International Institute for Engineering Education Assessment

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IN THIS ISSUE

WHO WE ARE

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An Examination of Graduate Education's Role in Preparing Engineering Students for Careers in Academia and Industry: A CAREER Grant Research Overview

Introduction

The Faculty Early Career Development (CAREER) program is a 5 year grant awarded by the National Science Foundation to junior faculty who best integrate education and research. We were awarded a CAREER grant (NSF grant #0747803) to investigate engineering graduate students and then to apply our research findings into deliverables faculty and others can use to prepare doctoral students more effectively for careers in academia and industry.

In recent years, many studies and reports have highlighted concerns and problems with engineering doctoral degree recipients. Criticisms have come from professionals in both industry and academia, as well as from current and former PhD students. Given the dissatisfaction of a variety of stakeholders, there have been calls from professional societies, disciplinary bodies and federal agencies to improve doctoral granting programs across the U.S. and to educate PhDs who are equipped with skills and attributes necessary to meet the highly-competitive and rapidly changing 21st century workforce[1,2]. However, there is little research on what skills and attributes engineering PhDs need in order to be successful in industry or academia.

Using a three-phase, mixed-methods approach, the goals of this research were to (1) identify, within academia and industry, the norms, skills, and attributes that engineering graduate students must embrace within a changing academy and society; (2) design, pilot, and validate an assessment tool that represents both the academic and industrial perspectives of these norms, skills, and attributes; and (3) evaluate the relationship between students' professional development

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Diana Bairaktarova, PhD, is an Assistant Professor of Engineering Practice in the College of Engineering at The University of Oklahoma. She completed her PhD in Engineering Education from Purdue University with a dissertation focused on the efficacy of mechanical objects in engineering learning. Diana holds BS and MS degrees in Mechanical Engineering from Technical University in Sofia, Bulgaria and an MBA degree from the Hamline School of Business, St. Paul, Minnesota. Diana has over a decade of experience working as a Design Engineer.

experiences within graduate study and their acquisition of norms, skills, and attributes needed for careers within industry and academia. We integrated research and education via the development of course modules and print materials reflecting research findings, the implementation of these modules in graduate engineering seminars and courses, and the involvement of undergraduate and graduate students in data collection, data analysis, and module development over the 5-year project.

> "Many Ph.D. recipients are ill-prepared to function effectively in the settings in which they work."[5]

Why study engineering PhDs?

In the future, U.S. engineers will increasingly represent a smaller percentage of the engineering profession[2]; therefore, U.S. engineering universities will have to compete more aggressively to attract engineers to conduct university research. Currently, however, engineering education researchers point to a competency gap between the performance expected of an engineer and engineers' actual performance resulting from a misalignment of which skills are taught and which skills are needed.

Research shows that industry values technical competencies more and is mostly satisfied with the engineers" technical abilities[3,4]. However, both engineering industries and the engineers themselves have pointed to the lack of "soft skills" or "professional skills" (e.g., communication, team work, leadership, management abilities, and lifelong learning) in engineers. This need has thus far been addressed superficially with seminars, minor curriculum changes, or on-the-job practice, but in order to maintain the standards and success of engineering higher education institutions, immediate focus on the recruitment and retention of engineering doctoral students within U.S. institutions is needed.

Moreover, the literature on preparedness of PhDs, as limited as it is, focuses on the PhDs in academic track and their ability to function as academics in college environments. According to Golde and Walker (2006), "Many PhD recipients are ill-prepared to function effectively in the settings in which they work" (p. 5). Comprehensive research on the preparedness of PhDs is needed so that engineering institutions of higher learning can best prepare their students for whichever job sectors in which they will work, be they academic, industrial, or governmental.

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Catherine G.P. Berdanier is a PhD student in the School of Engineering Education at Purdue University. She earned her BS in Chemistry from The University of South Dakota and her MS in Aeronautical and Astronautical Engineering from Purdue University. Her current research interests include graduate-level engineering education, including inter- and multidisciplinary graduate education, innovative and novel graduate education experiences, global learning, and preparation of graduate students for future careers.

