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Joy Watson is currently a STEM education consultant working with private industry, academia, and the U.S. Navy to develop a logistics/IT course for low-income, high potential middle and high school students. She completed her Ph.D. in the College of Engineering at the University of South Carolina in Aug. 2011. She obtained her B.S. and M.S. in chemical engineering from the University of Tennessee, Knoxville. Before entering the doctoral program, she worked as a process engineer in the pulp and paper industry and as patent examiner at the U.S. Patent and Trademark Office. At the University of South Carolina, Watson worked in two different middle school classrooms as a NSF GK-12/Pi Fellow. While at the University of Tennessee, she participated in the co-op (industrial internship) program and was appointed a co-op ambassador to mentor undergraduate students pursuing industrial internships. She also has mentored undergraduate research assistants during her master’s and Ph.D. programs. Her primary research interests include preparing doctoral students for industry and academic careers and the rheology of ionic liquids and cellulose solutions.

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Perceptions of Engineering Doctoral Programs

Abstract

The broad objective of this study is to determine the expectations that potential Ph.D. candidates have of engineering doctoral programs. This objective was accomplished by surveying over 150 potential engineering Ph.D. candidates, including undergraduate engineering students and engineers who had completed their undergraduate degree. Participants were asked to rate how well they thought a Ph.D. program would prepare them in a number of areas. Participants were also asked to rate the extent that they were interested in various components of typical and non-typical Ph.D. degree programs. Results indicated that participants felt that doctoral programs would be prepared to do almost everything on the survey, including things not typically taught. In response to a question about challenges to pursuing a Ph.D., potential Ph.D. candidates frequently mentioned financial concerns, and often stated that they “did not want to teach” reflecting a lack of understanding that the doctoral degree is relevant to industrial jobs. Results from this study can be used to inform doctoral programs and enhance the recruitment efforts of engineering doctoral students in the United States.

1. Background

The traditional expectation of engineering Ph.D. students is that they will become scholar-teachers at a research university or researchers in an academic or a national lab, performing basic research\(^1\)\(^-\)\(^3\). However, in 2006, over 70% of doctoral recipients in engineering did not hold positions in academia. Approximately 55% were employed in the for profit sector, 7% were in government, 4% were in private non-profit institutions, 4% were self-employed, and 4% were in other areas of employment according to NSF Division of Science Resources Statistics\(^4\). Previous work has shown that overall engineering doctoral students are well prepared in many of the skills desired by industry and has analyzed how academia develops these skills in their engineering doctoral students\(^5\)\(^-\)\(^7\).

Doctoral education in the United States prepares the next generation of highly skilled workers while creating new knowledge vital to US competitiveness in a global knowledge-based economy\(^8\). The technological innovation of the US is quickly eroding unless current trends are reversed\(^9\). The percentage of American students pursuing Ph.D.s in engineering has declined from 70% in 1985 to 55% in 2005\(^10\). Yet, only 64% of students who begin engineering doctoral programs complete their degrees within a ten year period according to the Council of Graduate Schools\(^11\). Research shows that doctoral students leave these programs because it was a “wrong fit” suggesting that incoming doctoral students may have misconceptions about the Ph.D. programs\(^13\).

2. Methodology

The broad objective of this study is to determine the expectations that potential engineering Ph.D. candidates have of engineering doctoral programs. This objective was accomplished by surveying over 150 potential engineering Ph.D. candidates including undergraduate engineering students and engineering bachelorette degree holders. The survey consisted of two parts. The first part was based on a list of 32 skills Ph.D.s may need in industry. Each participant was
asked to rate how well they thought a Ph.D. program would prepare them in each skill. The
second part contained a list of techniques used in doctoral education, and participants were asked
to what extent they were interested in each technique. The initial draft of the survey was
reviewed by a content review panel, which consisted of a senior mechanical engineering student
and an electrical and computer engineering freshman. The final survey was created with Class
Climate®, an online survey tool.

The first part was based upon a list of skills seen in Table 1. This list was developed in previous
research through a review of advertised job solicitations for industry positions requiring an
engineering Ph.D. 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 root for the first question was:

*Listed below are abilities that may be essential for Ph.D.s in industry. Please mark how
well you think a Ph.D. programs prepares students in the following areas.*

This root was followed by the list of skills. A two-pole, four choice Likert-like scale was
provided for responding about each skill. Participants were given the choices “Does Not
Prepare”, “Barely Prepares”, “Moderately Prepares” and “Prepares Well”.

