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Factors Associated with Female Chemist Doctoral Career Choice within the Physical Sciences

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Supporting Information

ABSTRACT: Research shows that women are entering the field of physics at a faster rate than the field of chemistry through bachelor's and doctoral degrees. However, STEM studies primarily compare women to men or examine them as a single entity. Therefore, a paucity of research exists that examines what may differentiate women in certain critical and underrepresented fields of STEM education, such as the physical sciences. The focus of this study is to examine differences among women in chemistry in the physical sciences based on background demographics and motivational factors such as academic achievement and experiences ranging from secondary through postsecondary education. This study examines the following research question: *On average, do females who select chemistry as compared to physics doctoral programs differ in their reported personal motivations and background factors prior to entering the field?* This question is analyzed using variables in a logistic regression from the Project Crossover Survey data set through a subset of female physical science doctoral students and scientists ($n = 1137$). Results show that females who have higher secondary and postsecondary grades and positive experiences in postsecondary chemistry as well as negative postsecondary physics experiences are more likely to enter the field of chemistry as opposed to physics. Therefore, success and experiences in entry-level chemistry courses are critical for female entry into the field and should be further examined. Overall, analyses show that women should not be studied in comparison only to men or as a single entity; they should also be compared to one another to uncover what motivation and background variables influence them to enter a particular field.

KEYWORDS: *Women in Chemistry, Graduate Education/Research, First-Year Undergraduate/General, General Public*

FEATURE: Chemical Education Research

INTRODUCTION

According to the National Academy of Sciences[1] and U.S. Department of Education,[2] development of a STEM workforce is necessary to ensure that the U.S. remains competitive in the global economy. Current estimates show that the science, engineering, and technology workforce comprises 4% of workers in the U.S. Yet, the U.S. Department of Labor estimates that by 2018, 9 out of 10 of the fastest growing professions will be in fields that require at least a bachelor's degree in science or mathematics.[3]

Based on these concerns, the NAS[1] released a formal report, *Rising Above the Gathering Storm*, with recommendations for how to improve the U.S. STEM workforce. A primary emphasis has been a focus on increasing the number of women pursuing and achieving success in STEM education and careers.[1] This report and recent research calls for a focus on early background and motivational factors such as demographic factors, interest, family influence, academic achievement, and secondary and postsecondary experiences in order to examine what may influence female persistence, degree attainment, and career choice.[1,2,4−14] In particular, these reports emphasize the lack of women in such degree programs and areas of STEM expertise as doctorates in chemistry.[1,2,4] From the perspective of the field, women have the potential to make significant and critical contributions to work in chemistry. From the perspective of individuals, entrance into the chemistry workforce could help women obtain higher salaries and maintain a better standard of living, as chemistry careers are often better paid.[15]

Women have made significant gains when it comes to representation in bachelor's degrees in all STEM fields (see Figure 1).[3] Strikingly, females remain unequal in almost all other doctoral degrees except agricultural and biological sciences (see Figure 2).[3] Due to this under-representation of women, educational research and policy has focused on what causes a difference of representation between men and women in certain STEM bachelors and doctoral degree programs such as chemistry.[4]

WOMEN IN CHEMISTRY

One area of interest has been how to bolster female representation in chemistry.[4] Over a 45-year time period female representation has increased within chemistry degree programs. Women earned almost one-fifth of chemistry bachelor's degrees in 1966 (see Figure 1).[3] As of 2011, women earned about one-half of bachelor's chemistry degrees (see Figure 1).[3] The current proportion of females in chemistry doctoral degrees is slight in comparison to the proportion of bachelor's degrees. Women received over 1/20 of chemistry doctoral degrees in 1966 (see Figure 2).[3] In 2011, females received over one-third of chemistry doctorates (see Figure 2).[3]

