AC 2012-3274: INVESTIGATION OF THE WORK ENVIRONMENT OF ENGINEERING PH.D.S IN THE UNITED STATES

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Investigation of the Work Environment of Engineering Ph.D.s in the United States

Abstract

Currently, the majority of engineering Ph.D.s in the United States work in for-profit organizations, ranging from large corporations to small businesses. The goal of this study is to investigate both the research environment and the skills needed by engineering Ph.D.s who work in such organizations. The approach involved semi-structured phone surveys with six Ph.D. engineers working in large corporations and six Ph.D. engineers working in small businesses. The surveys were examined to uncover themes. Findings suggest that engineering Ph.D.s frequently work in teams. In order for teams to be successful each team member should possess a unique technical skill set and good communication skills. The need to have critical and analytical thinking skills was also a common theme. This paper presents the summaries of case studies, discusses common themes, and suggests implications for engineering doctoral degree programs.

1. Introduction

The traditional expectation of engineering Ph.D. students is that they will become a scholar-teacher at a research university or work in an academic or national lab performing basic research[1-3]. In recent decades, there has been a shift in employment options from academic to non-academic positions. This phenomenon is attributed to less federal funding going towards basic research, and fewer new academic positions being created. The focus of engineering doctoral research has also shifted from basic research to applied research[2]. In 2006, 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].

With this phenomenon in mind, various universities within the United Kingdom (UK), Sweden, Denmark and the United States have developed programs that allow doctoral students to work in industry or in a simulated industrial work environment[5-13]. Universities in the UK have been partnering with industry for approximately twenty years with support from UK's Engineering and Physical Sciences Research Council. Students in this program transition through four roles: consultant, researcher, innovator and entrepreneur. In this way students take an idea from conception to the market[6]. With support from the Foundation for Advancement of Knowledge and Competence, Sweden's Linköping University has students focus on one role: researcher, engineer or consultant[12]. In the United States, the National Science Foundation has developed the Integrative Graduate Education and Research Traineeship Program (IGERT) to be a catalyst in educating future research engineers with the skills needed in an interdisciplinary background[14]. In one IGERT program, an engineering doctoral student is paired with a master's of business administration student and two law students to study the commercialization potential, technology transfer, legal protecting and marketing issues of the engineering doctoral students' research project. This program creates a greater awareness of the value of engineering students'

research, develops their understanding of how to sell research ideas to industry, and develops engineering students' ability to discuss their technology to non-technical audiences[13]

Despite efforts to involve engineering doctoral students' in industry-like work experiences, the work of engineering Ph.D.s in industry has not been systematically investigated and reported in the literature. The information that is available focuses on managing and motivating research and development groups and creating effective teams[15-20]. The literature does not adequately address the challenges that engineering Ph.D. graduates face transitioning from academia to industry. This study thereby assists in the documentation of the industrial work environment for engineering Ph.D.s, and their transition from academia to industry, in order that academia can continue to prepare doctoral students for the work place.

2. Methods

This study on the engineering Ph.D. work environment and Ph.D.s transition to industry was based in grounded theory. Grounded theory allows a theory to emerge from the data. In other words, the proposition or hypothesis was tentative and suggested by the data rather than tested by the data. The research consisted of three phases: research design, data collection and data analysis.

In the research design phase the research questions were clearly defined. The questions were focused, but flexible enough to allow for "accidental" discoveries[21-23]. Individual semi-structured phone surveys were conducted. The survey questions were developed from findings from the initial questionnaire[24]. The loosely structure format prompted participants to discuss their transition from academia to industry and their current work environment. The questions included:

1. How do you conduct research for your company? If you don't conduct research for your company please describe your work environment.
    a. How does teamwork play a role in your work environment?
    b. Can you describe the type of projects and their timeline that you work on?
2. Explain how you handled the transition from academia to industry. What were the biggest challenges you faced during this transition and how did you overcome those challenges?
3. What are the most important skills for an entry level Ph.D. engineer in your organization?
4. How do you wish your Ph.D. program had better prepared you for work in industry?
5. Do you have anything else you would like to add to enhance this study?

The survey participants were identified as part of a related research project and consisted of Ph.D.s in engineering who were working in industry[24]. That study involved a survey of engineering Ph.D.s working in corporations or small businesses. The survey included an option for participants to supply contact information for follow-up activities. Through subsequent communication, twelve participants volunteered to discuss their work environment. The participants consisted of nine males and three females. The phone surveys were conducted in October and November of 2010. For each phone survey, the conversation was recorded and field notes were taken.

The data analysis began by summarizing each survey. Member checking was performed on the summaries in order to establish credibility and prevent misinterpretation of results[25]. This process was accomplished by emailing the participants a summary of their survey, and asking them to review the summary, and to respond if it did not correctly reflect their conversations. Two participants suggested minor changes to their summary, such as the number of years between completing their bachelor and doctoral degrees. Six participants replied to the email stating that the summary correctly reflected their conversation. The researchers assumed that the summaries accurately reflected the conversations of the four participants who did not reply.

Each summary was then analyzed through a constant comparative method, which allowed a theory to emerge in a systematic method using explicit coding and analytic procedures. The data from the individual summaries was then collected and entered into a database. The database allowed the researcher to refine constructs by identifying gaps in the data or holes in the developing theories. This process also enhanced the construct validity, internal validity and reliability. The emergent theory was then compared with existing literature, improving the construct definitions, internal validity and ability to be generalized[21-23].