Sara Branch, PhD, obtained a BA from the University of Portland and a MS and PhD from Purdue University. Her research interests focus on how dispositional and situational factors influence motivation in the domains of academic and career choices. She currently works as an assistant professor of psychology at Hobart and William Smith Colleges.

Our Research Goals

In response to the limitations of previous studies, we set out to examine ways that current educational practices help graduate students to embody the norms, attributes, and skills needed by future engineers working in academia and industry in the U.S. Our research objectives were as follows: (1) to identify, within academia and industry, the norms, skills, and attributes that engineering graduate students must embrace given that the half-life of an engineer's knowledge is estimated to be less than 5 years; (2) to design, develop, and validate an assessment tool that represents both the academic and industrial perspectives of these engineering norms, skills, and attributes; (3) to evaluate the relationship between students' professional development experiences within graduate study and their acquisition of norms, skills, and attributes needed for careers within industry and academia.

Using this research, we hoped to translate the findings of into deliverables that would enhance the professional development of engineering graduate students and undergraduate students with the potential to pursue graduate study. This has been achieved through the following objectives: (1) the development of interactive modules and print materials that introduce engineering faculty, current graduate students, and undergraduate researchers with interests in graduate school to the norms, skills, and attributes that are needed of engineers within a changing society and academy; (2) the development of interactive mentoring workshops that allow students to reflect upon their acquisition of these norms and give them opportunities to create personal development plans for broad career preparation within engineering; (3) the revision of graduate seminars within engineering education and traditional engineering disciplines to include modules developed within this research; and (4) the involvement of undergraduate researchers in this project so that they gain multidisciplinary research experiences and begin to reflect upon ways that they can be prepared more broadly within engineering.

Main Findings

Career trajectories

Curricula vitae (CVs) of more than 30 PhD-holding engineers were divided into four categories: academia-only careers,

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Jeremi London, PhD, obtained a BS and MS in Industrial Engineering and a PhD Engineering Education from Purdue University. Her research focuses include education policy issues surrounding the role of cyber-learning in undergraduate science, technology, engineering, and mathematics (STEM) education; characterizing and measuring the impact of federal investments in STEM education research; and applications of simulation & modeling tools to conduct undergraduate STEM education curriculum evaluation. As of Fall 2014, she will be a post-doctoral researcher at Arizona State University.

industry-only careers, and those of engineers who had transferred from academic careers to industry, and industry-to-academia. The CVs were then analyzed to determine common career trajectories for engineering PhD-holders.

Participants in academia tended to hold multiple positions as shown in academia-only, industry-to-academia and academia-to-industry groups. These observations suggest the flexible nature of positions in academia and also the potentially high work load for faculty members. However, as suggested by our findings, the flexibility and the commitment to multiple appointments could also mean a high workload and the need to balance teaching, research, community service, and leadership responsibilities. Most of participants held some type of leadership position at some time of their career across the four groups in our study.

This highlights the significance of leadership in engineering PhDs. PhD-holders are considered to be the leading force for knowledge-based economies[8]. Multiple engineering educators have started to focus on the leadership qualities of engineering graduates[5,10]. Our findings here emphasized the importance to promote leadership trainings in engineering graduate programs to facilitate their future career development.

Curricula vitae and stewardship

The same CVs were then used to see how Golde and Walker's stewardship framework[5] would fit engineering, based the number of occurrences of stewardship tenants in each CV. Golde and Walker[5] described generation as "the ability to conduct research and scholarship that make a unique contribution and meet the standards of credible work" (p.10). This definition of generation within the context of engineering as presented within the CVs was operationalized in several ways. Generation was demonstrated via descriptions of academic and industry job titles (professor, researcher, director, etc.); awards and honors that demonstrate advancement in the field; scientific accomplishments as an individual or in research group, research initiation, and promise; publications in journals, books, conference proceedings, or technical briefs; grants in which participants served as a principal investigator (PI) or Co-PI, and authorship as first or contributing author.