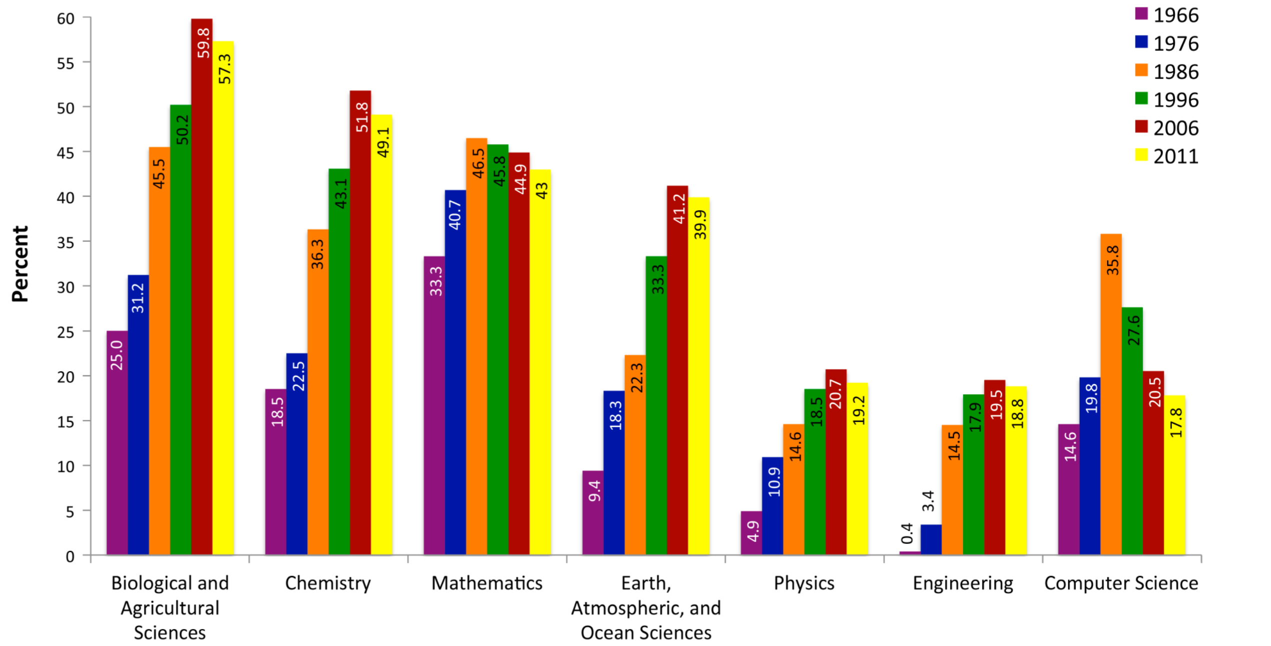

Figure 1. Proportion of bachelor's degrees earned by women in selected STEM fields, 1966–2011.[3]

