Career Path Barriers of Women Doctoral Students in STEM

(Science, Technology, Engineering, Mathematics) Disciplines

by

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ABSTRACT

The under-representation of women in science, technology, engineering and mathematics (STEM) fields indicates the presence of gender related barriers that impacted the persistence of women in science and engineering doctoral studies. The purpose of this study was to investigate the barriers of women doctoral students in STEM fields which identified supporting factors for them as well. This study also tried to determine if there was any difference in perceiving barriers among three disciplines - engineering, life sciences and natural sciences. An online questionnaire (19 Likert-type questions and one open-ended question) was sent to women STEM doctoral students studying at the Arizona State University (ASU). Questions were based on some factors which might act as obstacles or supports during their doctoral studies. Both quantitative and qualitative analyses were conducted. Factors such as work-life balance, time-management, low self-confidence, lack of female role model, fewer numbers of women in science and engineering classes, and male dominated environment revealed as significant barriers according to both the analyses but factors such as difficulty with the curriculum, gender discrimination, and two-career problem were chosen as barriers only in the free response question. Positive treatment from advisor, family support, availability of funding, and absence of sexual harassment assisted these women continuing their PhD programs at ASU. However, no significant difference was observed with respect to perceiving barriers among the three groups mentioned above. Recommendations for change

in science and engineering curricula and active recruitment of female faculty are discussed to reduce or at best to remove the barriers and how to facilitate participation and retention of more women in STEM fields especially at the doctoral level.

DEDICATION

Dedicated to my husband

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INTRODUCTION

According to the available data, the number of women in higher education has been growing for the last twenty years. The percentage of female doctorates in all fields has risen to 46.8 in 2009 from 28.6 in 1979 (National Science Foundation (NSF), 2010). Women earned 60.6% of the master degrees and 57.4% of the bachelor degrees in all fields in 2008 (NSF, 2010). But they are still under-represented in science, technology, engineering and mathematic (STEM) disciplines. Although girls on average now perform as well as boys in mathematics (Hyde, Lindberg, Linn, Ellis, & Williams, 2008) and they are receiving math and science credits in high school at the same rate as boys (U.S. Department of Education, National Center for Education Statistics, 2007), they are far behind their male counterparts in terms of majoring in STEM fields. STEM fields are highly male dominated in undergraduate, graduate and faculty levels. At the beginning of college, men outnumber women in most of the science and engineering fields especially in physics, engineering and computer science. Women feel isolated and experience uncomfortable learning environments. The chilly climate affects women's self-confidence and self-efficacy (Zeldin & Pajares, 2000) which is directly related to women's persistence in the fields i.e. greater efficacy leads to greater probability of persistence (Bandura, 1986). Bandura (1986) identified four types of sources that influence self-efficacy: mastery experiences, vicarious experience, verbal persuasions and physical and emotional states. Other barriers along with less self-efficacy cause fewer females to reach at the higher levels of STEM education especially at the doctoral level. The gender gap becomes very prominent at the PhD in STEM subjects. Moreover, among women with a STEM background, some choose to work in non-STEM fields (Seymour & Hewitt, 1997) which makes their presence in the STEM workforce alarmingly low. Therefore, understanding the barriers that hinder women's progress in science and engineering disciplines is of special concern.

Although the numbers of women with a major in science and engineering have increased between 1979 and 2009, the percentage of women in computer sciences, the physical sciences and engineering remained lower than the other disciplines. In 2008, women received 77.1% of the bachelor degrees in psychology, 53.5% in the social sciences, 59.8% in the biological sciences and 51.2% in the agricultural sciences, 41.3% in physical sciences, 40.7% in the geosciences, whereas women received only 18.5% bachelor degrees in engineering (NSF, 2010). Women's representation in the computer science discipline has decreased since the mid-1980s (Spertus, 2004): 37% in 1984 to 28% in 2000 to 17.7% in 2008.

At higher levels of STEM education, the percentage of women declines rapidly. For example, women received 60.6% of the master's degrees in all the fields and they earned 45.6% of master's degrees in science and engineering. By specific fields, percentages were as follows: engineering: 23%, physical sciences: 35.8%, geosciences: 45.4%, mathematics & statistics: 42.8%, computer sciences:

26.8%, biological sciences: 58.7% and agricultural sciences: 54.6%, psychology: 79.2%, and social sciences: 55.8% (NSF, 2010).

In 2009, women earned 47% of all doctorates. Out of all the women doctorates, science and engineering doctorates: 42%; social sciences doctorates: 58.4%; doctorates in education: 66.9% and doctorates in humanities: 51.9%. Again, trends are different within fields of STEM. For example, women were awarded 54.5% of all life-science doctorates but earned only 29.5% of all doctorates in physical sciences. Out of all physical science doctorates, they earned 20.3% of the doctorates in physics and astronomy, 21.8% of the doctorates in computer and information sciences but 38.5% of the doctorates in earth, atmospheric and ocean sciences (NSF, 2010). Similar variation was observed across different sub-fields of engineering. Women were awarded 21.3% of all engineering doctorates and the distribution among the sub-fields was: Aerospace and mechanical engineering 13.9%, 15.3% electrical/electronics engineering, whereas 26.7% in chemical engineering (NSF, 2010).

Scarcity of women was evident in the employment sector in science and engineering fields. According to a special report of NSF in 2011, the percentages of men employed in science and engineering occupations were higher compared to that of women (74% men vs. 26% women). Higher percentages of females worked as part-time employees and were more concentrated in less prestigious ranks and institutions. Women’s share of employment was greater in educational

Table 1: Science & Engineering Doctorate Holders Employed in Academia (all positions *) in 2006 by Percentages, Sex and Field of Study

	Physical Science	Mathe matics	Computer Science	Life Science	Psycho Logy	Social Science	Engine ering
Male	81.7	81.0	79.3	60.7	45.6	63.6	87.9
Female	18.3	19.0	20.7	39.3	54.4	36.4	12.1

[* refer to full time senior faculty, full time junior faculty, post-docs, part-time positions, and full-time non-faculty]

institutions such as K-12 schools, 2-year colleges, junior colleges and technical institutes. Employment in science and engineering faculty positions is an area of special concern because faculty serves as role models to students. Data for 2006 demonstrated that women continued to hold a lower percentage of science and engineering full professorships compared to their share of science and engineering doctorates awarded in that year. In 2006, women constituted 19% of full professors, 34% of associate professors, and 42% of junior faculty. Women made up 33% of all academic science and engineering doctoral employment and 30% of full-time faculty in 2006, starting from 9% and 7%, respectively, in 1973 (National Science Board, 2008). Data suggests that gaps between male and female faculty members were more visible in the engineering, physical sciences, mathematics, and computer sciences disciplines compared to the life sciences, social sciences, and psychology disciplines (Table 1). Women's share of full-time tenured or tenure-track science and engineering faculty showed a growth from 10% in 1979 to 28% in 2006.

Consideration of the above outlined degree completion data and employment data suggests that women and girls are facing some barriers which stop a higher percentage of women from enrolling and maintaining their careers in science and engineering fields even if they were interested in studying science. Researchers have provided several explanations for the gender gap in science and engineering. They focused upon factors related to school or college (such as work environment, encouragement from teachers, teaching quality, pattern of interaction with students), family factors (such as role models, family support and guidance), personal factors (such as self-confidence, self-efficacy) or societal factors (cultural stereotype, sex discrimination, marriage and children).

Classroom climate starting from K-12 classrooms to university departments were more "chilly" toward girls and teachers did not treat boys and girls equally (Hall & Sandler, 1982). Such an environment impacted faculty-student relationships, networking and collaboration among peers and the overall success of women (Morris & Daniel, 2008). Classroom interactions found to be biased toward boys and men lead to lowering of women's self-confidence (Brainard & Carlin, 1998). Departmental culture played a significant role in the attrition rate of women graduate students (Ferriera, 2003). A dearth of women role models in science and engineering fields had significant impact upon girls' decisions to pursue a scientific careers (Blickenstaff, 2005). On the other hand, girls were interested in choosing scientific career when they were influenced by a scientist /engineer parents or close relatives (Seymour, Hewitt, 1997; Baker & Leary, 1995) or if that particular field of science was closely related with society and wellness of human beings. In addition to a lack of role models, women faced the challenge of a lack of "critical mass" causing dissatisfaction and higher attrition rate of women (Dresselhaus, Franz, Clark, 1995; Ferriera 2003). According to the theory of critical mass, as the number of women increases in science and engineering disciplines, they will have greater access to important resources and better integration within the community. Issues of work-life balance are another very important deterrent to women's progress in science and engineering careers. Balancing between demanding careers and family responsibilities creates especially strong barriers for women. Three things, marriage, pregnancy, and child-bearing, negatively impact women's careers. Often, women scientists and engineers postponed having children until later in their career and thus were delayed in establishing of families (NSF, 2006b). One important point to note here is that the whole discussion in this context does not imply that men do not experience the same issues. However, differences in socialization of men and women i.e. different gender role expectations produces special problems for women.

This study examines the factors that cause disadvantages for women during their doctoral studies rather than investigating the threshold effects which keeps women away from entering graduate programs in STEM. In doing so, the present study used a quantitative and qualitative approach to add more research in this area and to deepen our understanding of the factors influencing the educational trajectory of women in science and engineering. The research questions for this study were

- How much do the barriers listed in the research affect women in PhD programs in their careers as a scientist/engineer?
- What are the most significant barriers perceived by women in PhD programs?
- Do the barriers faced by women in PhD programs differ by disciplines such as natural science, life sciences, and engineering?

This study examined the factors through the lens of doctoral students' overall experiences, particularly their views on perceiving barriers and how their gender impacts upon their persistence in the science and engineering community. Thus the present investigation will provide us better insight about the factors which can increase the retention rates of women students pursuing doctoral degrees in science and engineering and also will make the present and future students involved in the STEM PhD program aware of this big issue. The results of the study can be used in policy development for offering support to the students.

