoral students to work in industry, but the analysis suggests several areas that could be improved, with perhaps the most needed attention being teamwork skills. In order to improve teamwork skills of doctoral students, a greater understanding of the industrial research environment, including the role of teamwork, is needed. With this understanding, effective strategies in Ph.D. programs may be developed to further align doctoral student preparation with industry needs.

6. Conclusions

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 and have a strong effect size, though the effect size varied between disciplines. The strong correlation indicates that overall academia appropriately prepares doctoral students for industry positions. It also implies that many of the skills valued by industry are also important for working in an academic environment. There are some exceptions, however, the most important being teamwork.

Teamwork is one of the most significant areas for improvement in preparing doctoral students. It is an important part of the industrial researcher's position, yet the necessity of demonstrating independent work during PhD preparation practically excludes the opportunity to develop teamwork skills. Additionally, following safety regulations is an area with significant room for improvement for chemical engineering doctoral programs. Other areas for improving the preparation of all engineering doctoral students include following environmental and safety regulations, understanding intellectual property processes and identifying customer needs, although the skill level required is not as high as for teamwork.

Improving teamwork skills of graduates from engineering Ph.D. programs that emphasize independent work and individual accomplishments will require careful consideration. This study suggests that industry places great importance on interdisciplinary teamwork, yet interdisciplinary teamwork is not traditionally emphasized in engineering Ph.D. programs. The Ph.D. degree inherently requires some degree of independent accomplishment in order to develop critical thinking skills and technical knowledge. Interdisciplinary coursework with required team projects could be explored as a way to develop interdisciplinary teamwork skills in engineering doctoral students. There are several obstacles to creating and implementing interdisciplinary coursework at the graduate level including: convincing students and professors that the course is valuable, determining who teaches the course, and determining how tuition is distributed among departments. Another obstacle includes convincing other disciplines of the value such course would bring to their students. Programs that develop interdisciplinary teamwork for engineering doctoral students, such as IGERT, have been developed but are typically grant supported.

Results suggest that academia emphasizes some skills more than industry does, such as writing peer-reviewed papers. However, this study does not want to dismiss the importance of having engineering doctoral students write peer-reviewed papers even if they plan to pursue careers in industry. Results from this study imply that the process of writing peer-reviewed papers develops students' written communication skills and critical thinking skills, both of which are valued by industry. Even through a doctoral student may not write another peer-reviewed paper after graduation because he or she works in industry, the skills gained through writing a peer-reviewed paper are critical to an engineering Ph.D.s success in industry.

With the emergence of globalization and multidisciplinary advances, doctoral students need the skills and dexterity required to orchestrate the challenges of discovery, innovation and entrepreneurship of industry. Results from this study may be used to enhance future efforts to further align engineering Ph.D. preparation with industries' needs in order to maintain historical excellence in engineering doctoral education.

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