The second part contained a list of techniques used in doctoral education as see in Table 2. The
list of techniques was developed through a systematic program review of engineering doctoral
programs in the United States. It consists of common techniques found in doctoral programs
such as independent research and major area coursework. Also included were techniques less
frequently found such as industrial internships. Participants were asked to rate the extent that
they were interested in each component listed. The root of the second question was:

*Below is a list of possible components of a Ph.D. program. If you were to pursue a Ph.D.
in engineering, to what extent would you be interested in each of these components?*

Again, a two-pole, four choice Likert-like scale was provided for responses. The terms “Very
Interested”, “Moderately Interested”, “ Barely Interested” and “Not Interested” were provided as
choices. The option to select “Do not know what this is” was also given. The survey also
included an open-response question asking participants what would make an engineering Ph.D.
more attractive them.

Potential Ph.D. candidates in engineering were the target population for this survey. Current
students and alumni associated with various engineering programs in the southeastern United
States were asked to participate. The total number of participants was 167, with 99 still
pursuing their undergraduate degree and 68 having previously completed their undergraduate
degree.
3. Results

3.1 Expectations of Skills Developed in Engineering Doctoral Programs

To determine the level of preparedness expected from engineering doctoral programs, participants were asked to rate how well they felt engineering doctoral programs would prepare them in different skills shown in Table 1. Results indicated that participants felt that doctoral graduates would be prepared to some degree in all the skills listed in Error! Not a valid bookmark self-reference. Over 70% of participants felt that doctoral programs would prepare them well in designing experiments. Results indicated that over 60% of participants felt that doctoral programs would prepare them well in written communication, reviewing literature, writing peer-reviewed papers, writing reports, learning independently and working independently. At least 50% of participants indicated that solving problems, designing computational studies and giving presentations were skills in which they expected to be well prepared in doctoral programs. Less than 15% of participants felt that doctoral programs would not prepare them to market products/processes, identify customer needs, lead teams, manage others, and demonstrate business etiquette.

The potential Ph.D. candidates who participated in the survey can be divided into two distinct groups: current undergraduate engineering students and engineering alumni. Thus, each group’s results were analyzed. Current engineering undergraduate students were asked how well doctoral programs prepare graduates in skills that were potentially valued by engineering Ph.D.s in industry. The distributions of responses for each skill are seen in Error! Not a valid bookmark self-reference. More than half of the undergraduate students thought that doctoral programs would well prepare them to design experiments, communicate in writing, give presentations, review literature, write peer reviewed papers, write reports, learn independently and work independently. Over 40% of the undergraduate respondents believed that doctoral programs would prepare them well in the following areas: innovation, finding problems, design computational studies, follow environmental regulations, work across disciplines, create proposals, work in teams and manage multiple projects. Approximately 12% of undergraduate participants felt that doctoral programs would not prepare them for marketing products/processes and identifying customer needs, but most participants indicated some degree of preparation in these and all skills.

Engineering bachelorette degree holders were also asked how well engineering doctoral programs would prepare them for skills that were potentially valued by industry. The distributions of responses for each skill are shown in Error! Reference source not found.. Responses showed that more than 50% of alumni believe that doctoral programs would prepare them well to solve problems, design experiments, design computational studies, communicate in writing, give presentations, review literature, write peer reviewed papers, write reports, learn independently and work independently. Over 40% of alumni believed that doctoral programs would prepare them well in communicating orally and creating proposals. More than 20% of alumni felt that doctoral programs would not prepare them to market products/processes, manage others and demonstrate business etiquette. Over 10% of the alumni felt that doctoral programs would not prepare them to identify customer needs, work across disciplines, communicate orally, lead teams, mentor others and manage resources.
3.2. Interest in Techniques Found In Engineering Doctoral Programs

All participants were also asked to indicate the interest level of different techniques found in engineering doctoral programs seen in Table 2. In Figure 4, over 50% of potential Ph.D. candidates indicated they were very interested in major area coursework, industrial internships and attending conferences. On the other hand, less than 15% of participants indicated they were very interested in online training and qualifying exams.

