

Exploring the experiences of female graduate students in the physical sciences: A comparative study

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Abstract

In this paper, the experiences of female graduate students in physics and chemistry are compared to their male counterparts. The data used in this analysis includes survey responses from 692 currently-enrolled graduate students (34% female). Areas of difference include: timing of first interest in science, sources of initial science interests (including the influence of a parent or mentor and school science lessons), and motivation for entering graduate school. In addition, female students are significantly more likely to report that their dissertation advisors are female and that their advisor's gender was a consideration when deciding to work with them, suggesting that some female students deliberately seek a mentoring experience from another female scientist. The results on the impact of school science lessons and encouragement by a parent/mentor are promising: they suggest that parents and K-12 educators have a genuine opportunity to improve the chances of female students choosing physical sciences as a career.

A persistent problem in the physical sciences is the continued lack of female participants, particularly at the post-secondary level. While female participation in physics and chemistry at the K-12 level has reached virtual parity in recent years, the proportion of females who choose to study the physical sciences at the post-secondary level drops sharply,

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and continues to decline at the graduate level and beyond (Ivie & Ray, 2005; Snyder, Dillow, & Hoffman, 2009). Overall, the proportion of female participants has been increasing for several decades, albeit at a pace that is very slow compared to other science fields (Snyder et al., 2009). For example, female enrollment in undergraduate physics is increasing at a rate of 4% per decade (APS Gender Equity Report, 2007).

At the same time, gaps between male and female performance on a number of mathematics and science measures have either vanished or consistently narrowed for some time (Hyde & Linn, 2006). However, differences in attitudes persist. There is a substantial body of literature showing that females develop depressed attitudes towards the physical sciences by the end of middle school and continuing into high school (Farenga & Joyce, 1999; Jones, Howe, & Rua, 2000). In order to combat the problem of females developing depressed attitudes and expectations, attempts have been made to reform the classroom environment (Gillibrand, Robinson, Brawn, & Osborn, 1999; Haussler & Hoffmann, 2002; Selimbegovic, Chatard, & Mugny, 2007). Notably, Lent, Brown, & Hackett's (1994) work has suggested that improving self-efficacy beliefs of students, particularly females, in physical science will have an influence over their career choices (Lent, Brown, & Hackett, 1994).

A number of questions remain unanswered. Importantly, the long-term impact of K-12 science experiences is unclear. It would be valuable to know whether successfully improving females' attitudes, performance, or expectations in K-12 will improve their persistence in physical science study later at the post-secondary level. Furthermore, for the small group of individuals who persist all the way to graduate school, might gender differences in attitudes or expectations become more negligible? It is plausible that the select group of students who have the desire and fortitude to pursue doctorates in physics and chemistry are more homogeneous than physical science students at earlier stages. It is these questions that are explored in the current study, by comparing attitudes and experiences of males and females who are currently enrolled as graduate students in physics and chemistry.

Methodology

The data used in this analysis was obtained as part of Project Crossover (NSF Award # 0440002), a mixed methods study designed to examine the transition from graduate student to independent researcher in chemistry and physics. The first phase involved the collection of qualitative data through a series of 125 semi-structured, open-ended interviews with graduate students, postdoctoral fellows, industrial scientists and tenured faculty (including two past Nobel prize winners) in chemistry and physics. The interviews focused on individuals' educational experiences (at the K-12, undergraduate and graduate levels) and their subsequent experiences in science (if applicable). Audio recordings of the interviews were transcribed for analysis, and also for hypothesis generation in the second phase.

In the second phase of Project Crossover, a pair of surveys were developed using the results of the interviews to inform their design, as well as prior literature on these topics (Bucher & Stelling, 1977; Golde & Dore, 2001; Gaff, 2002). One survey was designed for currently-enrolled graduate students in chemistry and physics.¹ It contained a total of 130

¹The second survey, not discussed here, was developed for individuals who had already completed their doctorates.

items covering topics ranging from early science motivations, undergraduate and graduate school experiences, scientific activities (publications, teaching loads, etc.) and respondents' attitudes about their satisfaction, career expectations, and research. The structure of most survey items were either Likert-type questions or were non-parametric in nature (such as questions asking respondents to select one or more items from a list of possible responses).