This chapter briefly described the background of the problems focusing on doctoral women in STEM disciplines and the significance of the study. Chapter 2 provides more insight and understanding of the issues faced by women over time by using an extended literature review. Chapter 3 presents the methodology for the study including an overview of the questionnaire. Chapter 4 discusses the findings of the study by presenting the data analysis of all the data gathered through the survey method. Finally, Chapter 5 concludes with implications for practitioners and further research.

Chapter 2

LITERATURE REVIEW

This section presents a summary of several explanations as found in previous studies for the poor participation of women at all stages of STEM careers. In 2009, women earned nearly 47% of all research doctorates among which 42% of the doctorates were awarded to women from science and engineering whereas in 1989, only 29% of women received doctoral degrees in science and engineering (NSF, 2010). This implies that women's situation in science and engineering is improving in a steady manner over time. The number of women earning doctorates in physical sciences increased 70% from 1999 to 2009, and the number of female engineering doctorate recipients nearly doubled over the decade. According to statistics, the rate of increase for women was three times more than the men doctorate recipients in physical sciences and engineering during the same period (NSF, 2010) (Fig 1).

In spite of women's great progress, the fact that women are under-represented in Science, Technology, Engineering, and Mathematics (STEM) careers is evident. This has been compared with the popular metaphor "leaky pipeline" which carries students from high schools to universities and also continues to the job market in STEM fields. This pipeline is called leaky because many students had to leave at different points in their career paths and select another field as a career. But the important point is that the drop-outs are

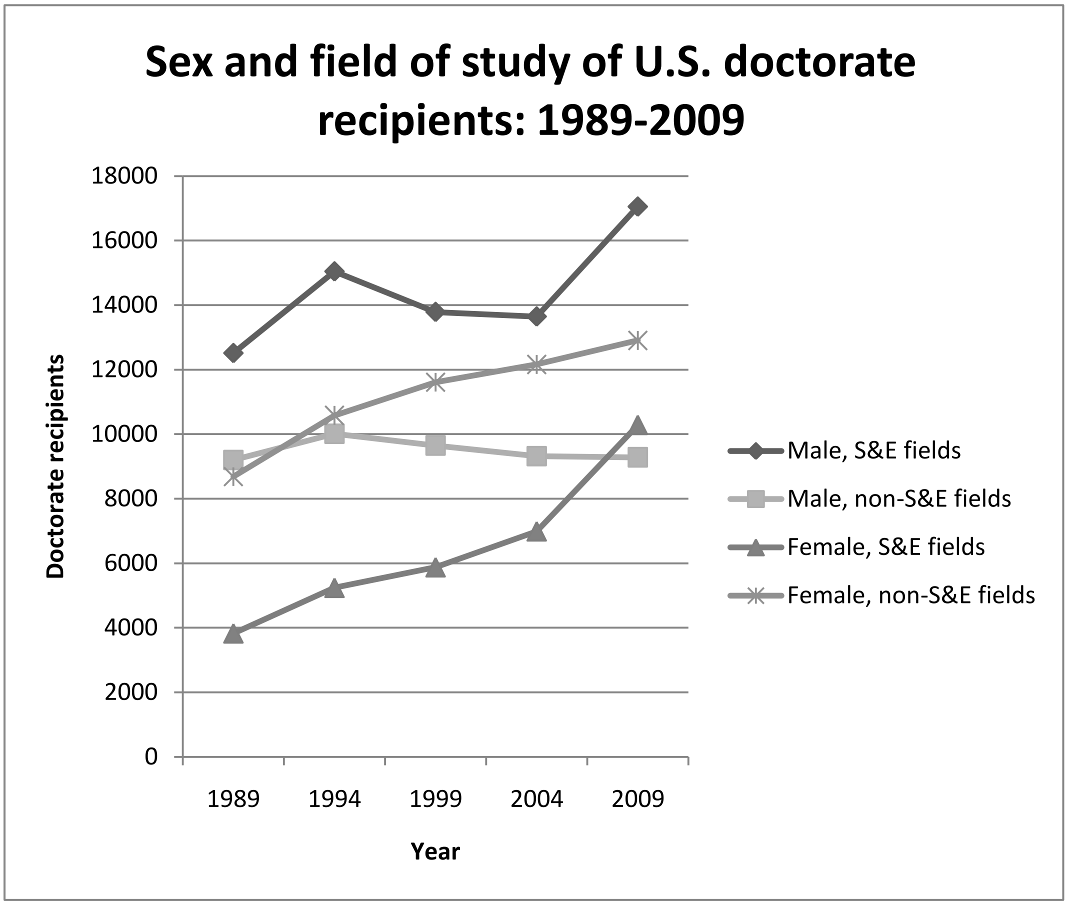

Figure 1: Sex and Field of Study of U.S. Doctorate Recipients: 1989-2009

excessively women and the persistence of women decreases as we go up to higher academic levels.

Although many girls have the skills to pursue majors in STEM when graduating from high school, fewer women than men take majors in these fields (National Science Board, 2010). For example, women earned 41.3% of the bachelor degrees in physical sciences; they earned only 29.3% of doctoral degrees in 2008 (NSF, 2010) (Fig 2).

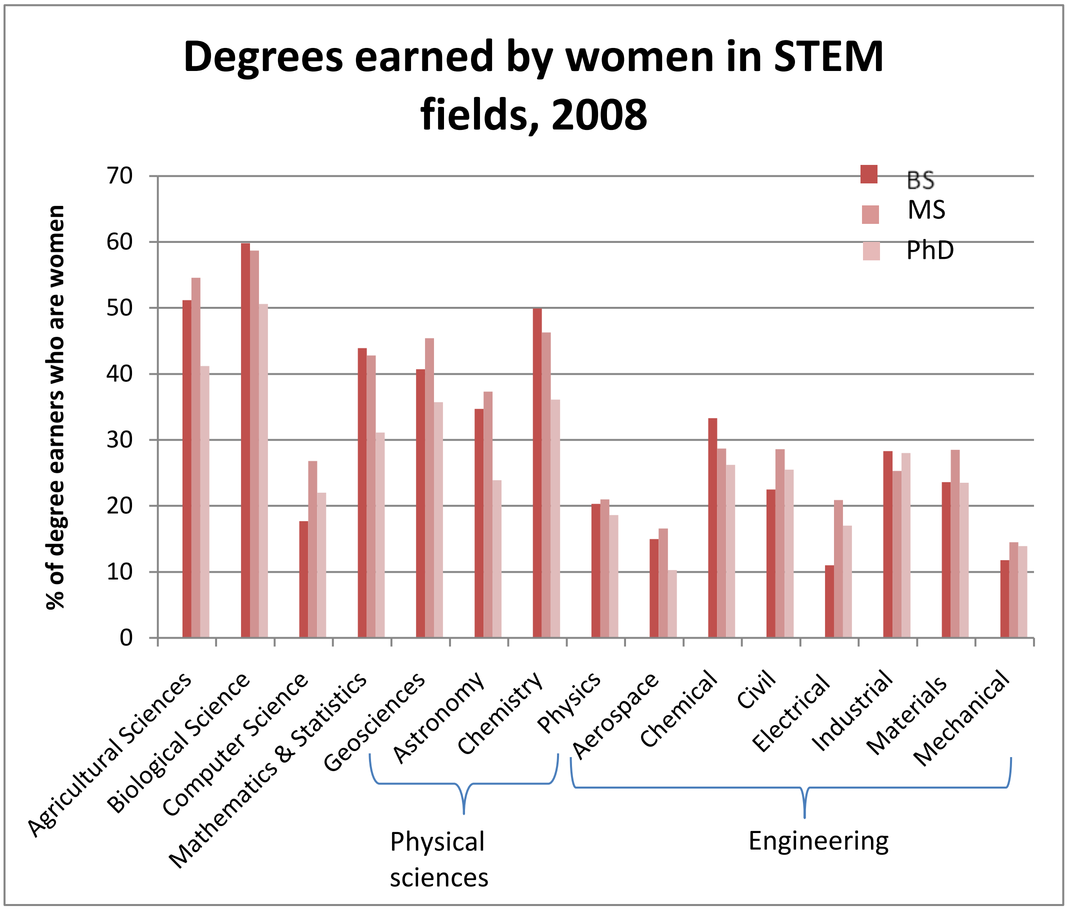

Fig 2: Degrees Earned by Women in STEM Fields in 2008.

Data show that the proportion of women in life sciences PhDs is quite good but is mostly under represented in physical sciences, computer science and engineering (Fig 3). Numerous research studies have proven that many inter-related social and career factors together create hindrances in women's careers and result in less persistence and retention for women in STEM. However, Ceci, Williams, & Barnett (2009) concluded that the most significant factor for determining women's careers is women's preferences whereas performances on