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JD McClurkin, MSABE, is a PhD candidate at Purdue University in Agricultural and Biological Engineering. She received her Bachelor of Science degree in BioEnvironmental Engineering from North Carolina A&T State University and MSABE in Agricultural and Biological Engineering from Purdue University. While in the doctoral program, she served as a research assistant on a project understanding Shelf-Life Improvement of Distillers Wet Grains with Solubles (DWGS).

Nikitha Sambamurthy is pursuing a PhD in Engineering Education at Purdue University. Her research interests include blended-learning in science, technology, engineering and mathematics (STEM) education, and the implementation and assessment of games for engineering knowledge transfer. She received a BS in Electrical Engineering from Purdue University.

Some differences were found in how generation was operationalized within academia and industry. Within academia, publishing often occurred at national and international disciplinary engineering conferences with some generation involving publications in non-engineering areas related to science, technology, engineering, and mathematics (STEM) education, pedagogical research, graduate and undergraduate course development, engineering outreach, and increased representations of women and minorities in engineering. Publications in industry, on the other hand, often resulted in internal company publications and journals. Major generation tasks within industry also related to leading process development and technology; analyzing technical analysis; and engaging in disciplinary engineering tasks.

Most of our participants in industry had quite higher representations of generation compared to the other two tenets in the stewardship framework, which may be due to the fact that it is critical to engineering companies to develop new technology and new products within the constraints of time and cost. This observation suggests the importance for professionals who are entering the industrial environment to be innovative and adaptive in developing new technology, products, or services.

Conservation involves the maintenance of "the continuity, stability, and vitality of the field" (Golde & Walker, 2006, p. 11). Tasks of conservation across CVs were noted by descriptions of academic and industry job titles (the teaching component of an academic title, information management, etc.); serving as a referee of journal and conference papers; and obtaining awards and honors that suggest participants' critical impact in a field, their scientific accomplishments individually or within a research group, or mentorship. Also included was participation in professional disciplinary organizations as a panel lead or reviewer for research projects or as a contributing member (i.e., officer, non-officer, or advisor) within national, regional, or local organizations. Other aspects of conservation included the supervision of students (includes high school, undergraduate, and graduate students as well as post docs and research associates) and thesis committees along with training certifications.

We found that participants with work experiences in academia demonstrated higher instances of conservation than participants with work experiences only in industry.

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Anne Tally is an undergraduate researcher pursuing a BA in Linguistics and a BS in Informatics from Indiana University. Her interests include sociolinguistics, social informatics, and interdisciplinary research. She hopes to pursue a PhD in Sociology after graduating in 2015.

Tasha Zephirin is currently a participant in the National Science Foundation sponsored Integrative Graduate Education and Research Training in Magnetic and Nanostructured Materials (IGERT-MNM) program-a collaborative effort between Purdue University, Cornell University and Norfolk State University. Her research interests include the development, evaluation, and assessment of co-curricular and extra-curricular STEM programs to diverse audiences across the education continuum (e.g. community members, K-12 students, undergraduate students, graduate students, and industry professionals) in varying contexts. She holds a BS in Electrical Engineering from Virginia Tech.

This might be a result of institutions' explicit expectations that faculty teach, advise, and mentor the next generation of scholars or may occur because of increased opportunities for faculty to engage in conservation. Conservation within industry, however, is not as evident, and as such, might need to be operationalized in greater detail within the context of Golde and Walker's[5] definition.

Golde and Walker identified transformation as "encompass[ing] teaching in the broadest sense of the word" (p. 11). Given this somewhat ambiguous definition, transformation was found to represent multiple facets. Within the CVs, transformation was identified through formal and informal teaching experiences, teaching awards and honors, presentations and poster sessions, professional societies and organizations outside of the discipline, commercialization and entrepreneurship, invited talks, and patents. Although transformation was quite traditional within academic environments, commercialization and patents were more prevalent instances of transformation within industrial environments.

"[Participants] highlighted four key categories crucial to professional success: analytical and critical thinking skills, technical knowledge, presentation and communication skills, and teamwork-related abilities."