3. Results and Discussion

Results provided in the appendix are the narrative summaries of each of the twelve surveys. In order to protect the privacy of participants, their names have been changed. For ease of discussion, participants working in large corporations were given names starting with "C", and those working in small businesses were given names starting with "S". These summaries provide insight into the variety of research environments found in industry by Ph.D. engineers. Themes identified from these summaries are compared and contrasted.

As participants described their work environments, two major themes developed: team research projects, and the constraints of time and money. Although these themes emerged from both participant groups, corporate and small businesses, members of each group had a slightly different perspective. The similarities and differences are discussed below. In addition, the participants were in general agreement on a number of the skills needed to be successful, regardless of their work environment. The survey indicated that technical ability, critical thinking skills, and communication skills are all important. Each of these skills is also discussed.

3.1 Work Environment

3.1.1 Corporate Work Environment

The questions regarding how participants conduct research and their transitions from academia to industry gave insight into the work environments of Ph.D. engineers in industry. Each participant discussed the role of teamwork. Several participants stated that each team member needs his or her own unique technical skill set. Tasks were often divided by members' technical strengths and individual personalities. For example, in designing a new catalyst, employees in Cam's company formed an interdisciplinary team. Members of this team included a mechanical engineer for expertise in crush strength, a chemical engineer for expertise in kinetics, a chemist for expertise in reactions, and an attorney for expertise in intellectual property. Team members

worked on projects only when their expertise is needed, not for the duration of the project. This situation was an example of cross-functional teamwork with team members from different disciplines[26, 27].

In the corporate group, several participants stated that they worked in teams of several hundred people; within these large teams, smaller teams existed. Chris's workplace had teams of 400-500 people with Ph.D.s in diverse areas. This large team was broken into teams of about 15 people with members in different locations. The team met virtually once per week. Cassy discussed the importance of communicating by email and virtual meetings while working in teams. Cam stated that he was both a team leader and an individual contributor to his team. He further discussed that the team culture was set by the leader by encouraging questions and having an open-door policy. He believed both actions have a huge impact on the team performance.

In order to contribute to the team, Ph.D.s must develop an understanding of the team constraints, which was a challenge for half of the participants working for large corporations. For example, as Carl transitioned from academia to industry, he joined a team working on an algorithm that he had studied during his doctoral program. In industry, the team was pursuing a different direction than the direction Carl had pursued in academia. While trying to persuade his team in the academic direction, he developed an understanding of the team's constraints, including budget, timing, and the team's skill set. These constraints influenced the team's direction for the algorithm. Carl summarized this challenge as "going from working individually to working as a team while being constrained by the business environment."

Time is one of the constraints of the business environment. The timeline for projects varied between participants from the corporate group. Chris, for instance, typically worked on a project for 5-7 years, while Carl's timeline was typically less than two years. It is important to note that Chris was working within the R&D department at his organization while Carl was in more of a manufacturing position. In both cases, projects typically had to meet certain milestones for the projects to remain economically viable.

Many of the participants in the corporate group discussed incorporating economic analysis into project milestones. Cathy explained that the company's goal was to make money. Each project the company undertook required an economic analysis. Throughout the duration of a project, there were multiple reviews. During each review, the cost benefits were analyzed to determine the future direction of the project. If a project's cost benefit was not satisfactory, the funding may be reallocated to a different project.

3.1.2 Small Business Work Environment

Teamwork was also important for Ph.D. engineers working in small businesses. Like their colleagues working for large corporations, Ph.D. engineers needed a unique skill set, along with breadth of knowledge according to Sara and Scott. Each person within Sara's company was involved in every project. Sara further explained that project tasks were broken down by a person's unique skill set and personality. This division was one of the keys to the company's success.

Unlike the corporate group's teams of several hundred, teams within the small business group remained small. The companies were small, but teamwork was not limited to employees within the company. Skip, Sara, and Scott worked with universities in different capacities and stages of technology development. Skip worked with a local university to validate the basic science concepts for his research. Sara, on the other hand, worked to commercialize technologies that had been developed at different universities. Scott delegated different projects and goals from SBIR grants to academia's leaders in order to develop new technologies.

The most frequently discussed challenges that participants faced in transitioning from academia to a small business were different than those discussed by participants working in a large corporation. In the transition to large corporations, participants discussed the need to develop an understanding of the team's constraints. The participants who transitioned from academia to a small business most often mentioned changing the focus of their goals. They stated that in academia, the goal was to publish a paper. Once in industry, participants focused on making the company money. In order to overcome this challenge, Skip found mentors at the local business school. Others reported that it took time and experience.

Similar to the findings from the corporate group, the timeline for project deliverables varied for each small business and project. The projects had milestones to meet. Sara explained the milestones as "kill" points. These "kill" points included not being able to reach a licensing agreement, or an analysis that lead to the conclusion that the new technology does not meet the need or desired expectation level. Unlike the corporate group, many participants from the small business group voiced concern about finding funding for a project. Scott mentioned that the timeline for each project depended on the funding agency, such as National Science Foundation, Department of Defense, Homeland Security or National Institute of Health. It is important to note that securing funding may have been emphasized by participants in the small business group, since they were recruited from NSF's SBIR award recipient listing[28].

Members of both the corporate group and the small business group had to develop an understanding of the economics and goals of a project. Several participants stated that in academia, the goal was to publish, to solve the problem, to explore a specific concept and to understand everything about it. Industry's goal was creating profit by developing a product or process that can be sold to make the company money. Economics was mentioned by 75% of participants when discussing their work environment without any prompting from the survey administrator. Half of the participants mentioned money related issues as being one of their biggest challenges when transitioning from academia to industry. Participants developed an understanding of the commercial implications of their research. This phenomenon was described by one participant as the need to develop an idea for a product that people will buy, not an idea for a paper.