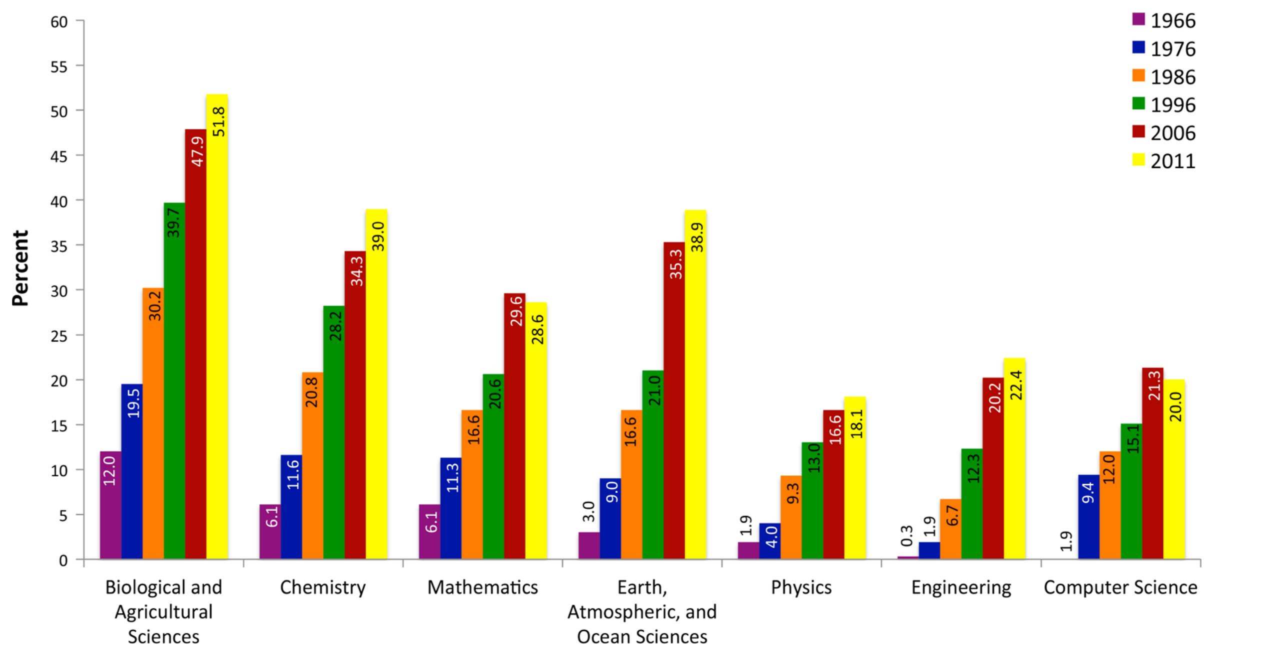

Figure 2. Proportion of doctorates earned by women in selected STEM fields, 1966–2011.[3]

Although women have made gains in representation, they still remain underrepresented in chemistry doctoral degrees. Looking across the proportion of women in STEM fields there is also the difference between representations of women in chemistry in comparison to other fields.

Females in physics have similar entry-level postsecondary courses to receive bachelor's degrees and enter into doctoral programs. Females received 1/20 of physics bachelor's degrees in 1966 (see Figure 1) and almost one-fifth of physics bachelor's degrees in 2011 (see Figure 1).[3] Females earned 1/50 of physics doctoral degrees in 1966 and about one-sixth of physics doctorates in 2011 (see Figure 2).[3] Research has yet to comparatively examine how females are closing the gender gap at a faster rate in the field of physics as compared to chemistry bachelor's and doctoral degrees and how to encourage a continued growth of female representation in chemistry.[16]

One method of promoting advanced science education of women has been the use of outreach and mentoring programs, such as the COACh program, to provide guidance and support to special interest groups both academically and professionally once they are in doctoral degree programs and fields.[17,18,1] The focus of this work has been on retention of female doctoral and academic scientists. Yet an examination of what motivates these female students and STEM doctoral graduates to enter specific doctoral programs of science such as chemistry in the first place is essential.[19] Despite longstanding educational efforts, females are still underrepresented at the doctoral level in chemistry. Research must target certain subpopulations in specific fields of study to truly understand the factors that are associated with entrance into graduate school and persistence of students.[20]

What we do know is that women, in comparison to men, are less likely to receive doctorates in chemistry, and when they do, they are also less likely to achieve tenure positions and tend to make lower salaries.[4,21] Theories and studies abound including lack of interest,[22] chilly climate,[23−29] lack of critical mass of women and jobs,[30,31] and conflicts between family and work life[32] as to why women in comparison to men do not persist in STEM fields.[17,18,33,34] The majority of this work examines factors that influence female persistence in their doctoral fields of study. Therefore, many questions still remain unanswered as to why existing background and motivation supports prior to entrance into doctorate fields of chemistry are not sufficient.[4]

There is a growing body of STEM research that indicates that a wide variety of background and motivational factors are associated with student persistence, degree attainment, and career choice in STEM. These motivational and background factors include such variables as demographic factors,[4,14] interest,[5,6] family influence,[7,8] academic achievement and self-efficacy,[9−11] and postsecondary experiences.[12,13]

Research of postsecondary classroom experiences shows that women in STEM have a preference for slower-paced content classes,[12] a focus on the role of being an altruistic scientist,[13] and smaller classrooms settings.[35] However, these studies focus on generalized STEM outcomes or gender comparisons and are inadequate when it comes to a thorough analysis that differentiates between women in different fields of study, such as doctorates in chemistry. This area of research may be the key to gaining a fuller understanding as to how we can encourage women to enter doctoral fields of chemistry.