Finally, although the majority of activities within the CVs were coded within the stewardship framework, several CV occurrences did not fit neatly into the framework. For that reason, a classification of "other" was created. Among the activities coded within this category included activities related to self-improvement, participation in research or other studies, non-disciplinary awards and honors, and non-work-related jobs. This category demonstrates the well-rounded nature of several participants who engaged in professional development workshops and community service activities and raises a concern about the possible limitation of the stewardship framework in defining scholarship among engineers who hold PhDs and work in academia and industry.

Attributes and characteristics

Our 40 interviewees' tasks were twofold: first, they were asked to identify attributes they found to be important for engineering PhD success; next, they were asked to identify potential strategies for PhD student recruitment and retention (RR).

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Jiabin "Emily" Zhu, PhD, is an Assistant Professor at Shanghai Jiao Tong University. She received her BS in Physics from East China Normal University and her MS degree in Optics from Chinese Academy of Sciences. She received a second Master's degree in Biomedical Engineering from Purdue University. In the spring of 2013, she obtained her PhD from the School of Engineering Education at Purdue University. While in the doctoral program, she served as a research assistant in multiple projects on the training and mentoring of engineering doctoral students. Her primary research interests relate to epistemological development of college and graduate students, comparative study methods and frameworks in engineering education, global engineering and mentoring of engineering graduate students.

Participants were asked to identify attributes they found to be important for engineering PhDs. In the end, they highlighted four key categories crucial to professional success: analytical and critical- thinking skills, technical knowledge, presentation and communication skills, and teamwork-related abilities. The most frequent individual attributes included strong analytical skills, multidisciplinary, abilities good communication skills, and creativity. Each of these attributes was mentioned by the vast majority participants. Many participants also listed practical ingenuity (i.e., an engineer's "skill in planning, combining, and adapting" to identify problems and find solutions). Interestingly, most participants did not consider business and management principles and adaptability as important to engineering PhDs as other attributes.

The expectations that respondents cited as most important varied depending on whether the hypothetical engineering PhD graduate in question chose to pursue a career in academia or industry. Leadership, teamwork, communication skills, and business management were commonly referred by respondents as the most essential attributes an engineering PhD working in industry should possess. On the other hand, respondents expected an engineering PhD in academia to demonstrate strong credentials related to finding research funds, teaching, conducting research, and publishing. Among those credentials, grant funding was the most commonly mentioned credential by respondents.

Recruitment and retention

Of the interviewees, more than half identified financial support and the emphasis on engineering degrees' relevance and rewards as useful strategies in RR. One of the participants commented on the financial problems and offered these possible solutions: "In order to get the best and the brightest one of the things we're going to have to do is increases in the offering of graduate degrees in other countries, and the fact that a portion of potential students are not willing to pause their lives to enroll in a full time PhD program: Incentivize them with two things. First of all, grand challenges. And then, a financial way of working on these problems. So either internships, or corporately sponsored scholarships, something has to be done here to make it actually happen."

Most participants also suggested that certain sociopolitical and economic conditions of today's world affect the RR of engineering doctoral students. Among the conditions they mentioned include the current economic climate, immigration issues (particularly after September 11, 2001), increases in the offering of graduate degrees in other countries, and the fact that a portion of potential students are not willing to pause their lives to enroll in a full time Ph.D. program.

Recommendations

What participants say

Interviewees were divided into four categories depending on what path they chose after earning their PhDs: those who had worked only in academia, those who had worked only in industry, those who went from academia to industry, and those who went from industry to academia.

Academia-only respondents suggested recommendations for students and for institutions. **Students** should produce genuine and novel research ideas, do independent and grounded research and implement a research plan, be critical and rigorous in their research efforts, cultivate the skills of writing high quality journal publications, develop their teaching skills, build a teaching portfolio, and develop their ability to mentor others. **Institutions** should help students understand the mission of a university (e.g., teaching-focused versus research-focused); should expose them to the "bigger picture" (marketing, business, social, environmental issues), and should expose students to more breadth in the curriculum.