3.2 Important Skills

From the discussion of work environments, it is apparent that teamwork skills are important. This study suggests that many teams in engineering Ph.D.s' work environment are cross-functional teams, with each member having a unique technical skill set[26, 27]. Different technical areas often have their own jargon and technical terms. The use of these terms can lead to

frustration and unsuccessful projects if ~~a~~ team members do not possess effective communication skills. Teamwork through cooperation and communication between the business, research, and development sectors within a company enhances success[29, 30]. Consistent with previous research, this study indicates that the need for technical expertise and excellent communication skills are required for engineering Ph.D.s working in industry[24, 31]. The results from this study also suggest that critical and analytical thinking skills are essential skills. These skills are discussed in more detail below.

3.2.1 Technical Ability

It has been previously reported that engineering Ph.D.s in industry are expected to have a high degree of technical competence and are seen as experts in their particular field[2, 3, 24, 32-34]. This study confirms this concept, in that, nine of the twelve participants stated that a high degree of technical competence is expected of engineering Ph.D.s. Three participants mentioned that breadth of technical knowledge was also important. For example, Sara discussed that technical breadth was important in her small business since she was continually encountering new technologies. While the specific area of expertise varies by field, it remains essential for engineering Ph.D.s to possess the high degree of technical knowledge in order to perform the required tasks within industry.

3.2.2 Critical Thinking Skills

Critical thinking and analytical thinking skills were the most common skills mentioned by participants (11 out of 12) that Ph.D.s were expected to possess. This concept was not found in previous work involving in a literature analysis of leadership skills[35], a job solicitation review for-profit positions for Ph.D.s engineers[31], or in a survey of the skills required of engineering Ph.D.s working in industry[24]. Seth explained this skill as the need to build on the work of others in order to solve a problem while looking at it from many different perspectives. He discussed the need to think deeply about a problem. According to Sara, this skill was developed during her academic experience by asking questions and exploring the answers freely. As she transitioned from academia to a small business, these skills were harnessed to prioritize the questions she wanted to ask. Carl had a slightly different viewpoint of critical thinking skills. He explained that Ph.D. engineers used critical thinking skills to develop practical solutions to problems, but the solutions were different in academia and industry. The academic's solution was typically the highest technological solution. The industrial solution was developed by modifying an existing solution to a different problem or thinking about the modified solution in an inventive way. Critical thinking skills were not limited to analyzing engineering subject matter according to Cam. He used these skills while analyzing other problems within his company.

3.2.3 Communication

The findings support literature that states that communication skills are important for engineering Ph.D.s working in industry to posses[24, 30, 36-38]. Eight of the participants (five from the corporate group and three from the small business group) stated that oral and written communication skills were critical to engineering Ph.D.s in industry. Calvin, Cathy and Chris elaborated by stating the importance of communicating effectively with diverse audiences and by organizing ideas in a

clear and concise manner. Ph.D. engineers need to discuss their research without using jargon and at the appropriate depth for the audience. According to Cathy, the ability to communicate effectively gives people access to more influential people than their peers.

This study revealed both similarities and differences between effective communication in academia and in industry. Skip explained the differences in communication styles and how he transitioned effectively. He said that academics wrote to publish their findings in respected journals and conference proceedings are conservative stating their ideas. They praise others' work within their field and discuss problems within their data. However, in industry, researchers boast about their research and the impact it will have within the industry. To change his communication style, Skip worked closely with several mentors through the several different venues including the local business school. Steve, Carl, Cassy, and Skip made similar comments that it was important to be persuasive while communicating their research to others.

In general, the participants in this study felt well prepared for careers in industry. However, results of this study suggest that working in interdisciplinary teams and developing an understanding of the economics and goals of an industrial work environment are areas that could be better addressed by engineering Ph.D. degree programs. This could be accomplished by industrial internships, similar to those common in the UK, Sweden, Denmark and Australia[5-13]. Another method of improving teamwork skills and developing an economic understanding is through coursework similar to Georgia Institute of Technology's Technological Innovation: Generating Economic Results Program[13]. Such programs expose doctoral students to interdisciplinary teams, which may better prepare them for working in industry.

4. Conclusion

This study focused on the corporate and small business work environments of engineering Ph.D.s. Results suggest that both environments frequently use teams to accomplish the company's goals. Additionally, each team member must possess a unique technical skill set and excellent communication skills. Results suggest that as Ph.D.s transition from academia to industry, they have to develop an understanding of the economics and goals of industry, which are different from the economics and goals of academia. This study also suggests that engineering Ph.D.s in industry need to possess critical and analytical thinking skills. This concept has not been thoroughly discussed in literature, and presents an opportunity for future work.

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Appendix: Phone Survey Summary Analyses

Chris

Chris obtained his Ph.D. immediately after his bachelor's degree. He interned with a large chemical company as an undergraduate and was able to rotate through different types of positions during his internships. His internships included research and development, end of life maintenance, and manufacturing. Through this experience he determined that he loved the design and concept phase. His research experience allowed him to be published as an undergraduate student. He also had the opportunity to attend conferences and talk to different people. As he approached graduation, he was not sure if he wanted to go to graduate school, but he applied and was accepted. He also applied for "real" jobs during this period. He decided to go to graduate school because it would allow him to do the type of work he wanted to do.

Chris works for one of the largest IT companies in the world with approximately 300,000 people. The research and development sector has a typical budget of 4-5 billion US dollars. Most of this money is spent in existing businesses to develop and improve products. Chris works in a large group to develop new products 3-8 years into the future. His group looks to where new businesses can be created. His large group consists of 400-500 people, most of whom have their Ph.D.s in very diverse areas. This large group is broken down into themes such as sustainability, transformation and organization. The theme that he focuses on is sustainability, especially with respect to reducing the environmental footprint across the industry.