In the end, women are better represented in bachelor's degrees in chemistry. The shift in attrition, however, occurs when they later enter doctoral programs.[3] Interestingly, women are closing the gender gap in the field of physics at a faster rate than in chemistry (Figure 2).[3] Research and theories tend to focus on variables within and following doctoral programs that promote female persistence and entrance into STEM fields. However, motivation and background variables preceding acceptance into doctoral programs such as chemistry are often overlooked. Current research examines female chemists and scientists in comparison to men or as a separate unit, meaning that little work exists that examines the differences within women in science prior to acceptance into doctoral programs. Therefore, instead of asking why females and males differ in their entrance into science fields, perhaps we should examine what causes females to enter one science field, such as chemistry, as opposed to another?

■ RESEARCH QUESTION

The significance of this study is its ability to provide a clearer picture of what factors may influence female entrance and persistence in chemistry. It will provide motivation and background variables that are associated with a career choice in chemistry. To date, the majority of literature examines career choice across gender, male to female, as opposed to within gender, female to female. One strength of this research is its ability to compare women's career choice of chemistry as opposed physics based on these early motivational and background experiences. This study includes research based on factors such as family influence, individual interest, achievement, undergraduate experience, and demographic influences on science career choice in the United States. Variables will range from early interest, potentially prior to school, and academic experiences through elementary school, middle school, high school, and college. A clearer knowledge of female career choice based on these factors and seminal experiences in the physical sciences can provide educational policy makers with research to better influence science education decisions in the United States.

This study examines female entry into chemistry doctoral programs through the following research question: *On average, do females who select chemistry as compared to physics doctoral programs differ in their reported personal motivations and background factors prior to entering the field?*

■ METHODOLOGY

This analysis examines data from Project Crossover survey. Project Crossover is a sequential mixed methods study that examines variables influencing entrance into physical science doctorate programs in addition to the transition from graduate students to independent scientists. The preliminary portion of the study used semistructured interviews of 125 physical science doctoral students and scientists to generate research hypotheses regarding this phenomenon in order to develop the subsequent Project Crossover survey. Interviews varied from 30 min to 2.5 h and included doctoral students, postdoctorates, faculty, and scientists. All interviews were recorded and transcribed for analysis and examined to generate research hypotheses to develop the subsequent Project Crossover survey.

Epidemiological survey methods were used in Project Crossover, which rely on the variation of the background and experiences of individuals who enter the physical science field as doctoral students or scientists. This method was used instead of an experiment consisting of treatment and control groups, which would be unfeasible in this case given the independent variables examined.[36] Although this research is not causal, it provides the ability to show either that a relationship does not exist or identify relationships that are associative and, therefore, worthy of follow up studies in the future. Similar methods have been used in other fields such as public health.[37]

The accuracy and reliability of self-report through survey depends primarily on context, relevance, and survey clarity.[38,39] In a review of existing research on self-report, Kuncel, Credé, and Thomas[40] concluded that self-report may be characterized as particularly accurate in samples where the surveys address issues relevant to the respondents. This survey falls into that category as it is conducted with professional physical science doctoral students and scientists where participants' reflection on their prior experience is commonplace.

The Project Crossover survey was developed from prior research within the field as well as the aforementioned interview data and consisted of 145 questions. Themes examined in the survey included demographics and background experiences such as interest, experiences, academic achievement, and occupational variables following doctoral completion. A list of prospective participant names was obtained from the American Physics Society and the American Chemical Society. In 2007, a random sample of 17,500 individuals were sent online and hard copies of the survey. Of this random sample, 3,600 did not fit the respondent group as they were nonscience degree holders and 550 of the surveys were undeliverable and therefore returned. A total of 4,285 participants returned completed surveys from the 13,350 possible survey respondents for a response rate of 32.1%.