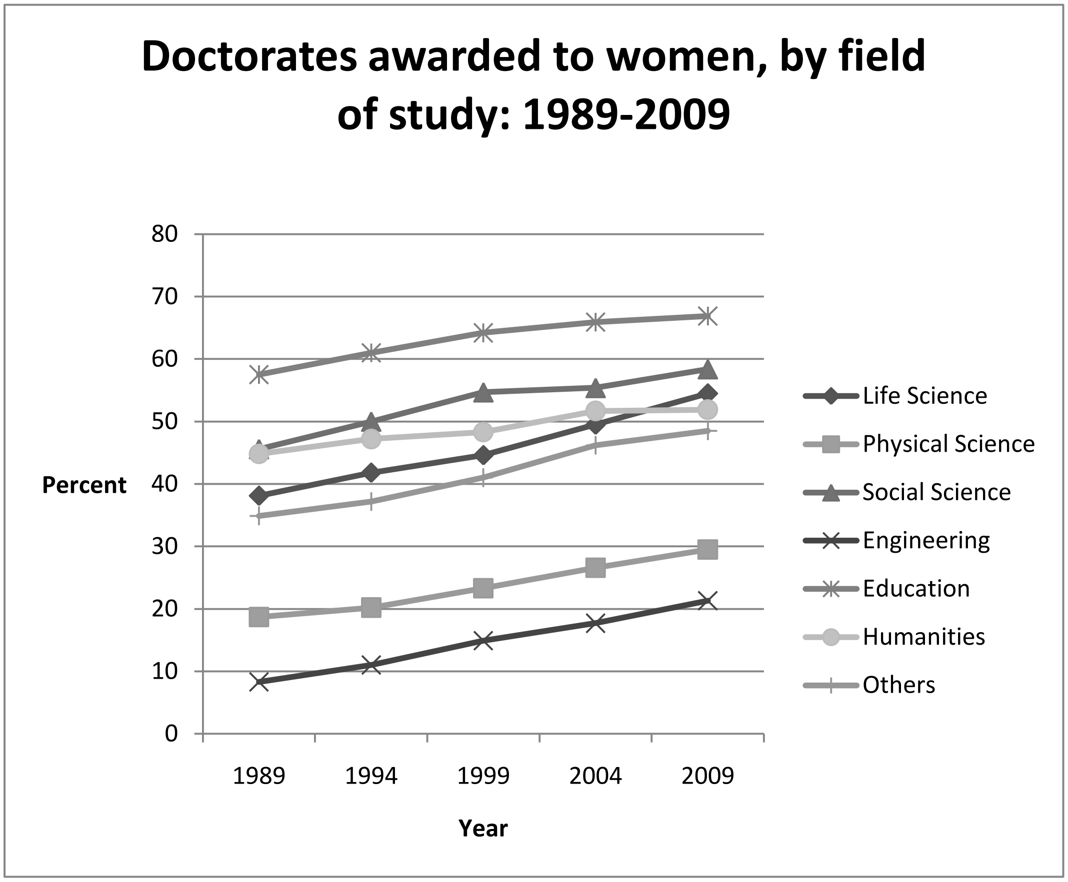

Figure 3: Doctorates Awarded to Women by Field of Study: 1989-2009

standardized tests (SAT, GRE) played a secondary role while examining women's underrepresentation in math-concentrated fields from biological and socio-cultural aspects. The reasons provided were 1) women expert at mathematics prefer careers in non-math intensive fields 2) more men than women achieve very high scores in SAT Mathematics and GRE quantitative reasoning sections and 3) women who are strong in mathematics are highly competent in verbal ability thus allowing greater choice of professions.

Due to fewer women PhDs in science and engineering, there is a scarcity of female faculty members in these fields. According to Eccles's general expectancy value model, three components of subjective task value i.e. utility value, attainment value and cost play significant roles toward gender differences in educational and job choices. That means individuals' educational and occupational choices are determined by their sense of self-efficacy in the task associated, relation of the task to individuals' long and short term goals, individuals' cultural, gender, social role and cost of effort and time in the task.

In summary, the reasons behind women's poor representation in science and engineering as described by researchers fit into two general hypotheses: The Deficit model and the Difference model. The Deficit model states that women get fewer chances and opportunities in their careers and thus outcomes are poor. The emphasis is on legal, political, and social obstacles which are structural and are embedded in social aspects of science (Sonnert, 1999). The difference model considers the disparity between women and men with respect to outlook and goals. This model states that women themselves are responsible for their poor achievement in science and engineering career. The gender differences are inherent and also stem from traditional gender-role expectations (Sonnert, 1999). I have attempted to explain some of the important issues that are faced by women scientists and engineers in the past. I have divided the barriers into eight broad categories and discussed the relevant factors under them.

1. Classroom climate

2. Dearth of women role models
3. Lack of preparation and encouragement for a science and engineering career
4. Low self-confidence/self efficacy
5. Cultural stereotypes and sex discrimination
6. Work-life balance
7. Two career problem
8. General problems such as lack of funding, trouble accessing non-academic position

1. Classroom climate in science/engineering classes:

Hall & Sandler (1982) have described the science and engineering classroom climate in schools. The departmental culture in colleges and universities played a significant role for women students' leaving or persisting and successfully receiving college level degrees in STEM fields (Margolis & Fisher, 2002; National Academy of Sciences, 2007; Whitten et al, 2003). Girls and women received unequal treatment indirectly and publicly compared to boys and men. Male peers often contributed to make the climate 'chilly'. Female attrition from undergraduate science programs happened partly due to the environment experienced by girls and women in their science classes.

Ferreira (2003) investigated the gender issues related to graduate student attrition in two science departments (biology and chemistry) using a sample of 170 graduate students (71 women and 99 men) at a large research university. She found that attrition rate is significantly greater for women students than that for men in both the chemistry and biology department and attrition rate is more prominent in chemistry than in biology. This study revealed that gender difference and attrition rate were related to department and discipline contexts and found that factors such as the working environment in the research laboratory played significant roles toward the difference of attrition rate of men and women graduate students. The average attrition rate of women in the biology department was 31% and 16% for men whereas in the chemistry department, the figures were 45% for women and 30% for men. Another important point was that during the time of the study, the women in each department reported a significantly lower self-confidence level than did the men though both groups started graduate school with similar self-confidence levels. This difference was greater in chemistry than in biology. It appears that the environment in the chemistry department more negatively affected the women students, as evident from their larger attrition rate and loss/drop of self-confidence. The women in chemistry indicated less agreement on questions regarding their comments being taken seriously by their male colleagues, or that they were asked for their opinion or help, or felt welcome to seek help from male colleagues. In the biology department, the stress was on collaboration among students but most women students in chemistry commented that each group focused on individual work. The women felt like outsiders in a male dominated environment and women in chemistry did not fully agree that their advisor had similar expectations for them as for their male peers.

Women doctoral students expressed similar dissatisfaction in a study conducted by Holmstrom and Holmstrom (1974). Women clearly reported dissatisfaction about treatment from professors and the other faculty during graduate studies. Results showed that these behaviors caused emotional stress for women students. Pattern of interaction between faculty and students revealed biasness toward men. Brainard and Carlin (1997) examined the factors affecting retention of females in science and engineering. They found that lack of self-confidence and fear of being excluded by their department were the two topmost perceived barriers for first-year and sophomore students. Almost one-third of the sample claimed that the professors showed biased behavior toward men, 20% of women were uncomfortable to ask professors for any academic help outside classroom and 25% of them agreed that male teammates participated more while working in group.

Multiple studies proved that bias was expressed through classroom interactions. Girls were less likely to handle laboratory apparatus and played more passive role in hands-on activities (She, 1999; Jovanovic & Steinbach King, 1998). Wasburn and Miller (2004) also found similar results such as women felt themselves as a minority among males, women found it challenging working in groups, sometimes they were afraid of male students and were undermined by male students.

2. A dearth of role models: Numerous studies have proved that the dearth of role models was a serious problem (Hartman & Hartman, 2008). Studies indicated that students in general were more likely to pursue non-traditional careers when they could identify a role model in the same career path and the probability was enhanced if gender were matched. Students if exposed to women scientists gained a more positive attitude toward women in science (Smith & Erb, 1986). Role models were found to have significant impact on selecting science careers (Strenta, Elliott, & Adair, 1994; Seymour & Hewitt, 1997; Adenika-Morrow, 1996).

Use of a cognitive framework in different studies revealed that girls often chose and persisted in science or engineering careers when they were influenced by their parents or near relatives involved in STEM careers (Baker, Leary, 1995; Buck, Plano-Clark, & Leslie-Peleckey, 2008). This is one important contributing factor to women's poor representation in science and engineering. Science and engineering disciplines are male dominated. Most of the scientists and engineers are men though the percentage varies depending on the field. This situation results in very few women role models in science and engineering, especially physics, mathematics, computer science and most of the engineering fields.

The concept of critical mass is applicable in this case. Critical mass means the mass consists of less than enough people of a particular type to constitute and maintain a feasible population or group. Therefore, women students in these disciplines are required to follow a model which is based on hard work and devotion to scientific research. This results in a tremendously competitive academic environment. Women scientists handle this problem in two different ways as identified by Etzkowitz, Kemelgor and Neuschatz (1994) (1) women who adapt to the male model and want others to follow (2) Women who try to follow another model which is more compatible with both their personal and professional lives. Etzkowitz et al described these women as instrumentals and balancers respectively.

The consequence of low number of women doctorates in science and engineering is directed to an even lower number of female faculty members in these fields. Again, fewer women as faculty poses a problem for women students to find someone who can act as an example to them with respect to handling women's issues. This factor is closely related to the chilly environment in the classroom.

Eileen Byrne (1993) compared the situation of women with a plant in a garden that does not grow that means when a plant doesn't grow in a garden, we first criticize the soil, water, sun or fertilizer but not the plant itself. Sonnert (1995b) mentioned that, in many cases, successful women scientists did not have children and that conveyed a negative message to many girls and women and they refrained from taking the challenge to balance a scientific career and family.

3. *.Lack of preparation and encouragement for a science and engineering career:*

Traditionally, women have faced the challenges of lack of encouragement and insufficient opportunities to succeed in math and science based subjects (Hartman & Hartman, 2008). In the early twentieth century, in the United States, the topic of chemistry classes for girls centered on home, cooking and food contamination (Rury, 1991). Also in the United Kingdom and in Australia, national and state governments proposed girls' curriculum based on home management skills. Australia acted on a sex-differentiated vocational curriculum and girls enrolled in fewer science courses than courses on humanities, commercial or domestic (Yates, 1998). All these events influenced girls' participation in science. Often, girls did not find any connection between science at school and their daily lives or science based careers (Hassan, 2000; Baker, Leary; 1995). Sometimes, women did not consider the entire range of available options which would be feasible for them either due to being unaware of the options actually existed or had very little scope to know about them (Eccles, 2007). Inappropriate information or lack of information regarding different career choices led women to make uninformed decisions.

Girls and women have been neglected in many ways in the science classes. Science textbooks were gender biased in Brunei and Jamaica (Elgar, 2004; Whiteley 1996). These all contributed to women's and girls' less positive attitude toward science. The classroom interaction differed between boys and girls students. Boys consistently received more attention, praise and support from teachers whereas girls received only passive mentoring from teachers. Different teacher expectations for boys and girls students were another way of discouraging girls from active participation in STEM fields. Even parents had higher expectations for boys than for girls and felt science as more important for boys (Andre et al., 1999).