Within each theme is a smaller group of about 15 people from various disciplines and locations. The goal of the smaller group is to build a net zero energy center. The team meets approximately once per week through virtual interaction. He also mentioned the cultural side of teamwork and stated that the leader sets the tone of the group. The leaders within his organization encourage others to ask questions to prevent ambiguity and also have an open door policy. Both have a huge impact on how they function as a team.

The timeline for the project that Chris works on is about 5-7 years and has multiple phases. Basic research takes place for 2-3 years. During this phase, his team has an idea, but they are not sure how to implement it. Next, the team begins developing a prototype which takes an additional 2-3 years. While in this phase, the business sector determines if the project is viable in the marketplace. The final stage lasts 2-3 years and consists of additional analysis to determine the commercialization of the project and transferring the project to a new team in order to take the project to market.

Technical ability is absolutely the most important skill that an entry level Ph.D. engineer should possess within Chris's organization. It is so important for his company, that many interviewees comment that their technical interview is worse than their qualifying exam. The second most important skill is the ability to communicate with people of different backgrounds. Researchers must discuss subjects and ideas outside of their comfort zone when it comes to research. His company wants passionate people who can work in teams. Being able to think broadly is also important. He did state that if a person is passionate, the "soft" skills can be developed.

Chris had several internships as a graduate student sponsored by his current company. He commented that one of the biggest challenges many Ph.D.s face in transitioning from academia to industry is their way of thinking. They have to be able to think of not only a specific topic, as they do in academia, but the big picture as well. The big picture is often missed by recent engineering Ph.D. graduates. Both are important, and it typically takes several years to be able to understand how their specific topic fits into the big picture. Another challenge is becoming accustomed to working with people from different areas of expertise. To overcome these challenges, it is important to have a good set of mentors. One mentor can help an entry level Ph.D. understand and see the big picture and another mentor can help develop an understanding of the company's business and marketing sector. It is also important for entry level Ph.D.s to jump in and get their hands dirty, realizing that if they stumble they will learn something. Failure is important because it helps people learn and continually improve. Chris felt he was able to move up the learning curve easily because of his exposure to industry as an undergraduate and graduate student.

When Chris was asked how earning a Ph.D. affected his career he stated that it helped him get his foot in the door in the research and development sector. He commented that he may have been able to obtain a similar position without a Ph.D., but it would have taken a much longer period of time. His graduate experience gave him the self confidence that he could achieve a long term goal and made him comfortable with the uncertainty of his research 4-5 years in the future. Perhaps he might make less money with his Ph.D., but he is satisfied with the trade-off because of his passion and level of job satisfaction.

Chris felt his Ph.D. program had well prepared him for his current position. He did mention that a Ph.D. is a function of the Ph.D. advisor and project and that the doctoral degree is a customized degree. He suggested that more emphasis needs to be placed on developing breadth of knowledge and developing soft skills.

Chris was concerned that he is beginning to have problems finding well-qualified people for open positions. He believes this trend will continue despite the high unemployment rate. He thinks there is a growing misalignment between Ph.D. programs and the needs of industry. He believes that the nation's workforce needs to be further trained to think critically in order to continue developing the nation's infrastructure.

Carl

Carl works for a large international company that focuses on many areas, including energy. His role within the company is product-focused. He takes proven technologies and creates new applications for these technologies. Typically, a project's timeline is less than two years. His work involves understanding the commercial needs, the product lines and communicating the commercial needs to the organization. His responsibilities are different from academia because of the firm deadlines and concern for short term return on investment. He feels the consequences are more severe if a deadline is not met in industry than in academia.

Carl stated that communication is the most important skill needed by an entry level Ph.D. in industry. He said both oral and written communication are critical. It is important to

communicate an idea in a clear, concise and persuasive manner while in a meeting. He further commented that a person with a Ph.D. is seen as an expert in a particular field and should be open to new problems and ideas. He or she is expected to come up with a practical solution. The practical solution is often different in academia and industry. In academia the highest technological solution is best, but in business it is necessary to think about the solution in an inventive way but still fitting within the business model. Industry considers if a solution is worth the investment to design something new, versus modifying a solution to a similar problem.

Carl went straight from his bachelor's degree to his Ph.D. When asked what his biggest challenges were in transitioning from academia to industry and how he handled those challenges, he stated that academia trained him well in his specific field, but for industry he needed application. His doctoral training was portable into the application of industry. A bigger problem for him was understanding the business side of the application including commercial implications, customers, methodology, culture of the organization and how people interact. He also mentioned that Ph.D. work is typically on an individual basis in academia, but most work in industry is done in teams. New Ph.D.s must determine how they are going to contribute to the team. Carl gave an example of when he first started working in industry. His team in industry had previously set the direction of their project. Carl was very familiar with the technology from his academic experience, but he had to spend time determining why the team had chosen their particular direction since it was different from the direction he would have chosen in academia. The challenges he faced can best be summarized as transitioning to working individually to working as a team while being constrained by the business environment.

Carl felt that having a Ph.D. has given him instant credibility. He is currently pursuing his MBA while working at his current company. He wants to keep options open and not be forced into a technical position because of an advanced technology degree. He wants the opportunity to go into management if he chooses.

Carl is happy overall with his doctoral preparation. He did mention that he wished that he had been encouraged to take classes outside of engineering to gain more of a business perspective. With more business classes he is not sure he would currently be pursuing his MBA. He also would have liked to work more in teams. He wishes he had some training on mentoring others to help them develop their research skills. This mentoring is not just grading or helping undergraduates with their homework, but training someone on how to prioritize their research.