The final survey sample consisted of physics and chemistry doctoral students, researchers, and holders of other physical science doctorates. The Project Crossover sample was found to be nationally representative based on a comparison to the National Science WebCASPAR data set with a focus on employment backgrounds (universities, profit, government agencies, nonprofit, and other) and demographics (race, ethnicity, and gender).[41]

The Sample

Analyses within this paper focus on the comparison of female physical science doctoral students and scientists. Project Crossover has a large sampling of female physical scientists and, therefore, is particularly relevant to the following analyses. A total of 1,221 or 28.5% of Project Crossover respondents are women. The sample for this paper consists of 1,137 female respondents because of listwise deletion of 13 participants with multiple responses for predictor and control variables as well as missing career outcome data for 71 participants (See Table 1).

Table 1. Sample Summary Comparison of Female Physical Doctorate Students and Scientists

Physics Doctorate Students	80
Chemistry Doctorate Students	234
Total Responding Doctorate Students	**314**
Physicists	271
Chemists	552
Total Responding Scientists	**823**
Total Sample	N = 1,137

The sample includes 80 female physics doctorate students, 234 female chemistry doctorate students, 271 female physicists, and 552 female chemists. The Project Crossover survey contains one of the most detailed sources of data of females from primary through postsecondary education in the physical sciences.

Analytic Approach

Analytic approaches contained in this study include descriptive analyses, variable correlations, and a logistic regression analysis. A description of each method of analysis and the reason for its selection in this study is detailed below.

Descriptive Analyses

Descriptive analyses were run for demographics and background variables for all participants in this study. Furthermore, these analyses were used to determine central tendency and to check for assumptions regarding logistic regression analysis prior to using the analytic methods of logistic regression analysis. The data met all of the assumptions regarding logistic regression analysis including outliers, normality, homogeneity of between group variance/covariance matrices, and the assumption of linearity.[42]

Variable Correlations

Following a series of descriptive analyses, all control and predictor variables were checked for potential collinearity, or significant correlations, in the data. Significant correlations in the variables could influence the significance of the predictors, in addition to any potential outcome of any subsequent logistic regression analysis.[42] Therefore, collinearity was examined through cross tabulation with a series of Pearson correlations. Composite variables were created where appropriate due to the unique nature and representativeness of the factors in the data set.

Logistic Regression Analysis

The research question in this study seeks to examine whether there is a difference in background and motivation factors between females who select a career in chemistry or physics and whether this predicted or influenced a career choice in chemistry.

Logistic regression analysis is the analysis of choice for differentiation between chemistry and physics career choices with control and predictor variables that were continuous and dichotomous.[42] In addition, multivariate assumptions are more lenient in logistic regression models with regard to predictor variables in the separate outcome variable selections.[42−44] Therefore, data analysis for the research question was completed with a logistic regression analysis due the larger flexibility of multivariate assumptions and the capability to account for all control and predictor variables therein in the model. SPSS 19.0 was used to complete the logistic regression model.

Logistic regression analysis imparted several strengths to this study. First, the results provided parsimony to the description of females in the physical sciences, and second, the interpretation of this data was quite clear. In regard to the Project Crossover survey, descriptives of 16 motivational and background variables were examined of women in chemistry and physics. Second, logistic regression analysis singled out the variables in the model that have significant residuals through significance tests. Significant control and predictor variables were reported with relevant odds ratios that provide the reader with a better understanding of how these variables predict female career choice in the physical sciences.[42] Finally, McClelland and Judd[45] note that interaction effects are not required to examine the results of this study. Nevertheless, a few pertinent interactions were reviewed of control and predictor variables to further distinguish that significant predictor variables were associated with the physical sciences career outcomes in the models.[42]

Logistic regression analysis was used in this study with the outcome of female chemists as opposed to physicists. The logistic regression model contained the full sample of participants and examined the descriptive background and motivation predictors that will be described more fully below. Altogether, with dummy-coded variables for race, ethnicity, and citizenship, these analyses included 16 variables. The large number of variables selected for these analyses was not a concern because of the relatively large sample size (1,137) in comparison (see Table 1). Given that the sample size to variable ratio was quite large (1,137 to 16, or 71 to 1), the resulting standard coefficients and correlations were stable and provided for more reliable descriptive analyses.[43,46,47]

Outcome Variables: Female Chemist

Prior research usually examines females in comparison to men as opposed to in comparison to one another to determine demographic and background variables in STEM.[48,49] Recent research had determined that comparative analyses could be utilized to examine females within the physical sciences based on these variables.[50] This study provides the ability to determine what variables may predict women's entrance into underrepresented fields such as chemistry within the physical sciences and, therefore, inform educational public policy in STEM fields.[51] As always, the results of a logistic regression should be utilized with caution, as they are correlational and not causal.