Gender gaps existed in the choice of subjects in high schools. Many girls tended to avoid physics and calculus courses in high school which was one of the reasons for not choosing a STEM major in college and that reduced the number of women having technical degrees (Blickenstaff, 2005). However, Seymour and Hewitt (1994) found that there were no real differences in high-school preparation and ability among undergraduate students persisting in science and engineering and the students who dropped out or changed to other fields. This finding was supported by another study conducted by Brainard. She did not find any differences in performance (as measured by GPA) between those women who persisted and those who walked out of STEM programs. Hazari, Sonnert, and Sadler (2010) found that several high school physics class experiences such as emphasis on conceptual understanding, use of examples from real-world, encouragement and support from teachers and some other factors contributed to developing students' physics identity though females occasionally reported experiencing conceptual understanding and making real-world connections with theories. However, the discussion of underrepresentation of women in science positively influenced female students' physics identity. Amazingly, experiences such as female scientist guest speakers, discussion of women scientists' work, and the frequency of group work were found to be non-significant.

4. *Low self-confidence:* Lack of confidence is a major problem for many women scientists/engineers. Many factors, such as lower expectations from women, neglecting girls' opinions, faculty attitudes and beliefs toward women often

exacerbate the situation. The longitudinal study of women in science and engineering by Brainard and Carlin proved that first-year women students, sophomores and juniors did not experience any barrier to persist in their engineering or science education until they became 4th- and 5th-year seniors. Lack of self-confidence was revealed as one of the most frequently perceived barriers in the senior years. The percentage of senior students who reported low self-confidence as a barrier more than doubled the percentage reported by first-year students. The percentages were 23.5% at the first year and 69% at the 5^{th} year. It clearly indicated that most of the women students in engineering and science started with a very high level of self-confidence in their science and math abilities. However, levels of self-confidence dropped significantly ($p< .01$) over the course of their first year and did not return to the original value though they were regained slowly over the rest of the years (if they persisted in science and engineering**)**. Similar findings were obtained in a study with females in computer science majors (Margolis & Fisher, 2002). A significant decrease in math and science self-confidence was reported by women who switched during their sophomore years.

It has been verified through studies that lack of knowledge related to science and engineering courses, scarcity of female students in class, feeling like out-of-place can lower self-confidence. Lack of self-confidence acts as a great barrier for many women students to pursue a science career. Goodman (2002) pointed out that women tend to have lower levels of self-confidence in their math and science abilities than do men and this played an important part for getting success in STEM major (Seymour & Hewitt, 1997; Cohoon & Aspray, 2006). Women often were found discouraged by low grades which could be due to lower levels of self-confidence. Some studies proved (Concannon & Barrow, 2010) that women's retention in engineering disciplines depends on whether they mastered the coursework and received good grades such as 'A' or 'B' whereas men's persistence was strongly related to their abilities to complete the coursework. This factor also contributed to lack of interest in continuing research in these fields.

Self-confidence can generate from the sense of self-efficacy in one's ability to do math and science well. Therefore, the concept of self-efficacy and SCCT (social cognitive career theory) are important to consider in the research literature related to pursuit of STEM majors and careers. Self-efficacy can be defined as the belief of an individual in his capabilities to plan and take the required steps to achieve a particular outcome (Bandura, 1986). Self-efficacy is one of the strongest predictors of positive career expectations for male-dominated fields. Cordero, Porter & Israel (2010) used two interventions to measure the increase in math self-efficacy among undergraduate male and female students. The first intervention was based on performance accomplishment and another was a combination of performance accomplishment and belief-perseverance techniques which asked participants to show a reason for their future success in math/science university courses. The results of the study indicated that male students were able to exhibit higher math self-efficacy in the combined intervention than female participants. There was no significant difference between the scores on the math test obtained by the female participants and their male counterparts and rating of performance on math test between them. However, a significant difference was present between the math self-efficacy of male and female students where female participants' reported considerable less math self-efficacy (Mean = 6.77, Standard Deviation =1.30) than male participants (Mean = 7.43, Standard Deviation = 1.04), $t(97)= -2.733$, $p < .017$. Gender difference was also evident in other related factors, such as, desire to enroll in math/science courses, confidence of attaining success at math/science courses and interest in pursuing STEM careers. Result from MANOVA was notable indicating female participants' significantly low confidence regarding getting success at math/science courses and significantly lower interest in STEM careers than male participants.

Marra, Rogers & Shen (2009) have investigated change in self-efficacy for women engineering students in a two year longitudinal study by collecting data from five different U.S. institutions. The Longitudinal Assessment of Engineering Self-Efficacy (LAESE) was used as the instrument for this study (AWE, 2008). According to the findings, women's efficacy increased significantly in some subscales of self-efficacy such as coping self-efficacy, engineering self-efficacy II, and math outcomes expectations. However, feelings of belonging became significantly negative from the first to second measurement. Data from all students, especially from African American students, clearly indicated a relationship between ethnicity and feelings of belonging. Correlation values between subscales of the instrument and responses to retention items revealed that women's self-efficacy was dependent on their plans to persist in the discipline. Research demonstrated that different sources might have a role in developing the self-efficacy beliefs of men and women who pursue STEM careers. The source of men's self-efficacy beliefs is mastered experiences and those for women are social persuasion and vicarious experiences (Zeldin, Britner, & Pajares, 2008).

5. Cultural stereotype and sex discrimination:

Two factors that are particularly important for decreased participation of female students in male dominated academic areas are sex discrimination and cultural stereotype threats. Girls are discriminated against on the basis of cultural stereotypes. They were considered as not able to do math and science and were unfeminine in science and engineering fields (AAUW, 2010; Hartman & Hartman, 2008). Females were aware of and believe in the stereotypical image of a scientist as a man (Buck et al., 2008). Several studies proved that stereotypes can affect women's and girls' performance and aspirations in math and sciences which is known as "stereotype threat." This is one of the reasons for girls avoiding mathematics-intensive discipline and science.

The principal reason for women not choosing physical science and engineering occupations is due to assigning different gender values to different types of education rather than gender differences in ability to do mathematics or self-efficacy to attain success in these occupations and women prefer work directly related to social purpose (Eccles, 2007; Konrad, Ritchie, & Jr., 2000; Margolis, Fisher, & Miller, 2002). Findings from the study by Singh, Allen, and Scheckler (2007) proved that even if women were interested in using computers for educational and social purposes, a gender gap existed in the study of computer. However, data from different cultures such as South and East Asian demonstrated that success depends more on individual effort rather than inborn ability to produce a greater number of math and science graduates, especially women scholars (Stevenson & Stigler, 1992). The difference between female students' higher grades in math and science and their lower performance on high-stakes tests such as SAT-math was attributed to stereotype threat (AAUW, 2010; Nguyen & Ryan, 2008). These views cause inappropriate stereotypes regarding physical science or engineering thus resulting in women leaving without considering the choice. Many researchers examined the impact of stereotype threat that can affect an individual's performance. According to Lewis (2005), girls' less competency and ability in mathematics is one of the reasons for the existence of negative stereotypes.

Analysis of PISA mathematics scores showed that boys performed better than girls in mathematics and girls did better in reading (Machin, Pekarinem; 2008). However, results from another study examining gender differences in PISA mathematics test performance indicated that gender gap in mathematics scores is a cultural phenomenon and does not hold true in gender-equal societies (Guiso, Monte, & Sapienza et al., 2008). This result was supported by another study based on performances in U.S. mathematics test for grades 2 to 11 (Hyde et al, 2008). In a recent study, Murphy, Steele, and Gross (2007) showed videos to two groups of male and female undergraduate science majors at Stanford University. One group was 50% male, 50% female while the other group consisted of 75% male and 25% female. Those who watched the gender-unbalanced video suffered from identity threat, in which their heart rate increased compared to the women who watched the 50%–50% video.

Sex discrimination has been defined as "an unjustifiable negative behavior directed at a person on the basis of his or her sex" (Stephan & Stephan, 1996). Women may lose confidence in their ability to succeed in male dominated areas if they perceive any discrimination. More than two thousand undergraduate male and female participants from a private university in the United States were utilized in a study by Steele, James and Barnett (2002). The key measures for the study included self reported current and future sex discrimination and stereotype threat. They found that first-year and final year female undergraduates in a male-dominated academic area (i.e., math, science, or engineering) reported higher levels of discrimination and stereotype threat than women in a female-dominated academic area (i.e., arts, education, humanities, or social science). Conefrey (2001) noted that sexual discrimination is a major problem in science education

Seymour (1995) conducted a deeper investigation. He explored the reasons behind women's opting out of STEM careers by looking at their experiences during undergraduate study in science, engineering and mathematics in a greater depth using data from a three year ethnographic study. He explained that women's sexual images predominate over their images as scientists or engineers considering male peers' views. He also mentioned that women respond in a different manner than men in science, engineering and math classes. Women often expect more personal interactions with professors and male peers.

6. Work-life balance:

Balancing work and life is probably one of the most significant issues women have been facing since long. Various studies identified the difficulty in managing professional work with home and child responsibilities (Hartman & Hartman, 2008; Kahle & Meece, 1994; Scantlebury, Fassinger, & Richmond, 2004; Valian, 1998). This was the most frequently chosen barrier for women's limited participation in science and engineering as perceived by both the male and female college students (Morgan, 1992) and this finding was consistent with that obtained from the 1964 National Opinion Research Center study. There was no significant gender difference in choosing the most chosen barrier. Balancing personal and professional responsibilities act as a grand barrier to women's progress in science.

Etzkowitz et al (1994) investigated the conditions for which women are at a disadvantage during their doctoral study and at the beginning of their academic careers. They discussed three types of barriers such as socialization barriers, academic advising and career choice in this regard. Socialization barriers included factors such as different expectations related to gender role, less self-confidence, and expectations regarding the impact of children on women's academic careers. They argued that marriage and children can hinder women’s academic science careers at three vital times: playing responsibilities of mother with graduate study, getting married when looking for job and pregnancy before achieving tenure. They also found that sometimes women were considered to be less serious if they were married.