Carl also mentioned that there should be a tighter integration between industry and academia. He feels that industry experience would make the transition from academia to industry easier on the student. Another comment was that all the graduate problems he encountered felt fabricated. He wanted more "real world" problems. He also was concerned about the lack of awareness for jobs and industries within his area both, geographically and technically.

Cathy

Cathy is currently in a management position at a large corporation with a focus on materials science and technology. She is accountable for the researchers at her site. Her company utilizes off-site test suppliers for the physical tests required in their research, which is typical for her

industry. While working in government and in academia, she has performed the tests needed for her research.

When asked about teams at her organization, she said that they work closely with test suppliers. It is important for the Ph.D.s to understand the nuances of the tests in order to determine where a test may go wrong. The test suppliers typically do not understand the subtleties of her company's research, and the actual people conducting the tests do not have their Ph.D.s. Researchers have to understand the tests on a detailed level so that they can perform the tests themselves in order to understand the test capabilities and to prevent inaccurate data.

The timeline of projects in industry is shorter with more frequent reviews than academia. In industry it is rare to not have a review of a project at least every six months, while academia may issue a report every 2-3 years. In industry, the goals for projects are related to the company's economic benefit. At industry's project reviews, questions about cost benefits are asked, which determine the future funding for the project. Project funding is evaluated every year at Cathy's current position, and she considers this standard throughout her industry.

According to Cathy, the most important skills for a Ph.D. in industry are not much different than those for a person working in industry without a Ph.D. These skills include oral and written communication. Successful employees need to organize their thoughts and present them in a clear manner. Ph.D.s need to realize others are not interested in the depth of their project and need to present a project to other employees with different backgrounds. Cathy stated that if a young Ph.D. can communicate coherently and present plans clearly he or she will have access to people whom his or her peers cannot access. Additionally, a Ph.D. needs to be organized, think critically, be able to plan, research, and determine the next step based on the results of a previous step.

Cathy's doctoral work had some short term relevance in industry that helped her transition from academia to industry. She felt isolated because she was the only person doing research in her area. Cathy developed a network of people to discuss potential solutions to problems. Unlike her academic experience, in industry, Cathy had to actively search to find the mentorship and team she needed. Cathy has learned to defend and advocate for her research in order to obtain the resources required. Industry is less nurturing than academia.

Cathy wished that her doctoral program had given her a better understanding of economic factors of science and technology and the everyday workings of a company. She thought an exposure to academic, government and industry jobs would have been helpful to gain a better understanding of various career options. She did mention that some of this comes from talking to people at conferences.

A suggestion she made for doctoral programs was to discuss the economics of a project during the defense. For example, the reasons why a particular test was chosen. On the other hand she gained a different way of thinking from her doctoral program. It has helped her determine what information is required when beginning a project and how to best use test results.

Cam

Cam became interested in graduate school while completing his undergraduate degree because he did not feel prepared to call himself an engineer. Also, he was not interested in bachelor's degree engineering jobs. He wanted a job on a world stage where he could be creative. He did not feel his bachelor's degree would allow him this opportunity. He participated in the National Science Foundation Research Experience for Undergraduates (REU). During the REU program he learned about graduate research, and it sparked his interest in research and graduate school. While in graduate school, he took and audited classes on foreign policy and international relations to confirm his desire for a job on the world stage. He is currently working in the oil industry. Cam went directly from his bachelor's degree to his doctoral program.

Cam works for a large corporation. He is an independent contributor as well as a team leader on various projects. He stated that his current position is not too different from a professor at a university research lab, but it has more of a business focus, not technology for science sake. Teamwork is used extensively within his organization. Teams consist of 3-4 people within his section of the organization and an additional 3-4 people from other sections. The teams have diverse backgrounds. Project timelines depend on the customer, but the majority of timelines are between 1-2 years. Team members are only on a project when their specialty is needed; therefore, they may not be on a project for the total duration of the project.

According to Cam, an entry level Ph.D. engineer needs to possess many skills. The most important skill is technical competence to be able to do the work the job requires for credibility. After Cam had completed his Ph.D., he thought his education was complete until he began his job. On his job, he continued to learn technical concepts. He did not feel prepared in his business and leadership skills. He is currently pursuing a MBA part-time to increase his skill level. He does feel that business skills can be learned on the job over time, but he does not want to wait the 15 years to learn them on the job. He has also learned some applied science while working.

When asked if having a Ph.D. has hindered his job, Cam said no. It is required for his current position. He believes a Ph.D. should develop skills on how to perform research, not just gain skills in a particular area. He feels that his Ph.D. program taught him how to perform research, and it developed his critical thinking, and his decision making skills. He applies his analytical thinking skills to various problems he encounters within the company both inside and outside of the laboratory.

Cam felt well prepared after completing his doctoral program. Professors prepare their students for careers in academia because it is what they know. Though some professors do have experience in industry. Cam entered the doctoral program with the goal of becoming a professor. His advisor and mentor helped him prepare for an academic career, but near the end of his program he realized that he did not want the pressures of academia. His graduate program gave him technical credibility to pursue other options.

He stated, in general, universities do not prepare students well to work in teams, follow environmental and safety regulations, or teach them about intellectual property processes. He

did discuss how industry values documentation. He further explained that documentation is important, but Ph.D.s' time is too valuable to spend an excessive number of hours documenting research when they could be working on a new project. Also, a lot of the research cannot be sent out for peer reviewed papers because companies have to protect their intellectual property and the information in peer reviewed papers may contain company secrets.