Project Crossover Survey Question 2 examines whether participants were in the doctoral fields of physics or chemistry. Female participants reported that 30.9% had entered the field of physics and 69.1% had entered the field of chemistry.

Predictor Variables

Predictor variables in this series of analyses included average grade in secondary chemistry, average grade in postsecondary chemistry, and experiences in postsecondary chemistry (see Figure 3). The chemistry questions provided below are identical to the physics questions, but with the word chemistry replaced by physics. Academic achievement and experiences have been correlated with entrance and persistence within both physical science and STEM fields.[50,52,53]

22. Please indicate your average grade in your CHEMISTRY course(s) during high school.
○A+ ○A ○A- ○B+ ○B ○B- ○C+ ○C ○D ○F ○N/A

24. Please indicate your average grade in your CHEMISTRY course(s) during undergraduate studies.
○A+ ○A ○A- ○B+ ○B ○B- ○C+ ○C ○D ○F ○N/A

26. On average, how would you characterize your experiences in undergraduate chemistry?
Please choose a number on the scale, with 1 being "Strongly negative/discouraging" and 4 being "Strongly positive/encouraging".

Strongly negative/discouraging (1) (2) (3) (4) Strongly positive/encouraging ○ I did not take any undergraduate chemistry courses

Figure 3. Questions 22, 24, and 26 from the Project Crossover Survey.

Grades for secondary and postsecondary physical science courses were independently dummy coded based on the following grades: A or B. Positive postsecondary chemistry experiences were dummy coded so that a negative experience was coded as 0 and a positive experience was coded as 1. Whereas negative postsecondary physics experiences were dummy coded so that a negative experience was coded as a 1 and a positive experience was coded as a 0. All academic achievement and experience variables were separately entered into the logistic regression model.

Control/Demographic Variables

STEM career[6] and gender literature[54,51] was used to determine which control variables were placed in this logistic regression model. The following Project Crossover Survey control variables were examined for a career outcome of chemistry: year of birth, racial/ethnic group, citizenship status, family interest in science, highest level of education completed by guardians, first interest in general science, and first interest in physics/chemistry.

Missing Values

All outcome, control, and predictor variables were examined for missing data prior to developing a logistic regression analysis. These missing percentages are reported in Table 2. Missing data analysis was used to find out if data was missing completely at random, missing at random, or not missing at random. Rubin[55] and Enders[56] recommendations were consulted based on this analysis to decide what missing data procedures may be necessary.

No systematic bias was found in the data, as the predictor and control variables did not differ due to the outcome career choice of chemistry or physics. Missing data procedures were not used based on this lack of systematic bias and low percentages of missing data.

Table 2. Project Crossover Sample Missing Data

Variable	Percent Missing
Race and Ethnicity	0.0
Age	1.6
Highest Parent Education	7.1
Citizenship Status	0.5
Family Interest in Science	0.0
General Interest in Science by K−5	0.0
Interest in Physical Science by K−5	1.1
Secondary Physics grade	1.7
Secondary Chemistry grade	1.3
Postsecondary Physics grade	0.9
Postsecondary Chemistry grade	1.0
Postsecondary Physics Experience	1.8
Postsecondary Chemistry Experience	1.4

RESULTS AND CONCLUSIONS

Analyses of female physical science doctoral students and scientists in this study are divided into the following sections: descriptive analyses, variable correlations, and logistic regression analysis. These analyses and tables were developed from the dissertation work of Dabney (2012).[57] Descriptive analyses include a report of the sample and variables, which examine demographics, interest, achievement, experiences, and chemist or physicist career choice. Variable correlations assess collinearity and connections prior to regression analyses. The logistic regression analysis examines female motivation and background factors associated with a career choice in chemistry as opposed physics.