A random sample of 4500 student members was generated from the membership of two national, professional scientific societies. These individuals were mailed paper copies of the surveys as well as provided with uniquely-identifying codes allowing them to respond to the survey over the web. Four reminder notes were also sent to those individuals who had not yet responded over a period of six months following the initial mailing. From the original sample, 475 were determined to have contained non-deliverable addresses (out of date, invalid, etc.), and 240 individuals were determined to not be qualified to take the survey (non-graduate students who erroneously appeared on these mailing lists, undergraduate students, etc.). Thus, the number of qualified individuals who had correct mailing addresses who comprised the original sample was determined to be 3,785. In total, 1065 of these individuals responded to the survey, which corresponds to a response rate of 28.1%. Of the respondents, 57% were students enrolled in chemistry programs, and 43% were enrolled in physics. Also, 34.0% of the respondents were female.

Once the survey data had been collected, it was collated and coded for statistical analysis. Once individuals who did not respond to the specific survey questions of interest in the current analysis were eliminated, a total of 692 individuals remained in the results quoted below. Two main types of statistical tests were used to compare the responses of males and females: for questions that had a linear scale, a set of analysis of covariance (ANCOVA) tests were carried out to compare responses of these two groups while controlling for the subject area of graduate enrollment (chemistry or physics); for non-parametric questions, a set of logistic regression analyses were run that also compared response rates of these two groups while controlling for subject area. The primary reason for using such tests (rather than simpler ANOVA and Mann-Whitney U tests) was to account for the variance that would arise due to subject area (chemistry/physics), as it was expected that the culture of each discipline would play a significant role in the domains under consideration and females form a greater proportion of chemistry students than physics. Thus, in all of the results that follow, one may assume that differences arising from subject area are not confounding the main effects.

Results and Discussion

The variables in which statistically significant differences between males and females were found are listed in Table 1 (nonparametric variables) and Table 2 (linearized variables). Most of the statistically significant differences were found for nonparametric variables; this is due to the predominance of this type of item that appeared on the survey. Many of the questions related to science interests, experiences, and attitudes were best approached by this type of question. There are several domains in which differences were found; for clarity, thematically-related results will be discussed together below.

Early Science Interests

The domain in which the largest number of differences were found is that of early science interests. One question asked respondents to indicate when they first became interested in science in general; females were significantly more likely to indicate that this occurred between 6th and 8th grade, 31% rather than 20%. This result reinforces other findings which have found that middle school is a key time to encourage females' science interest (Selimbegovic et al., 2007). Individuals were also asked to characterize the nature of their family's interest in science. Females were more likely to indicate that their family encouraged science to the same degree as other academic pursuits (53% vs. 45%) but were less likely to indicate that science was not a family interest (22% vs. 29%). These results suggest that females who come from families with little or no science encouragement are relatively less likely than males to pursue science (Andre, Whigham, Hendrickson, & Chambers, 1999).

Individuals were asked to indicate the top two sources for their initial interest in science. Several differences were found in responses, which lead to suggestions towards the more effective recruitment of females into the physical sciences. In particular, females were more likely to indicate that a parent's encouragement (19% vs. 12%), another mentor's encouragement (18% vs. 8%), or school science lessons (34% vs. 21%) were important sources of science interest. Also, females were more likely to indicate that receiving good grades/awards was a source of interest (36% vs. 26%) and were less likely to indicate that they enjoyed tinkering (10% vs. 19%) or that they enjoyed thinking about science (33% vs 49%). These results are consistent with the idea that females' self-efficacy through encouragement and performance is an important predictor of persistence (Lent et al., 1994) and other work that indicates boys have more early science experiences (Jones et al., 2000).

Graduate School Motivations and Research Experiences

With respect to many questions on students' current research groups, the nature of advisor/advisee relationships, graduate coursework, teaching loads, and expectations towards graduation and career success, no significant differences were found between males and females. This may be due to the heavy degree of socialization that graduate students undergo once they finally reach this stage of their studies (Bucher & Stelling, 1977); this may also be due to Type II error resulting from the high degree of variance in graduate research experiences.

However, there were a few areas of differences that were found. Similar to their initial science interests, females' motivation for entering graduate school were found to be less likely due to their enjoyment of thinking about science (31% vs. 45%) and more likely due to a general uncertainty towards their future plans (17% vs. 11%). Females tended to indicate that they spent somewhat less time per week on research-related activities (45.7 ± 1.2 vs. 49.9 ± 0.9 hrs) but also indicated that they preferred to spend less time on research-related activities per week (42.5 ± 0.9 vs. 48.0 ± 0.8 hrs). These latter results may suggest that female students are less willing to abandon a reasonable work-life balance. For related discussion, see (APS Gender Equity Report, 2007).