The key points in industry-only participants' recommendations to engineering graduate education relate to an introduction to skills that are not taught within a traditional engineering curriculum at the doctoral level. **Students** should gain hands-on experiences (e.g., interdisciplinary projects, lab work, and internships); should cultivate practical skill sets such as financial analysis and budgeting skills; should enroll in project management courses; and should increase their awareness of commercialization. **Institutions** should create workshops with industry professionals or bring in industrial representatives to interact with students; should emphasize rigor in students' communication skills; should help students to keep the end

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goal in mind; should assist students in the cultivation of a result- oriented mindset; should engage students in both research-based and industrial-based work; and should give students more responsibilities during their graduate experiences.

Similar to the industry-only group, participants in the academia-to-industry group stated the importance of students developing project management and business-type skills. Participants in this group also brought in expertise in bridging academia and industry expectations. They suggested the concept of academia-industry joint programs and suggested the following recommendations for **institutions**: (1) establish some academia- industry joint programs that introduce students to both environments; (2) teach students how to delegate; (3) teach students to critique their writing; (4) allow students to present to funding agencies; (5) promote interdisciplinary, collaborative work; (6) align their programs to be more relevant to society. Aligned with the key points presented in the above-mentioned three groups, the participants in the industry-to-academia group also highlighted the importance of developing industrial experiences among students, students writing peer-reviewed high quality publications, the establishment of a working relationship between mentors and students, and encourage students to work with each other.

Besides these major points, the participants in this group also brought in additional insights from working in both industrial setting and academia settings. A recurring theme included participants wanting to see more rigor in academia to make sure that engineering graduate programs produce higher quality engineering PhDs. What follows is a summary of their recommendations for **institutions**: (1) provide explicit ethics instruction, (2) enforce high qualifying exam standards, (3) develop a high quality graduate curriculum, (4) emphasize rigor in both oral and written communication, (5) avoid grade inflation at the undergraduate level, (6) give students work on problems with breadth and depth, and (7) teach students to solve real engineering problems. These respondents also recommended that the government provide more resources for graduate education.

Our Advice

Based on our preliminary findings from the four different groups of engineering professionals (academia only, industry only, academia-to-industry, industry-to-academia), several potential measures can be implemented within current engineering doctoral programs. **First**, bringing in non- engineering stakeholders into engineering graduate education can be useful for both engineering students and engineering faculty members. Strengthening the ties between academia and industry at the institutional level provides opportunities for students to develop both industrial and academia experiences. Meanwhile, it also provides venues for faculty members to build collaborations or gain more industrial experiences. **Second**, a curriculum with more breadth and depth needs to be implemented in engineering doctoral programs. A curriculum with more breadth and depth will allow students to situate engineering problems within a bigger picture while taking into consideration multiple perspectives such as marketing, business, and social and environmental issues. **Third**, it was suggested that engineering doctoral students should communicate clearly in both oral and written communication. On one hand, students need to communicate within the professional community via publishing high quality, peer-reviewed publications and presenting at professional conferences and other venues. On the other hand, students should present regularly at multiple other occasions and should interact with more people to convey technical issues in layperson's terms.

Doctoral training should not be left to chance. In order to address the trends and challenges mentioned above, **i²e²a** recommends an integrative assessment model that incorporates the need for engineering PhDs to demonstrate competency in industry and academia. We have developed such a framework, which will be available in 2015. We encourage faculty, administrators, accreditation bodies, and engineering societies to begin a global conversation that aligns workforce trends with assessments for doctoral engineering students. In this way, doctoral students may be exposed early in their graduate careers to technical and professional experiences that will allow them to become leaders in their workplaces and in a global society.

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Awards

Presidential Early Career Award for Scientists and Engineers (2008)

NSF Faculty Early Career Development (CAREER) Award (2009)

Look for our book, *Demystifying the Engineering Ph.D.*, coming out in 2015!

Successfully Defended Doctoral Research Assistants
2009-2014

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Diana Bairaktarova, PhD
Rocio Del Carmen Chavela Guerra, PhD
Jeremi London, PhD
Nathan McNeill, PhD
JD McClurkin, PhD
Jiabin "Emily" Zhu, PhD

Publications Resulting from NSF Award #0747803

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