Rosser and Lane (2002) conducted one survey among National Science Foundation funded Professional Opportunities for Women (POWRE) awardees to find out the institutional barriers which posed problems to women’s employment and advancement in science and engineering. A vast majority of respondents identified balancing careers and family as the most challenging issue for women scientists and engineers today. Expansion of this research by Rosser & Daniels (2004) compared the experiences of two groups of academic female scientists (POWRE awardees and Clare Boothe Luce (CBL) professorship recipients) with respect to perceiving barriers to better understand the nature of barriers across different academic settings. Responses from both the groups were very similar regarding identifying most challenging issues/opportunities experienced by women scientist and engineers. The topmost barrier was the balance between work and family duties irrespective of the group.

Mason and Goulden determined the impact of babies and children in women faculties’ career. Data were collected from the Survey of Doctorate Recipients and the University of California faculty Work and Family Survey. The findings indicated the presence of a considerable gap between the rate of achieving tenures for men and women faculty with babies at the early stages of their academic careers. Such women tended to remain in lower status positions, such as, lecturer or part-time faculty position (Mason & Goulden, 2002). Female faculty members who opted to climb the academic ladder had to accept late pregnancy and fewer children than their male counterparts. Another finding was that more than half of all married women with children among postdoctoral fellows at the University of California planned to leave academia.

7. *Two-career problem:*

Two-career problem is very common among many married women in all the fields but poses a special problem for women scientists and engineers. They face the challenge of aligning three opposing requirements of their own career, their spouse's career and becoming a responsible mother. Because women scientists often prefer to marry other scientists in the same field or from other fields and therefore a large number of women scientists face the problem of getting employed in two scientific jobs in the same location (Sonnert, 1997). This was not a big problem in the past because most women were less career-oriented and could easily move to new places with their husbands based on his job. Now the situation has changed and career relocation has become a matter of negotiation.

In science and engineering, especially in academia, there are not plenty of jobs available. When both the woman and her husband work in the same field, it becomes more problematic to get two suitable jobs in the same place. The probability of hiring both the husband and wife in the same department or university is unlikely. This is known as the two-body problem, a joke according to a significant term in mechanics. According to the results from a previous survey, forty-three percent of women had moved due to a change in a spouse's job location whereas only seven percent of men had relocated (Holloway, p. 103). It was evident that in most of the cases, women had to trade off more to manage the problem, often by accepting a low profile career. Few women chose to break up personal relationships for the sake of their careers (Etzkowitz et al, 1994).

8. *General problems:*

Factors such as lack of funding and trouble accessing non-academic positions are some of the general problems for both male and female doctoral students but are more challenging for women students. Financial support is a critical need when students pursue their research. Enrollment decisions, rate of persistence and rate of completion of degrees and the duration of studies depend on the availability of funds. An increasing proportion of doctoral students now primarily depend on research assistantships, fellowships, and grants instead of personal funding for their doctoral studies compared to previous years. According to an NSF report in 2009, fellowships/grants were the major primary financial support for doctoral students in life sciences and research assistantships were the most important source in engineering and physical sciences. Availability of financial support is determined by self-support rate and the amount of educational loans. In 2009, more than 66 percent of doctorate recipients in life sciences and more than 75 percent of those in physical sciences and engineering fields were free of any kind of debt related to graduate studies at the time they received the degree. Fenske, Porter, and Dubrock (2000) found that students in science, engineering and mathematics persisted and graduated at higher rates but took longer to graduate than did non-SEM majors. They also found that merit rather than need was the basis for receiving award or gift aid for SEM majors compared to non-SEM majors.

There are few women who want to join academia and become professors. Women and people of color reported less satisfaction regarding the academic workplace compared to their white male peers, and also tend to discontinue their academic careers at an earlier stage (Trower & Chait, 2002). Trower (2008) also found in the COACHE survey that sense of “fit” i.e. the sense of belonging to the department was the most important predictor of job satisfaction for both male and female faculty. Also, female faculty members agreed less than male faculty members on the factor of institutions’ support of having and raising a child during the tenure track. An engineering career magazine expressed concern about the scarcity of women faculty who plan to continue to senior faculty positions, although the number of women receiving Ph.D.s in science and engineering disciplines has increased rapidly in the last few years (Ritz, 2005). Scientists blamed four factors for this situation:, the pipeline, climate, unconscious bias, and balancing family and work.

Van Anders (2004) designed a study to investigate the factors related to motherhood which discourage women from seeking academic careers. Results showed that more men than women planned to go into academia. The barriers associated with motherhood and mobility, but not the teaching and research problem, were found to negatively influence women's decisions to follow an academic career. Another study by Rosser (2004) found that women graduate students and post-doctoral scholars were avoiding academic jobs because they did not enjoy working in a research environment during doctoral studies. NSF data showed that women's representation is increasing among tenured and tenure-track faculty and among full-time full professors with science and engineering doctorates. Women also face problems regarding receiving funding. Women received smaller grants and were offered fewer postdoctoral fellowships compared to men but they were also required to publish at more than double the rate for men (Dewandre, 2002; Williams, 1998).

Chapter 3

Methodology

This study was designed to answer the following questions :

- How much do the barriers listed in the research affect women in PhD programs in their careers as a scientist/engineer?
- What are the most significant barriers perceived by women in PhD programs?
- Do the barriers faced by women in PhD programs differ by disciplines such as natural sciences, life sciences, and engineering?

Sample

The study was conducted in Arizona State University. The ASU College of Liberal Arts and Sciences was contacted to obtain a database of women PhD students. A sample of 557 women PhD students who enrolled in Fall 2010 in any of the STEM disciplines was recruited through email. One hundred and sixty five women completed the survey. The response rate was slightly less than 30%. The STEM disciplines included computer science, various sub-fields of engineering (electrical engineering, industrial engineering, mechanical engineering, biomedical engineering, chemical engineering, civil, environmental and sustainable engineering), sub-fields of life sciences (biology, microbiology, molecular and cell biology, biomedical informatics, computational biology, biological design, environmental life sciences), mathematics (including statistics), natural sciences (physics, chemistry, geological sciences and related fields such as astrophysics, nanoscience, biochemistry). Audiology, psychology, social science, speech and hearing science, cognitive science, and social psychology were also considered STEM fields in the database. The percentages of participants in each field were as follows: engineering (25.5%), life sciences (26.7%), natural sciences (26.7%), others (12.7%), mathematics (6.7%), and computer science (1.8%)

Instrument

The participants completed an anonymous online questionnaire. A complete questionnaire can be found in Appendix A. The questionnaire consisted of twenty questions. Nineteen questions had two parts. The first part used a Likert-type scale (strongly agree to strongly disagree) and the second part was a checklist containing sub-items. For example, let us consider the following question.

I have difficulties balancing work and personal life 1---2---3---4---5 (First part)

I have difficulty meeting deadlines

I have difficulty taking leave

I have difficulty taking additional work home (Second part)

I have difficulty finding time for leisure activities

I have difficulty finding time for pastimes with family/friends

I have difficulty taking care of my children (if applicable)

I have difficulty in taking care of older relatives (if applicable)

None of the above

The first part determined the extent the participant agreed or disagreed with the statement in each question and the second part looked at the reasons that contributed to their rating. The nineteen questions were based on some factors (which included family, personal, and societal factors such as work-life balance, low self-confidence) which might act as issues/challenges/opportunities that women researchers in STEM fields are facing today when they plan their careers and also the questions asked them about the climate during their PhD studies. The last question was open-ended. This question asked which factors were most challenging for them and why. This was a mandatory question. At the beginning of the questionnaire, there was a demographic section based on educational information. This information helped to filter the results according to different disciplines.

Survey method was used for the data collection because of its cost-effective nature and also it facilitated reaching a population that is really busy and difficult to reach. The development of the survey was based on an extensive literature review to select factors that have influenced women's persistence in STEM fields. Factors from the studies by Anders (2004), Barrow (2009), Brainard (1997), Ferriera (2003), Hazari (2010), Hartman (2008), Holmstrom & Holmstrom (1974), Luzzo (2001), Murray, Meinholdt, & Bergmann (1999), Siann & Callaghan (2001), Wasburn & Miller (2004) and Wentling & Camacho (2008) were used with slight modification in language. Examples of questions are: 1) I often feel my comments/ideas are taken seriously by my male colleagues and, 2) I often feel my comments/ideas are taken seriously by my advisor (Ferreira, 2003). Previously designed instruments for identifying barriers, such as the Longitudinal

Assessment of Engineering Self Efficacy (LAESE) were also reviewed. Examples of LAESE questions are: 1) someone like me can succeed in an engineering career, and 2) I can make friends with people from different backgrounds and/or values. The factors (such as work-life balance, low self-confidence) associated with each question were selected/adopted primarily from the findings from the study by Rosser & Lane (2002). As many of the questions were drawn from various studies, no independent reliability and validity analyses were conducted for the present study. Very few changes were made to the initially designed questions to meet the requirement of the survey software. For example, adding checkboxes to the left side of the sub-items under each question. Adding radio-buttons for different points on the scale (strongly agree, agree, neutral etc) instead of marking 1 to 5 on the scale.

The survey was administered online after obtaining permission from the Institutional Review Board of Arizona State University. Participants received an e-mail informing them of the purpose of the study and a link to the on-line questionnaire. An informed consent form appeared at the beginning of the on-line questionnaire and individuals gave consent to participate by clicking on the agree button. There was no award associated with the study and participation was completely voluntary. Data were collected in two phases in March 2011. A follow-up email was sent to the participants (whose responses were incomplete till then) to increase the sample size.

Chapter 4

DATA ANALYSIS AND RESULTS

To analyze data, each research question was examined separately. One hundred and sixty-five women completed the online questionnaire and all of these responses were considered for the first and second research question. For the third research question, which was a comparison among different disciplines with respect to perceiving barriers, responses from three disciplines (total one hundred and fifty-one responses from those three disciplines) were considered. The remaining fourteen responses belonged to computer science and mathematics disciplines and were not taken into account as separate disciplines due to poor participation rate (less than 2% participation from computer science and less than 7% participation from mathematics) of women from those fields.

Research Question 1:

How much do the barriers listed in the research affect women in PhD programs in their career as a scientist/engineer?