Cassy

Cassy was looking for an industrial position after completing her bachelor's degree. After about 5-6 months of looking for a job, an interviewer suggested that she consider pursuing her Ph.D. At first, she considered working in industry with her bachelor's degree for a few years and then pursuing her Ph.D., but she decided to pursue her Ph.D. immediately after obtaining her bachelor's degree. After beginning graduate school she realized that she liked being in the lab and doing research.

Cassy works in the research and development department of a large chemical corporation. Research projects originate from upper management or occasionally from individuals within her department. Projects generally go through an early economic analysis to determine project milestones. If the results of a milestone are not satisfactory, the project is killed. These milestones include optimizing processes. The early stage of a project is typically a year, though a few projects have lasted 2-4 years. Project milestones are set for every few months. Projects are eventually given to the technology center if they are deemed viable for commercialization. The same team will follow a project from the conception to the hand-off stage within the R&D department. It is not uncommon within Cassy's organization to have teams located in Europe, India and several states within the US working on various aspects of the same project. The key to success for these large teams is to determine the responsibilities for each group, schedule meetings, and communicate frequently through email. These meetings include senior level technicians as well as Ph.D.s involved in the project.

According to Cassy, it is important for entry level Ph.D.s to have good initiative and willingness to ask questions. It is a detriment to their career if a person does not ask questions. Oral communication skills on technical subject matter are extremely important as project updates are often informally presented to peers at team meetings. If a project is to be presented to upper level management, such as the Vice President of R&D, the presenter is typically coached so the presentation is appropriate. Cassy also mentioned that the ability to write reports is important, but the writing standard is not as high as writing a journal article. It is also important to be able to work within various cultures because her team is located in many different areas of the world.

In graduate school, Cassy felt that she had a good team environment; therefore, the transition to working as part of a team in industry was not a big deal for her. She feels that her company placed a large emphasis on safety, and her workplace has more paperwork to ensure safety than in academia. One challenge she had was learning how to interact with technicians in order to have their "buy in" on a project. Other challenges she faced during her transition were developing an understanding of the economics of a process. She wishes academia emphasized process economics more, how to handle the error involved in data analysis, and how to present data more effectively.

Calvin

Calvin returned to school for his Ph.D. after working as a mid-level engineer. He decided to pursue a Ph.D. because he did not think that he could continue at his current job until he retired. He wanted more in-depth problem solving and the opportunity to work with higher levels of technology.

Calvin works in a large corporation as a government contractor. Most of his research involves internet and library searches and working through previously solved problems. He works closely with the other 6-10 people within his department. His department is part of a larger team of 100-200 people. This larger team consists of mechanical engineers, electrical engineers and software specialist. For his job, it is important to understand the accomplishments of his department on a daily basis in order to explain their accomplishments to the larger team. A project's timeline will vary depending on the focus of the problem. There may be a month or two of intense work on a project, or he may be involved in a project for years and work only ten hours a week on the project.

Calvin believes that an entry level Ph.D. within his organization needs to learn and work independently. New Ph.D.s typically concentrate on analyzing new computer codes to solve narrow and specific problems. A skill secondary in importance to the analysis is the ability to document and present the analysis to middle management and lower level government workers. As a person advances in his or her career, more management skills are needed. He also feels that being able to communicate to a wide array of audiences is important. He stated that he is often a translator, explaining complex, technical issues to others with non-technical backgrounds.

Calvin had anticipated staying in academia after completing his Ph.D., but the job market for academia was poor so he began to pursue industry jobs. Most of his current work is government contracting. He believes that American citizens with a technical Ph.D.s have a great job market. The transition to industry from academia was easy for him because he approached graduate school as a full time job working 50-60 hours per week.

Calvin was satisfied with his Ph.D. program. He felt that he had adequate opportunities to write in addition to hands-on and analytical experiences. He would like to see more opportunities for presenting papers to others. He had the opportunity to present often, but knows many students who presented their work three times during their doctoral program. He often presents things several times per week. The audience may be 100 engineers or a two star general. The inability to present and document work can be career limiting.

Since completing his Ph.D. he has written two peer reviewed papers with his doctoral advisor and no other papers. In his current position that type of information cannot be released to the public, though writing peer reviewed articles is not frowned upon. Calvin stated that writing is critical for Ph.D.s. They need to be able to write in paragraph form; he often receives reports written solely in bullet format. He believes that the process of writing peer reviewed articles teaches a doctoral student how to explain the process and results of the research. It also teaches

Ph.D. students to explain their recommendations for future work. All of these skills are valued by industry, though industry does not value the editing, formatting and submission process as much as academia. Calvin stated that writing and documenting work is almost as critical as being able to do the work. If a person cannot write and document their work, it can be career limiting.

Sara

Sara had always wanted to get a Ph.D. since she knew what a Ph.D. was. She realized that a Ph.D. was required for her career to advance and to obtain the responsibility she wanted. After her bachelor's degree, Sara worked for a few years in industry before going to graduate school. She admitted that this choice may not have been the best financial choice, but she knew that by obtaining her Ph.D. she became a member of an elite club.

Sara works for a small venture creation firm in the Northeastern part of the US. The company consists of six employees which includes a CEO and an administrative assistant. Her company's goal is to start 1-2 companies per year. In order to accomplish this goal, her company identifies a key area of need within the drug discovery discipline and a technology from academia that meets the identified need. The company conducts a technical, intellectual property, and business analysis to determine if the technology is viable in the market place. The next step is to create a business and technical plan for the technology which then becomes part of her company's portfolio. Within these various steps, there are many points where a project could be "killed". For example, a project is "killed" if a licensing agreement cannot be made or if the technology does not meet the needs or the desired expectation level. Sara's company wants to "kill" projects early and often. Project timelines vary from several months to several years depending on the technology involved. Her company continually analyzes new technologies from a technical and business standpoint, and she feels that doctoral preparation gives students the necessary critical thinking skills to analyze new technologies from both standpoints.