Descriptive Analyses

This section will provide a review of the sample and a series of descriptive analyses regarding all control, predictor, and outcome variables in this study. These background factors are examined as a means to provide the reader with an understanding of the variables, including general distribution and trends. Sample representation of variables is not meant for causal or associative purposes but instead to provide a basic knowledge of the variables that will be used in the logistic regression analysis later examined in this study.

Demographics. The race and ethnicity distribution for this study is provided in Table SI1 in the Supporting Information. A total of 72% of respondents were Caucasian, 19% were Asian/Pacific Islander, 5% were African American, 4% were Latino/Hispanic, and Native American and those who selected the Other option comprised 1% of the sample. Ages in the sample, shown in Supporting Information Table SI2, ranged from 21 to 102, with the majority of respondents being age 25 to 44. A composite variable was created for the highest reported education between the mother and father of each participant (see Supporting Information Table SI3). Highest parent education had a slight negative skew. A total of 58% of the sample reported their parent had a bachelor's degree or less education. In regard to citizenship, the majority of the sample, or 67%, reported being a U.S. citizen (see Supporting Information Table SI4). A total of 23% of respondents had either a green card or temporary visa, and 9% were naturalized citizens of the U.S.

Interest, Achievement, and Experiences. Family interest was reported as a continuous variable in this analysis, ranging from 0 to 4. Here, participants were asked to mark all statements that applied to their family's past interest in or support of science. Therefore, if a participant marked a 0, then they reported no family interest in science, whereas a 4 would indicate four specific types of family interest in science. The majority of the sample, or 67%, reported that their family had no interest in science or one instance of family interest in science. See Supporting Information Table SI5 for a full description of family interest.

Aside from family interest, personal science interest was reported with regard to both general science and the physical sciences. The series of analyses here focus on respondents that showed an early interest in these two forms of science prior to the fifth grade. Specific to this sample, a large percentage of participants, 41%, indicated a general interest in science before fifth grade (see Supporting Information Table SI6). With regard to physical sciences interest, only 8% of participants reported an interest prior to the fifth grade (see Supporting Information Table SI7).

Subsequent to variables of interest, academic achievement, or grades, were examined. This study focused on academic achievement in high school chemistry (see Supporting Information Table SI8) and physics (see Supporting Information Table SI9). Sample respondents indicated that their high school chemistry grades were distributed as 84% achieved an A, 11% achieved a B, and 2% achieved a C, D, or F. High school physics grades showed a similar trend, with participants indicating that 72% achieved an A, 16% achieved a B, and 2% achieved a C, D, or F.

A similar trend was found in the distribution of undergraduate grades in chemistry (see Supporting Information Table SI10) and physics (see Supporting Information Table SI11). Specific to undergraduate chemistry, 61% of the sample had an A, 27% had a B, and 2% had a C, D, or F. Sample participants also indicated that their distribution of undergraduate physics grades were: 57% had an A, 35% had a B, and 6% had a C, D, or F.

Next, this study examined whether participants reported a general negative or positive experience in their undergraduate chemistry (see Supporting Information Table SI12) and physics courses (see Supporting Information Table SI13). A total of 75% of sample respondents indicated a general positive undergraduate chemistry experience. Furthermore, 65% of sample participants indicated they had a general positive experience in their undergraduate physics course.

Chemist or Physicist. Analyses reported in the descriptive statistics have been examined as a total sample and in the perspective of whether females choose a career in either chemistry or physics. A more in-depth look at the percentage of students and scientists in chemistry and physics (see Supporting Information Table SI14) may provide a better understanding of the sample as a whole. Overall descriptive analyses indicate that 28% of the participants were doctoral students at the time of survey completion, whereas 72% were scientists with a completed Ph.D.

Variable Correlations

Significant correlations, or collinearity, between variables could potentially make it hard to determine the significance of these variables in the logistic regression analysis. Due to this concern, a series of Pearson correlations were run for all control and predictor variables in the data set. Only one set of variables, mother and father's highest level of education, were combined due to a significant correlation (0.466, $p < 0.01$). These variables were combined so that the highest level of education reported between the mother and father remained in the data set under a new variable labeled highest parent education.