Closed Questions:

The summary of the results are as recorded in Table 2. To determine the extent with which the factors affect women's career, I computed the percentages of response associated with each point on the 5-point Likert-type scale (strongly disagree to strongly agree) for each question. Then I considered that particular point associated with maximum percentage of response as the general trend of response. If agree or strongly agree was the most chosen response, then that factor was considered to affect greatly or support greatly depending on the statement in the question. The items (under each question) chosen by the highest percentage of participants were also noted.

The data indicate that more than 40% of the participants agreed that they find it challenging to maintain a balance between family and career. Most of the women mentioned that finding time for pastimes with family/friends and for leisure activities is difficult for them. More than half the women (50.92%) believed that their self-confidence affects their work and they felt that their fields lack women role models, but they indicated that they are confident of succeeding in the classes critical to them. Nearly 38% women hold the opinion that there is a low number of women in their fields and reported that there are fewer female professors than male professors in their departments. As a result, they (34%) indicated their field as male-dominated. Approximately 41% reported that time-management was critical to them and most of them reported that they finish things at the last moment. These women did not have a problem synchronizing own careers with that of a spouse although 14.43% of them reported living away from their spouse due to their career. More than half (58.9%) of the women strongly agreed that they received family support/encouragement and 40.5% of the women stated that they received positive treatment from their advisor. They also felt that the advice was free of gender bias. Twenty nine percent of the women felt that there was no gender discrimination in their fields and 59.6% of the participants agreed that they gained credibility from others. Approximately 42% did not agree that there is a lack of camaraderie among their peers. Rather, these women found a friendly climate in their science and engineering classes and reported that professors encourage positive interaction among students. The majority of the participants did not have any issues due to lack of funding (27%).

Table 2: Summary of Responses for Research Question 1

Questions	Most frequently chosen response	Comments	Most frequently chosen items
I have difficulties balancing work and personal life	Agree (40.5%)	Affects greatly	I have difficulties finding time for pastimes with family/friends and time for leisure activities (24.8%)
I have difficulties balancing two careers	Neutral (37.2%)	Neither affects nor supports	I live separately from partner to maintain career (14.4%)
I have family support/encouragement	Strongly agree (58.9%)	Supports greatly	My parents/guardians are very supportive (25.4%)
The treatment from my advisor is positive	Agree (40.5%)	Supports greatly	I do not feel that sex does affect the quality of advising I receive (17.9%)
I am no longer interested in continuing research	Strongly Disagree (41.1%)	Does not affect at all	At the beginning of my PhD, I was confident of completing the degree (24.4%)
My self-confidence affects my work	Agree (50.9%)	Affects greatly	Someone like me can succeed in a science/engineering career (22.4%)

Questions	Most frequently chosen response	Comments	Most frequently chosen items
			I am confident of succeeding in classes critical to my area of study (22.2%)
My field lacks women role-models	Agree (32.5%)	Affects Greatly	I think more women role models are needed in science/engineering (35.7%)
There are low number of women in my field	Agree (38.3%)	Affects greatly	There are fewer female professors in my department than male professors (50.0%)
I am perceived as credible by others	Agree (59.6%)	Supports Greatly	Professors encourage positive interactions among all students (17.7%) I feel comfortable talking with other friends when I have academic problems (17.6%) There is a friendly climate in my science/engineering classes (17.2%)
There is a lack of camaraderie among my peers	Disagree (41.6%)	Does not affect	I feel comfortable asking for help from male peers (23.3%)

Questions	Most frequently chosen response	Comments	Most frequently chosen items
I have difficulties with time-management	Agree (40.9%)	Affects greatly	I often get things done at the last minute (29.7%)
Lack of sufficient funding	Disagree (27%)	Does not affect	I cannot continue my research studies without funding (27.3%)
Tough competition affects my work	Disagree (36.7%)	Does not affect	I feel pressure in mind when there is a tough competition (31.4%)
I prefer a non-academic career	Neutral (27.6%)	Neither affects nor supports	It is difficult to get a good academic position (37.3%)
I have experienced sexual harassment	Strongly Disagree (53.8%)	Supports greatly	None
There is gender discrimination in my field	Disagree (29%)	Does not affect	None
I am in a male dominated environment	Agree (34.0%)	Affects greatly	My field is dominated by men (47.6%)
I have difficulties networking	Disagree (28.4%)	Does not affect	None
I have difficulties with the curriculum	Disagree (41.0%)	Does not affect	Difficulties in writing algorithm or programming (12.4%)

They do not agree that tough competition affects their work (36.7%) and that they have difficulties networking with people (28.4%) or difficulties with the curriculum (41.1%). These women (41.1%) strongly disagreed with the statement that they are not interested in continuing research and also 27.6% did not agree with preference of non-academic career. They (53.8%) also indicated that they did not experience any sexual harassment.

Open Questions:

The survey contained one open-ended question. The responses to the question were powerful as the women voiced their individual experiences as a female doctoral student pursuing a science and engineering PhD. Though very few women (3.3%) stated that they did not experience any gender related barrier, most of the students expressed concerns similar to those identified by the closed questions. However, some inconsistencies were observed in their responses, for example, factors such as gender discrimination, difficulty with the curriculum and two-career problem was found as barriers only in the free responses and the factor difficulty with the curriculum became more pronounced in the free responses compared to closed responses (19.9% agreed in free responses vs. 11.7% agreed in closed responses). A vast majority of women identified issues related to work-life balance (23.8%), difficulty with the curriculum (19.9%), time management issues (13.2%), gender discrimination (11.3%), two-career problem (8.6%), lack of confidence (6.6%) and the lack of women role models/low number of women (8.6%) while describing the most challenging barriers for them.

Work-life balance

It is clear from the comments that these women really struggled to maintain a balance between career and family:

> It is very difficult for me to balance my work and life; at times my personal life gets neglected. Specifically, when people think that as a female I should be the care-giver as well as the bread-earner of the family, there is no consideration about the difficulty in balancing everything around me.

> I work full time, am a full time student and a mother of 2 children under the age of 5...life is BUSY!

> As a woman in my 30's in a PhD program, I am torn not because I am a woman, or that I'm married, but because I am a mother. That restricts the time I have outside of 9-5 to study and work off hours.

> Balancing home life and work life is always going to be challenging, but it is for everybody. Being a woman does make it more difficult, and it will be a major consideration in the career I choose after getting my PhD.

Women expressed barriers specific to incompatibility of raising children and pursuing a career in academics:

> There is no 'good' time to have a child in an academic STEM career. I do not think universities in the US are structured to help women succeed both in their careers and in raising their families.

> My husband and I want to have children, but we have no idea when that is going to be possible because of how busy I am as a graduate student. Also, we hardly ever spend time together now because I am always in the lab working, or at home working.

> Tenure necessitates a 'front-end loaded' approach to an academic career necessitating a delay in starting a family. Taking time off or working part time is not generally an option for engineers.

Two-career problem

The respondents mentioned problems finding jobs in the same geographic region or sacrificing their own career from the highest potential:

> I think finding a job in the same state will be the most challenging factor For my career. Although a spouse has not prohibited me from pursuing a Graduate degree, I do have family and obligations here that I am not willing to leave in search of the perfect job.

> I am graduating in a few months, and took a temporary position so that my partner could continue his studies at ASU. I am putting my desire for a tenure-track position on hold for 1-2 years, while he finishes law school. Once he graduates, we will have to try to find jobs together. Our fields are very different, but we are both specialized, which will

make finding jobs difficult. I think that I will be the one who has to make professional sacrifices, if problems in the job search arise.

If your spouse is an academic, your career trajectory may end up being dictated by him.

Difficulties with the curriculum

The participants expressed their concerns regarding ability to do programming, understanding of mathematical concepts and coming up with entirely new scientific ideas:

Explaining things with facts' is the most challenging both as a presenter and a writer. I experienced this difficultly while passing my cumulative exam which is largely based on an oral exam and written report. I can pick up the new material, but explaining it via a clear and logical step-by-step process is the most important way to appear confident enough to publish.

I don't have a strong mathematical background. It is a little difficult for me to do equation deduction, especially partial differentiation.

The most challenging is programming since it is not taught, but physics students are expected to know how.

> Insufficient experience with math, science, and computer programming courses throughout my primary, secondary, and undergraduate education. Am now struggling with math-related concepts in my field, and also lack basic programming knowledge that would help me execute my experiments more efficiently/effectively.

> Performing Scientific experiments. The design and interpretation of data can bias the results and lead you to wrong conclusions.

> Generating new ideas is the most difficult for me in my career because I am pursuing a career in academia and research and the ability to generate new ideas will be vital to securing research funding.

Gender discrimination

Many participants experienced discrimination and had to say these:

> Male advisors tend to be biased towards men and this is apparent in their behavior and statements. This is very discouraging. I have observed many female biology PhD students in my field drop out specifically because of conflicts with their advisors including verbal abuse and lack of support (academic, financial). Female students who become pregnant are spoken of badly. I feel as though I have to work twice as hard to be recognized as just as good as an equivalent male student.

Males dominated environments tend to underestimate the women's capacities, looking at them as weak, which can diminish ideas and capacities of women in the work area.

Many male scientists behave as if you are not completely dedicated to your research neglecting the rest of your life then you are not a truly serious scientist. I believe that women must work harder than men to achieve the same perceived credibility. They must produce more, and make fewer mistakes if they wish to be treated as equals.

I think that individuals tend to listen to males in my field, if when the males are incorrect.

Females are unconsciously judged more harshly than males. This has been demonstrated with hiring and publication biases.

Role-model:

They identified female role models as critical needs for them:

There are no good female role-models - all women in my field who are successful have sacrificed having children or rising to the highest levels.

> I think the most challenging thing in my career is that there is a lack of female role models. I wish that there were more women who had a successful family and academic life and weren't too old to enjoy it!

Low number. of women:

Participants commented about lower representation of women in their classes:

> I feel a lot of pressure in my field. The lack of women in the field makes it more difficult to get motivated.

> Though there is not blatant sexism it can be difficult in that there are significantly fewer women in my courses. This keeps the pressure on 'representing women well'.