The results of each group were also analyzed. Over 95% of the undergraduates indicated that they understood each component listed in Figure 5 along with the interest level of each component. Over 50% of the undergraduate participants indicated that they were very interested in industrial internships, attending conferences and major area coursework. More than 40% of them indicated that they were very interested in research assistantships. Less than 20% of undergraduate students were very interested in online training, seminars on non-technical skills and qualifying exams.

Over 98% of the alumni working in industry indicated that they understood each technique as seen in Figure 6. Over 50% of participants with their bachelor’s degree indicated that they were very interested in major area coursework and industrial internships. Over 40% of participants working in industry with their bachelor’s degree indicated that they were very interested in independent research, giving presentations, teaching assistantships, research assistantships and attending conferences. Less than 5% indicated that they were not interested in minor area coursework, major area coursework, giving presentations. These results have implications for how doctoral programs are advertised in graduate handbooks.

3.3. Making Doctoral Programs More Attractive to Potential Ph.D. Candidates

Potential Ph.D. candidates were asked what would make an engineering Ph.D. degree more attractive to them. The two themes that emerged from coding responses to this question include the ability to have “real world experience” and financial matters. “Real world experience” was indicated by 5 students and 10 alumni as attractions to doctoral programs. Participants indicated that they felt a doctoral degree in engineering would result in them being out of touch with the “real world.” They wanted authentic experiences on the application of the theoretical knowledge gained in doctoral programs. One participant elaborated by stating that doctoral programs with close relationships to industry and/or government agencies would make a doctoral program more attractive. It should be noted that in the European Union, engineering doctoral programs have been successful in allowing doctoral students to work closely with industrial partners. However, there are concerns about 1) guidance of the student 2) intellectual property and 3) the amount of time students require to meet industry’s expectations.

Another common theme centered around financial concerns, including financial assistance for school and the return on investment completing their doctoral program. Both alumni and students voiced these concerns equally. For example, potential Ph.D. candidates indicated they would be interested in pursuing a Ph.D. if “tuition cost less” or they had “significant financial assistance”. Yet, according to NSF’s Science and Engineering Indicator, approximately two-
thirds of science and engineering graduate students receive support of their graduate studies, most often as research assistants. From applicants’ responses, it was unclear if they were not aware of the support often available to them through research assistantships or perhaps they were not willing to live on the traditionally low stipend of a graduate student for multiple years.

Another financial issue raised by potential doctoral candidates was their return on investment. One person stated “a Ph.D. program is not attractive because it does not have a good return on investment. I do not believe that the cost and time spent will provide a significant increase in earnings or satisfaction.” This sentiment was mentioned by 5 other survey participants. Akay also discussed the lack of return on investment for engineering Ph.D.s when compared to the amount of time invested in the degree and the differences in compensation and opportunities to advance compared to a master’s in business administration or juris doctor (law degree).

4. Discussion

The design of this survey allows for a comparison between the expectations of two different populations of potential Ph.D. candidates. Current undergraduate students, more so than baccalaureate degree holders, indicated that doctoral programs would well prepare them in skills that are not traditionally part of doctoral programs such as working in teams, leading teams, managing others, managing resources and managing multiple projects. However, alumni indicated that doctoral programs would well prepare them in areas where doctoral programs traditionally well prepared doctoral students, such as, designing computational studies, reviewing literature, writing peer-reviewed papers and working independently. This contrast suggests that undergraduate students have less understanding of the skills a doctoral program will give them than baccalaureate degree holders. This suggestion is reinforced by comments undergraduate students made in the open response question that asked what would make an engineering doctoral program more attractive. For example, three participants explicitly stated that they thought the only thing a Ph.D. is prepared to do is teach. They further explained that they had chosen not to pursue a doctoral degree because they did not want to limit their career options to academia. Another participant stated that a doctoral program would be more attractive if there was “...the ability to work with the advisor to customize courses and content to best suit their research.” These comments imply that undergraduate students, more so than baccalaureate degree holders, do not understand the career options of a Ph.D. and how a doctoral program prepares them for careers outside of academia.

The student and alumni interest in different components in doctoral programs was also compared. Students indicated more interest in attending conferences than their counterparts working in industry, which may indicate that they understand the need to develop professional networks while alumni have already established networks. However, alumni were more interested in giving presentations which may suggest that they have seen the need for oral communication skills and reinforcing the result that they expected doctoral programs to well prepare them to communicate orally.