Teamwork is more important to Sara's current position than any of her previous positions because of the company's small size. Everyone within the company is involved in each project. One of the keys to the team's success is the ability to divide the labor and work to accomplish their goals. Tasks are divided amongst employees by individuals' strengths in technical skills, commercial experiences and personal skills. When asked what skills are needed for an entry level Ph.D. within her organization, she stated that technical breadth and the ability to think broadly across various engineering disciplines is important. She also stated that entry-level Ph.D.s need a solid foundation in basic technical knowledge because of the various technologies she encounters.

After obtaining her Ph.D., Sara felt that the transition from academia to industry was less of a shock for her than some of her peers because of her previous industry experience. Her academic experience gave her the opportunity to ask questions and to explore their answers while thinking broadly and creatively. Her academic experience was invaluable because it is where she developed her finely honed analytical skills. In industry, she had to harness those analytical thinking skills to analyze previous data in order to prioritize the questions she wanted to ask.

She summarized this thought by stating that industry wants a product at the end of the day while academia wants papers.

When asked if obtaining a Ph.D. had hurt or hindered her career she felt that it had helped in all possible ways. She has a personal level of satisfaction from the sacrifice and time involved in obtaining a Ph.D. She also felt that it empowered her in her career and gave her a level of technical rigor in a relatively short period of time. She also stated that a Ph.D. helped her command respect because of its high honor and established her as an expert. This expertise gives her authority.

In response to how her Ph.D. program might have better prepared her to work in industry, Sara wished for the opportunity to have a co-op or internship program lasting six months to a year. She thinks that exposure to industry at the graduate level will allow students to consider careers in industry, not only careers in academia.

Sam

Sam decided to go to graduate school for his Ph.D. because he was fascinated with technology as a child. In high school, he was encouraged by teachers to pursue engineering. Once in college professors further encouraged him to pursue a graduate degree. He began his graduate studies immediately after completing his bachelor's degree.

Sam works for a small business. His company runs experiments in the lab, then applies the results to field prototypes. He works in teams of 2-3 people. Typically the team is responsible for the project from conception to completion. Each project is broken into several phases. The first phase lasts about 6-9 months and consists of creating a proof of concept in a laboratory. The second phase transitions from the laboratory into prototyping and lasts between 1-2 years. The timeline for each phase is driven by funding.

Sam feels the most important skill for an entry level Ph.D. engineer within his organization is flexibility. At his place of employment, each person is simultaneously responsible for multiple projects, and it is important to switch between projects and handle interruptions. He also believes a baseline of technical knowledge is required. Sam commented that the work environment is more complicated in industry than academia.

Sam's biggest challenge in transitioning from academia to industry was the change in mindset. He stated that the transition was not a problem, but he went through an adjustment period and shift in attitude. He explained that while both academia and industry are goal oriented, the goals are different. Academia is driven by curiosity to understand a problem better, but industry is driven by the problem. Industry's goal is to accomplish specific objectives for a project. Examples of industry goals are creating a prototype or releasing new software.

Sam is satisfied with his doctoral program and did not feel improvement is needed. He did mention the communication classes that that he took in engineering writing and presentation were helpful.

Seth

Seth is a CEO for a small software development firm. He works to define the problem for others who conduct the research. He feels that clarity is the most important task because it helps determine the real issues of the problem. In his experience, a person's individual skills are equally as important as teamwork. Each person within a team needs a unique skill set, otherwise teams are not effective and a waste of time. For a team to be effective, members need the right skills, talent and personality. A typical project that a Ph.D. engineer might investigate or solve lasts more than six months. He wants the Ph.D.s to solve the difficult problems.

One of the most important skills an entry level Ph.D. should possess is the ability to think independently. Seth elaborated on this comment, explaining that Ph.D.s need to build on the work of others while solving a problem. They should look at the problem from different angles and think deeply about the problem.

One of the challenges he faced transitioning from academia to industry included understanding the type of business and the company culture. This challenge was overcome with time by becoming one of "them". He further stated that it is impossible to always make dramatic changes because business does not work that way in today's world, but hopefully a person can contribute to a small change. For instance, if a person with a bachelor's or master's degree in engineering can solve the problem of going from A to D by going from A to B to C to D, a person with a Ph.D. can go from A to C to D without knowing anything about B.

Seth felt that academic work is always important, but industry is interested in creating products from academia's research. Academia is learning things for the sake of knowledge and understanding the problem. The academic papers are important in doctoral programs because students develop basic reasoning and knowledge. Peer reviewed papers are not emphasized in industry because less research is performed. Also, industry does not need the external opinions to validate their ideas.

Scott

Scott always wanted to develop technology. After he completed his bachelor's degree, he worked for one year then returned to graduate school to pursue his master's and doctorate degrees. Scott is from a small country and was not aware of doctoral programs before he began his master's program. He decided to pursue a job in industry because he received his Ph.D. from a non-top ten university. He did not feel that he would be able to compete for a job in academia. He had an internship while pursuing his Ph.D., and the company proposed the idea of doing research with the company after graduation.

Scott works in a very small business. His role within the company is to pursue Small Business Innovation Research (SBIR) grants from various government agencies to develop technology for the marketplace. His research is more technology development than basic research. His company is a manufacturing company and employs two engineers, Scott and the company's president. Scott delegates projects and goals from the SBIR grants to academia's leading research groups to develop new technology. The timeline for each project depends on the

funding agency. Some of his funding agencies include the National Science Foundation, Department of Defense, Homeland Security and the National Institute of Health. For example, SBIR funded by the National Science Foundation has two phases and can last 3-4 years if both phases are funded.