Table 1: Significant results of logistic regression tests for non-parametric variables.

Domain	Variable	% of Females	% of Males	Significance ^a
A	First interest in science in 6 th - 8 th grade	31	20	**
	Family interest in science:			
	Same as other pursuits	53	45	*
	Science not an interest	22	29	*
	Source of initial science interest:			
	Good grades/awards ^b	36	26	**
	Parent's encouragement	19	12	**
	Mentor's encouragement	18	8	**
	Enjoyed tinkering	10	19	**
	Enjoyed thinking about science	33	49	***
School science lessons	34	21	**	
B	Reason for entering graduate school:			
	Enjoyed thinking about science	31	45	**
	Uncertainty about future plans	17	11	*
	Advisor's gender is female	15	8	*
	Advisor's gender was a consideration	13	3	***
C	Improving the advisor selection process:			
	More contact with senior graduate students	14	20	*
	More opportunity to gain research experience	40	31	**
	No changes need to be made	7	12	*
N		234	458	

^a*, p<0.05, **;p<0.01, ***:p<0.001

^bFor this question, note that individuals each gave two responses so, in total, the response rates quoted sum to greater than 100%; adding rates for all possible responses – not just those appearing in this Table–sum to 200%.

Table 2: Significant results of ANCOVA tests for linearized variables.

Domain	Variable	Females (Mean ± SE)	Males (Mean ± SE)	Significance ^c
B	Average number of research hours / week	45.7 ± 1.2	49.9 ± 0.9	**
	Preferred number of research hours / week	42.5 ± 0.9	48.0 ± 0.8	***
C	Female percentage of research group ^d	42.2 ± 1.6	23.5 ± 0.9	***
		N	234	458

^c**:p<0.01, ***:p<0.001

^dThis result needs to be treated with some skepticism. See text for discussion of this finding.

Gender of Advisor and the Advisor Selection Process

One area within the graduate experience in which notable differences were found was with respect to the selection of dissertation advisors. Female students were more likely to indicate that their dissertation advisor was female (15% vs. 8%) and were more than four times as likely to indicate that their advisor's gender was a consideration when deciding to work with her/him (13% vs. 3%). It is worth noting that, nationally, only 10% of faculty in PhD-granting physics departments are female (AIP Statistical Research Center, 2006) and 11.9% of faculty in PhD-granting chemistry departments are female (ACS Committee on Professional Training, 2008), which means that female graduate students apparently choose female advisors at somewhat higher than average rates, while male students choose female advisors at slightly lower rates. A related result is that female students reported a substantially larger percentage of their group as being female ($42.2 \pm 1.6\%$ vs. $23.5 \pm 0.9\%$); however this finding must be treated with some skepticism. In fact, due to the way in which research group sizes were collected, the data is actually ambiguous as to whether or not this result means that females cluster together in research groups.

Student respondents were asked to indicate ways in which the advisor selection process could be improved. Females were more likely to indicate that they would prefer more opportunities to gain research experience (ie. lab rotations)—40% vs. 31%—but were less likely to indicate that they would prefer more contact with senior graduate students (14% vs. 20%) or that they thought no changes need to be made (7% vs. 12%). These results may reflect some gender differences in the level of satisfaction with individuals' dissertation advisors.

Issues for Further Investigation

Our finding on the potential of school science lessons to impact female participation in physical science are encouraging. This implies that work such as Gillibrand et al (1999) and Selimbegovic, Chatard, & Mugny (2007) that explored ways in which differential female attitudes/performance can be influenced by classroom reform may, indeed, have long-term importance to the careers of female scientists (Gillibrand et al., 1999; Selimbegovic et al., 2007). Of course, the current results are too broad to say precisely what aspects of school science lessons will help to encourage females in the physical sciences but should, nonetheless, encourage more research in this direction. Furthermore, our results on the importance of family support to female science students is consistent with earlier work (Andre et al., 1999).

Another area that requires further investigation is the question of whether there is a "clustering" effect of female students in graduate studies. The current results showed that female students do, indeed, tend to select female dissertation advisors at higher-than-average rates, although it remains unclear whether there are "other" females they also group with. This may be due to the continued dearth of females at the graduate level—it may still be too rare for females to have the opportunity to choose to join a research group with two or more other females.

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