I think it is very difficult to belong to a department with zero female faculty members.

Lack of self-confidence

Participants often wrote about not feeling confident enough to continue research in STEM fields.

> I often do not feel fully qualified and capable of obtaining a PhD even though I

am successful in my lab work and do well in my classes.

Isolation from others while in the laboratory makes me question whether I have chosen the right path.

I do have a lot of men in my field (I am the only woman in my lab), and I feel like they have more self-confidence.

Research Question 2:

What are the most significant barriers perceived by women in PhD programs?

Considering the responses for closed questions and open-ended questions, I concluded with the following list of significant barriers perceived by the women in STEM PhD programs. This in turn will also identify supporting factors for them as well.

Factors acting as significant barriers:

- Work-life balance
- Low self-confidence
- Fewer number of women
- Lack of female role model
- Time-management
- Male dominated environment
- Difficulties with the curriculum
- Gender discrimination

- Two-career problem

It is important to remember here that the last three factors in the above list revealed as barrier according to free responses only whereas the others were identified as barriers in both the free and closed responses.

Factors acted as support:

- Family support/encouragement
- Positive treatment from advisor
- Sufficient funding opportunity
- Absence of sexual harassment

Research Question 3:

Do the barriers faced by women in PhD programs differ by disciplines such as natural sciences, life sciences and engineering?

I conducted a one-way analysis of variance to determine if any significant differences exist among the three disciplines with respect to perceiving barriers. Discipline was considered as the independent variable which had three categories – engineering coded as 1, life science coded as 2, and natural science coded as 3. The total score on all the questions for each participant was taken as the dependent variable. Sample size N, mean values of scores and standard deviation for each group were as shown in Table 3. The result of ANOVA was not statistically significant as $F(2, 127) = 0.103$, $p = 0.902$ >> alpha value of 0.050 (Table 4). Therefore, the difference observed among the three disciplines happened merely due to chance. There is no significant difference among the disciplines in terms of barriers faced by women in PhD programs**.** Follow-up test

(Tukey or Sheffe) was not conducted as the result was not statistically significant.

Table 3: Descriptive Statistics Results

Total score on all the questions

	N	Mean	Standard deviation
Engineering	42	56.62	9.978
Life Sciences	43	55.84	7.819
Natural Sciences	45	55.84	9.472
Total	130	56.09	9.071

Table 4: ANOVA Result

Total score on all the questions

	Sum of Squares	Df	Mean Square	F	Sig
Between Groups	17.216	2	8.608	.103	.902
Within Groups	10597.676	127	83.446		
Total	10614.892	129			

Chapter 5

DISCUSSION

The last chapter begins with a brief revisiting of the findings as analyzed in the previous chapter and discusses some recommendations based on the data obtained. It also mentions the limitations of the present study and in turn talks about future studies. Data from the ASU women doctoral students provided insights into the barriers that need to be reduced or at best can be eliminated in order to help increase the representation of women in science and engineering disciplines especially aiming at retention of more women at the doctoral level.

The findings of the study revealed that a combination of social and environmental factors are responsible for the under representation of women in STEM doctoral studies. These findings are consistent with those of the previous studies in this field but indicated some improvement in the situation of women with respect to perceiving some of the barriers which certainly depicts an optimistic picture. It is evident from the findings of the study that these women participants during their doctoral studies were hindered by issues related to work-life balance, low self-confidence, fewer numbers of women in their classes, lack of female role models, gender discrimination, difficulties with the curriculum, or the two-career problem. Therefore, the cultural and institutional barriers were dominant even in this study and these restricted women's full participation in STEM fields. Women PhD students still experienced an unfavorable academic climate when they tried to remain in the so called "leaky pipeline." Women raised voices against the difficulties they have to face if they choose STEM academic careers after completion of their PhDs. Many participants mentioned the strong contradiction between achieving academic tenure and child-bearing responsibility and they also stated a possible delay or uncertainty about starting a stable family. This finding was the same as the earlier studies conducted by Mason and Goulden in 2002 and Etzkowitz et al in 1994. Thus gender still plays a significant role in excluding women from full participation in science and engineering higher education especially doctoral studies. Some of the respondents wrote about the challenge of adjusting their own career to that of a spouse in the same region. This finding resonated with an earlier study by Etzkowitz et al in 1994. This becomes a special problem if the woman is married with a person from the same field. Although the participants were interested in continuing research, they acknowledged the barriers of low self-confidence. Lack of female role models as well as a low number of women students in classrooms made them feel isolated and insecure which also leads to lack of confidence. Along with the barriers previously mentioned, participants identified the barrier associated with gender discrimination which arises from various cultural stereotypes. Women reported being under-estimated and perceived as not completely dedicated to research in male-dominated fields. The study findings revealed the importance of including more women in the classes to motivate them. In this study, women also expressed their inadequate ability to execute specifics of their curriculum, such as computer programming, understanding and applying mathematical concepts, performing scientific experiments or explaining things in a logical way.

But there were some factors which appeared as supporting for them, such as positive treatment from advisors and there was no gender bias associated with the quality of advising. This is unlike previous study findings (Brainard & Carlin, 1997; Ferriera 2003; Holmstrom & Holmstrom, 1974). Women also mentioned that their families encouraged them to pursue careers in science and engineering and were extremely supportive of their decision of doing a PhD – findings unlike previous studies (Hartman & Hartman, 2008; Andre et al 1999). Moreover, these women did not have much concern related to availability of funding though they expressed it as an important need for continuing their studies. In addition, ASU had been considered a safe place by the majority of the participants as they did not experience any kind of sexual harassment either in their departments or the university.

Based on the outcome of the study, some implications will be discussed that will help increase women's representation in science and engineering disciplines especially at the PhD level. These policies also can improve the experience of anyone studying graduate or undergraduate STEM regardless of the gender and race.

First, science and engineering courses should be revised emphasizing on its social application and benefits to mankind starting from the introductory level. Women and girls will be more interested if they find a connection between everyday life and facts from science. It will become easier to retain women and girls when they can feel that being involved in science and engineering professions will allow them to serve people (AAUW, 2000; Seymour, 1995; Siann & Callaghan, 2001).

Second, information regarding science and engineering careers should be available through information sessions or outreach programs to all girls studying in middle schools. This will help females to make informed decisions regarding their careers. Often girls lack the opportunities to know about different possibilities that science and engineering can offer. Information about various subfields within both science and engineering will allow them to choose the right path. Availability of various course guides, related job prospects, former students' feedback about the courses will enable women and girls to plan ahead about a career which potentially matches with their interests.

Third, fewer major concepts should be introduced at each level with greater depth and should include more hands-on and laboratory based activities. The learning experience should be highly interactive and collaborative learning should be incorporated. If girls and women can enjoy their learning, they will better understand the concepts and will feel confident to continue their education in these fields. Also mutual learning will reduce the feeling of isolation and will make them more comfortable.

Fourth, high school curriculum should offer opportunities to learn computer programming and should increase the number of courses for higher level abstract mathematics, such as, calculus, abstract algebra etc. for those females who wish to remain in the STEM fields. This makes women familiar with the concepts before they arrive at the college and will compensate for the differences in skills with men. These courses should be of longer duration to enhance the possibility of gaining clear understanding. Further, inclusion of mandatory real-life projects into STEM courses should be encouraged in order to help women and girls understand the great value of science and engineering to the society.

Fifth, faculty members and professors should try to maintain a learning environment that is not excessively competitive and unfriendly to women. They should encourage all the women students to participate in class discussion or to accept the leadership responsibility in any kind of team-work. Professors should assign both boys and girls to the same group. Students' wrong responses should not be neglected rather should be used to clear conceptual misunderstandings. More frequent and detailed feedback should be provided for women students who lag behind their peers. Faculty members should strongly encourage women students to contact them and other classmates outside class hours for course related help. Discriminatory behaviors should be avoided from all respects.

Sixth, active recruitment of female faculty should be increased because women faculty positively affects the retention of women students in science and engineering disciplines and in academia (Seymour & Hewitt, 1997; Nelson, 2005) and plays a significant role toward advancement of women on campus as mentioned in the reports of the University of Wisconsin and MIT (University of Wisconsin System, 1999; Hopkins 2002). This way, role models will be available to women students and more mentoring opportunities will be available. Formal and informal mentoring programs are important both for the students and faculty. Mentoring programs guide them about professional development opportunities, networking opportunities and tenure processes. An informal mentoring program is also necessary to encourage female faculty and students.

Finally, the issue of balancing between work and family life faced by women students and faculty probably requires the maximum attention. This issue also affects women's decisions about when to have children or whether to have children at all. Family friendly policies such as stopping the tenure clock during pregnancy and making adjustments to the tenure clock during early stages of child-bearing, offering family-friendly leave policies are some of the steps that could alleviate this issue. Again, many women scientists and engineers are married to male scientists or engineers, often from the same field and face dual-career problems. Institutions should adopt a dual career hiring policy which can help both male and female faculty members (Wenniger, 2001; Wilson, 2001) and also helps academia retain potential women scientists in STEM fields.

Future studies need to be conducted to explore the related research topics involving experiences of women faculty in STEM disciplines. Longitudinal studies would be helpful to develop a better understanding of perceived barriers. Longitudinal data will be able to determine the change in the type and extent of barriers at each year for a specific group of women. Also, studies should be conducted at certain STEM departments where the percentage of females is very low compared to other STEM departments. For example, women from computer science and mathematics departments who had poor participation in this study. Additional studies looking at comparison of perceptions of barriers for both male and female doctoral students can also be helpful to understand the distinction between their experiences.

It is important to remember that the study has some limitations. The study was based on a single institution and only experiences of women doctoral students were considered. Also, the participation in this study was completely voluntary which is different from the sample that does not volunteer. Moreover, this study employed a survey method rather than interviewing women. But this research study is certainly a great addition to the existing literature focusing on the experiences of women doctoral students in science and engineering. It was also crucial to analyze the experiences of those women who managed to persist to the highest academic level in a male dominated area and the role gender played in their careers. It also increased our awareness by identifying some factors that assisted women's retention. In summary, I would say that, the situation is slowly improving and I hope, by focusing on the strategies discussed above, women's participation and retention in the doctoral program in STEM disciplines will likely be increased leading to further advancement of women.