Alumni indicated more interest in minor area coursework suggesting an understanding of the need for breadth of knowledge in industry. Alumni were also more interested in online training than their undergraduate counterparts. This phenomenon may be due in part to responsibilities
outside of their education such as a family, and online training allows the alumni group more flexibility.

5. Conclusion

Results indicate that baccalaureate degree holders have a better understanding than undergraduate students of the skills an engineering Ph.D. possesses at the end of a doctoral program. The alumni population showed a stronger interest in online coursework while it was the least desired learning option for the student population. Both groups had financial concerns about how to pay for a doctoral program and if the additional time and money spent on education was worth the investment. Results from this study can be used to inform doctoral program and enhance the recruitment efforts of engineering doctoral students in the United States.

Acknowledgement

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Table 1: Skills Included on the Survey of Potential Ph.D. Candidates

<table>
<thead>
<tr>
<th>Learn independently</th>
<th>Create proposals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work in teams</td>
<td>Follow safety regulations</td>
</tr>
<tr>
<td>Communicate in writing</td>
<td>Provide technical support</td>
</tr>
<tr>
<td>Communicate orally</td>
<td>Optimize products/processes</td>
</tr>
<tr>
<td>Solve problems</td>
<td>Lead teams</td>
</tr>
<tr>
<td>Work independently</td>
<td>Follow environmental regulations</td>
</tr>
<tr>
<td>Design experiments</td>
<td>Design computational studies</td>
</tr>
<tr>
<td>Practice professional ethics</td>
<td>Manage resources</td>
</tr>
<tr>
<td>Give presentations</td>
<td>Develop specifications</td>
</tr>
<tr>
<td>Review literature</td>
<td>Write peer-reviewed papers</td>
</tr>
<tr>
<td>Write reports</td>
<td>Understand intellectual property processes</td>
</tr>
<tr>
<td>Work across disciplines</td>
<td>Mentor others</td>
</tr>
<tr>
<td>Innovate</td>
<td>Scale-up systems</td>
</tr>
<tr>
<td>Find problems</td>
<td>Identify customer needs</td>
</tr>
<tr>
<td>Manage multiple projects</td>
<td>Manage others</td>
</tr>
<tr>
<td>Demonstrate business etiquette</td>
<td>Market products/processes</td>
</tr>
</tbody>
</table>
Figure 1: Percentage distribution of how well potential Ph.D. candidates think doctoral programs prepare students. (1=Does Not Prepare, 2=Barely Prepares, 3= Moderately Prepares, 4= Prepares Well).
Figure 2: Percentage distribution of how well undergraduate students think doctoral programs prepare students. (1=Does Not Prepare, 2=Barely Prepares, 3= Moderately Prepares, 4= Prepares Well).
Figure 3: Percentage distribution of how well baccalaureate degree holders think doctoral programs prepare students. (1=Does Not Prepare, 2=Barely Prepares, 3= Moderately Prepares, 4= Prepares Well).
Table 2: List of Techniques Used in Doctoral Programs

<table>
<thead>
<tr>
<th>Independent Research</th>
<th>Seminars of Non-Technical Skills</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualifying Exams</td>
<td>Teaching Assistantships</td>
</tr>
<tr>
<td>Give Presentations</td>
<td>Research Assistantships</td>
</tr>
<tr>
<td>Major Area Coursework</td>
<td>Industrial Internships</td>
</tr>
<tr>
<td>Minor Area Coursework</td>
<td>Attending Conferences</td>
</tr>
<tr>
<td>Seminars on Research</td>
<td>Online Training</td>
</tr>
</tbody>
</table>
Figure 4: Percentage distribution of baccalaureate degree holders' and students' interest level of doctoral components. (0=Does not know what this is, 1=Very Interested, 2=Moderately Interested, 3= Barely Interested, 4= Not Interested)
Figure 5: Percentage distribution of undergraduate students’ interest level of doctoral components. (0=Does not know what this is, 1=Very Interested, 2= Moderately Interested, 3=Barely Interested, 4= Not Interested)
Figure 6: Percentage distribution of alumni’s interest level of doctoral components. (0=Does not know what this is, 1=Very Interested, 2=Moderately Interested, 3=Barely Interested, 4=Not Interested)
Bibliography