For Scott, the most important skill for an entry level Ph.D. is dependent on the type of business. In a small business, he feels that being able to learn and solve problems, create concepts, secure funding and manage projects are some of the most important skills. Based upon interviews with large corporations, he believes they want more specific skills, but he has never worked in a large corporation.

The transition from academia to industry was not difficult for Scott because he had an internship for one year with his current company during his graduate program. His current position includes creating high level research projects while handling technical development. He feels he has a lot of flexibility to be creative in his current position as long as he is within the core market and is able to develop concepts to produce and manage those products.

Earning a Ph.D. gave Scott the maturity to develop projects with a high level of knowledge. He explained that with a master's degree a person can solve the problem that others find, but with a Ph.D. a person defines the problem and creates new concepts. His advisor was very hands-off and caused him to have fewer publications but more maturity in developing his own ideas. He felt a more involved advisor is typically younger, helps students publish more and gives students the tools and security for any type of project. His current area is very different from his doctoral work. His doctoral program gave him a breadth of knowledge because his publications were not focused on one particular area. It also gave him the maturity to manage teams and create proposals.

Steve

After Steve received his bachelor's degree he continued his education to avoid the draft during the Vietnam War. He obtained his Ph.D. because it was not out of his capabilities. He commented that he always enjoyed school and the challenges courses bring. He loves math and has continued a mathematical approach to his research.

Steve currently is involved with three small businesses. The first business is a materials research and processing company. He uses theoretical analysis to solve production problems. This problem solving approach has allowed him to write over 70 papers. His career path began by writing a summary on 20 years of particle size technology and analysis that referenced fundamental equations to molecular weight. The theoretical analysis has practical applications in the optimization of particle size and shape of paint. He also works with a coatings company and a thermo litigation technology firm. His work with all three companies centers on particle size and particle size distribution.

When asked about teamwork in his work environment, he said that he is currently working more on the marketing aspect. He takes work that is formulated by others using his models and finds

practical applications. He currently is working on a proposal to market these applications. Some of his potential customers include the Department of Defense, Boeing and Brunswick.

The timeline for these projects vary, but overall the timeline is shorter since he began this work. A project that once took 5-20 years is now typically 3-4 months because there is no money for extra experimentation. Companies now want the maximum experimentation for the money opposed to supporting lots of research that may not be needed.

He stated that sales techniques and technical knowledge are the most important skills for an entry level Ph.D. engineer within his organizations. Sales techniques are important, he stated, because they allow a person to convince others that a particular solution is the best. He stated that Ph.D. programs are missing opportunities to incorporate sales jargon into their programs. Other skills that would be helpful are reading a balance sheet and reading a profit and loss statement. He stated that these skills are typically learned on the job.

Steve said the most useful thing he did when transitioning from academia to industry was take a sales class. The class was very beneficial because it taught him various techniques, which he uses frequently in his work and personal life, such as how to close a deal. Steve considers this class one of the best classes he has ever taken. He feels that these techniques should be integrated into engineering coursework because the approaches are not always obvious to people with technical backgrounds.

Skip

Skip works for an early stage start-up company where he is the only employee. His company's technology was initially created through his graduate research. After obtaining his Ph.D., he began a start-up company to build upon a previous system with a new technology. Skip designs and modifies the experiments based on previous results. These experiments allow him to optimize the system and determine product feasibility.

Even though Skip is the only employee of his company, he does not work alone. He collaborates with a local university to validate the basic science techniques and another company for instrumentation development. Skip's company is the end user for the instrumentation development company's product. He feels that it is always best to work in a team.

The timelines for various projects are dependent on funding. The more funding that is available the more people work on a project. Currently, deliverables, such as feasibility testing, is reported every six months. The company's long term goal is to have marketable products within 2-3 years.

Skip feels that entry level Ph.D.s need to have dynamic personalities, as well as, the ability to learn and switch quickly between projects. They also need to think critically, creatively and to question the status quo.

As Skip transitioned from working in academia to working in industry his biggest challenge was the change in mindset. According to Skip, academia's mindset is to perform research to publish

papers in respected journals and conference proceedings. In order to make this transition, a person in academia needs to be conservative in stating their ideas, to praise others within their field and to openly discuss problems within their data. Money, at times, is seen as evil in academia. However, industry's focus is to make money. A person in industry will talk about their product or process and its huge impact within the industry. To change this mindset he worked closely with several mentors he found at the local business school. This business school has a program that mentors entrepreneurs through networking and has a competition for writing business plans. Still, another challenge he faces is to create a short-term and long-term vision for his company and himself. Another challenge he faced was building a website, but Skip did not consider this task a difficult challenge.

Skip feels that earning a Ph.D. has defined his career. It has allowed him to become an inventor. As he was considering a Ph.D. after his bachelor's degree, he did not like jobs in which he was not the boss. He feels that a Ph.D. allows him to be in charge. He does not think that having a Ph.D. has hindered his career, but it may for others because they could be over qualified for certain positions.

Skip wishes his program had placed more emphasis on writing, specifically writing proposals. He stated that if you cannot communicate your ideas to others, your ideas are worthless. During his doctoral program he never wrote a proposal or business plan. He suggested that doctoral candidates begin writing proposals during their third year of candidacy. He does not agree with the argument that proposal writing is what you learn to do as a post-doc. Skip stated that his Ph.D. was all technical and he completed his degree in four years.

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