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APPENDIX A

QUESTIONNAIRE

Educational Information:

* Field of study

a) Computer Science
b) Engineering
c) Life Sciences
d) Mathematics
e) Natural Sciences
f) Other (Please specify)

Please rate the statements <u>in bold</u> (1-19) by choosing any point on a scale of 1 to 5 to indicate the extent you agree or disagree with the statements where 1= Strongly Disagree ; 2= Disagree ; 3= Neither disagree nor agree ; 4= Agree ; 5= Strongly Agree. Select all of the sub items in each category that contribute to your rating.

1. I have difficulties balancing work and personal life 1---2---3---4---5

I have difficulty meeting deadlines
I have difficulty taking leave
I have difficulty taking additional work home
I have difficulty finding time for leisure activities
I have difficulty finding time for pastimes with family/friends
I have difficulty taking care of my children (if applicable)
I have difficulty in taking care of older relatives (if applicable)
None of the above

2. I have difficulties balancing two careers 1---2---3---4---5

I live separately from my partner to maintain my career
I have changed my educational institution due to my partner's relocation
I have changed my level of degree (e.g. PhD to Masters) due to my partner's relocation
I have taken a break in my career due to a two-career problem
I had/have geographical constraints on the choice of an educational institution
I had/have geographical constraints on the choice of job
I changed my career goals to avoid confliction with my husband's career
My career has suffered because of my husband's career
My husband's career has suffered because of my career
The break in my career has affected my career goals
None of the above

3. I have family support/encouragement 1---2---3---4---5

I was encouraged by my parents to pursue careers in science/engineering
My parents/other family members helped me in understanding science/mathematics in high school
My parents/guardians are very supportive of my decision to do a PhD
My spouse is very supportive of completing my research successfully
I get moral support from other family members to continue my PhD
None of the above

4. The treatment from my advisor is positive 1---2---3---4---5

My advisor provides effective academic advising
I receive support from my advisor when I face academic problems
My advisor shows interest in me
I do not feel my sex affects the quality of advising I receive
I am given the same opportunity as male students to prove my abilities
My opinion/comments are considered seriously by my advisor
None of the above

5. I am no longer interested in continuing research 1---2---3---4---5

I do not feel any enthusiasm for science
I no longer want to continue my research in science
I regret my decision to do a PhD
I am not very confident of completing a science/ an engineering PhD degree
At the beginning of my PhD, I was confident of completing the degree
I received low grades in most of my courses
I am not interested in continuing my research after completing my PhD
None of the above

6. My self-confidence affects my work 1---2---3---4---5

My personal abilities match those needed to pursue research in science/engineering
I am confident of succeeding in classes critical to my area of study
Someone like me can succeed in a science/engineering career
I have much in common with the other students in my program
I feel afraid asking questions to clear my doubts
I feel uncomfortable if other students watch me doing an experiment in the lab
I feel uncomfortable if my professor watches me doing an experiment in the lab
None of the above

7. My field lacks women role models 1---2---3---4---5

   In my research field, I am expected to follow a “male model” (e.g. working long and irregular hours)
   I think more women role models are needed in science/engineering
   I know very few names of women scientists/engineers
   I am inspired by male scientists/engineers
   None of the above

8. There are low number of women in my field 1---2---3---4---5

   There are fewer female professors in my department than male professors
   I feel isolated because of the lack of women in my field
   I feel insecure because few women are doing research in my field
   Mostly, male peers determine any decision regarding group work
   I feel uncomfortable if all the other people around me are male
   None of the above

9. I am perceived as credible by others 1---2---3---4---5

   Faculty show an interest in me
   Faculty behave equitably toward male and female students
   There is a friendly climate in my science/engineering classes
   Professors encourage positive interactions among all students
   I feel comfortable talking with other students when I have academic problems
   Professors encourage contacting them outside of classes for academic reasons
   None of the above

10. There is a lack of camaraderie among my peers 1---2---3---4---5

   Male peers in my group seek help from me
   Male peers in my group value my opinion
   Other students in my class share my personal interests
   I feel part of the group while working together
   I feel comfortable asking for help from male peers
   None of the above

11. I have difficulties with time-management 1---2---3---4---5

I spend longer hours completing class assignments
I spend more time on TA/RA responsibilities than doing my own research
I spend too many hours in meetings that are not worthwhile
I often get things done at the last minute
None of the above

12. Lack of sufficient funding 1---2---3---4---5

Financial aid at my institution is sufficient
Currently, I do not get financial aid from my institution
The probability of getting funding is very low in the current economic condition
I cannot continue my research studies without funding
I am ready to change my institution if funding problems arise
None of the above

13. Tough competition affects my work 1---2---3---4---5

I feel pressure in mind when there is a tough competition
My performance becomes poor in highly competitive environment
High level of competition leads to lack of collaboration/cooperation among students
None of the above

14. I prefer a non-academic career 1---2---3---4---5

I prefer industrial career over academic career
I think an industrial career is more compatible with family life for women
It is difficult to get a good academic position
None of the above

15. I have experienced sexual harassment 1---2---3---4---5

Sexual harassment is a common occurrence for women in my discipline
The probability of sexual harassment is less in the academic areas of education and the social science than in a science/engineering discipline
I experienced sexual harassment by people in my discipline
Sexual harassment is one of several reasons for women leaving science/engineering
None of the above

16. There is gender discrimination in my field 1---2---3---4---5

In my field, women are considered less dedicated to work than men
Others in my field assume women to be less competent than men
Others in my field assume that women find it hard to work independently
Others assume that women have difficulty working until late at night in the lab
Others assume that women are not comfortable in what might be perceived as an unsafe environment (e.g. fieldwork in a deserted place)
None of the above

17. I am in a male dominated environment 1---2---3---4---5

My field is dominated by men
I am uncomfortable with male professors
I can not learn more from male professors
I feel that women have fewer opportunities to demonstrate their abilities than men in group work
Male students in my group do not consider me as scientist/engineer
None of the above

18. I have difficulties networking 1---2---3---4---5

I cannot relate to the people around me in my classes
I cannot approach new people in my field without feeling intimidated
I do not know many people working in my research area
I have not joined the professional organization (e.g. IEEE, WIE) related to my PhD studies
I cannot make friends with people from different background/values
I do not try to attend conferences/workshops regularly
I do not keep in contact with the people I meet at conferences
None of the above

19. I have a difficulties with the curriculum 1---2---3---4---5

Difficulties in:
Conceptual understanding
Generating new ideas
Performing scientific experiments
Conducting scientific investigation
Making scientific observations

Using mathematical models to present abstract ideas
Conducting rigorous mathematical analysis of results
Writing algorithm/programming
Designing computer simulation
Formulating a scientific problem
Making hypothesis
Inventing new things
Explaining things with facts
Collaborating with others
Solving problems
Awareness regarding current trends of research in my field
None of the above

20. Which of the above factors do you think is the most challenging for your career? Why? Please justify your answer in one to two sentences. *

APPENDIX B

PERMISSION LETTER FROM INSTITUTIONAL REVIEW BOARD, ASU

ASU Knowledge Enterprise Development

Office of Research Integrity and Assurance

To:	Dale Baker EDB
From:	Mark Roosa, Chair Soc Beh IRB
Date:	02/10/2011
Committee Action:	**Exemption Granted**
IRB Action Date:	02/10/2011
IRB Protocol #:	1102005989
Study Title:	Career path barriers of women doctoral students in STEM (Science, Technology, Engineering, and disciplines

The above-referenced protocol is considered exempt after review by the Institutional Review Board pursuant to Federal regulations, 45 CFR Part 46.101(b)(2) .

This part of the federal regulations requires that the information be recorded by investigators in such a manner that subjects cannot be identified, directly or through identifiers linked to the subjects. It is necessary that the information obtained not be such that if disclosed outside the research, it could reasonably place the subjects at risk of criminal or civil liability, or be damaging to the subjects' financial standing, employability, or reputation.

You should retain a copy of this letter for your records.

APPENDIX C

CONSENT LETTER

Hello and Welcome to this survey!

You are invited to participate in our survey which tries to measure the extent to which different factors act as barriers or supports to women doctoral students in acquiring the PhD in STEM fields. The survey will take approximately 30 minutes to complete.

Your participation in this study is voluntary. You can skip questions if you wish. If you choose not to participate or to withdraw from the study at any time, there will be no penalty. The study may not be directly useful to you but will increase your understanding of the barrier faced by women in STEM fields working on their PhD as well as identify supports. There are no foreseeable risks or discomforts to your participation.

Your responses will be anonymous. The results of this study may be used in reports, presentations, or publications but your name will not be used. Only group data will be reported.

If you have any questions concerning the research study, please contact at: dola.chaudhuri@asu.edu or dale.baker@asu.edu. If you have any questions about your rights as a subject/participant in this research, or if you feel you have been placed at risk, you can contact the Chair of the Human Subjects Institutional Review Board, through the ASU Office of Research Integrity and Assurance, at (480) 965-6788.IRB Protocol #: 1102005989

Responses you provide to the survey questions will be considered your consent to participate in this research study.

Thank you very much for your time and support. Please start with the survey now by clicking on the **Continue** button below.

☐ I agree to participate in the survey

APPENDIX D

RECRUITMENT EMAIL

Dear Participant,

I am looking for your help with data gathering for my masters thesis project addressing the barriers for women doctoral students in science, technology, engineering and mathematics (STEM) disciplines. I would appreciate if you would spend sometime to respond to the anonymous survey (link provided below). This survey has been approved for exemption by the ASU Office of Research Integrity and Assurance (IRB Protocol # 1102005989). If you have any questions, please contact me at dola.chaudhuri@asu.edu or my advisor at dale.baker@asu.edu.

Please go to the following URL to start the survey:
http://questionpro.com/t/AEtpIZIs4l

Thank you very much for your time and assistance.
Sincerely,

Dola Chaudhuri
Mary Lou Fulton Teachers College
Arizona State University