Race/ethnicity and citizenship status variables also included the following significant correlations: Asian and U.S. citizenship status (0.508, $p < 0.01$) and Asian and green card/temporary visa status (0.418, $p < 0.01$). Further significant correlations were found for Caucasian and U.S. citizenship status (0.553, $p < 0.01$) and Caucasian and green card/temporary visa status (0.436, $p < 0.01$). Due to this series of correlations, race and ethnicity were further examined in relation to citizenship status of participants. Female physical scientists who were U.S. citizens showed the following race and ethnicity representation: 87% ($n_{total} = 667$) were Caucasian, 4% ($n_{total} = 29$) were Asian/Pacific Islander, 3% ($n_{total} = 25$) were African American, 2% ($n_{total} = 17$) were Latino/Hispanic, and 3% ($n_{total} = 25$) were Native American/Other. Green card and temporary visa holders were more widely represented, with 37% ($n_{total} = 98$) being Caucasian, 46% ($n_{total} = 122$) were Asian/Pacific Islander, 6% ($n_{total} = 15$) were African American, 6% ($n_{total} = 15$) were Latino/Hispanic, and 6% ($n_{total} = 15$) were Native American/Other. Naturalized citizens in the sample were distributed as 35% ($n_{total} = 36$) Caucasian, 43% ($n_{total} = 44$) Asian/Pacific Islander, 4% ($n_{total} = 4$) African American, 11% ($n_{total} = 11$) Latino/Hispanic, and 8% ($n_{total} = 8$) Native American/Other. Although the connection between race, ethnicity, and citizenship status provides a greater understanding of the representation of female participants, the variables were not combined due to their unique demographic measurement and representation in the data set.

Final significant correlations were uncovered among variables regarding undergraduate academic achievement and experiences. Specifically, undergraduate grade in chemistry was significantly correlated with positive experience in undergraduate chemistry (0.549, $p < 0.01$). In addition, undergraduate grade in physics was significantly correlated with positive experience in undergraduate physics (0.438, $p < 0.01$). A more in-depth look showed that participants with positive undergraduate chemistry experiences reported the following grade distribution: 72% ($n_{total} = 609$) achieved an A, 26% ($n_{total} = 216$) achieved a B, 1% ($n_{total} = 5$) achieved a C or less, and 1% ($n_{total} = 12$) did not report a grade in chemistry. Participants with a negative undergraduate chemistry experience had the following distribution of grades: 40% ($n_{total} = 75$) had an A, 49% ($n_{total} = 91$) had a B, 10% ($n_{total} = 19$) had a C or less, and 1% ($n_{total} = 2$) did not report a chemistry grade. A total of 71% ($n_{total} = 515$) of participants with a positive experience in undergraduate physics achieved an A, 27% ($n_{total} = 199$) achieved a B, 1% ($n_{total} = 6$) achieved a C or less, and 1% ($n_{total} = 7$) did not report a physics grade. Participants with a negative undergraduate physics experience had the following distribution of grades: 31% ($n_{total} = 113$) had an A, 52% ($n_{total} = 191$) had a B, 16% ($n_{total} = 58$) had a C or less, and 1% ($n_{total} = 5$) did not report a physics grade. Overall, participants with positive undergraduate experiences had a greater percentage of higher grades as undergraduate students in either chemistry or physics. In addition, participants with negative undergraduate experiences had a greater percentage of Bs or Cs or less. Undergraduate experiences and grades in chemistry or physics were not combined due to their ability to paint a more detailed picture in the analyses that followed and, as described in below, this set of variables remained significant regardless of their simultaneous placement in within the logistic regression model.

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Table 3. Logistic Regression Model Summary with Odds Ratio

Variables	B	SE	Wald	Significance	Odds Ratio [EXP(B)]	95% C.I. for EXP(B) Lower	95% C.I. for EXP(B) Upper
Intercept				Included			
Demographic/Background				Included			
Secondary Physics grade	−0.059	0.036	2.758	n.s.	0.942	0.878	1.011
Secondary Chemistry grade	0.119	0.045	7.047	*	1.126	1.032	1.230
Postsecondary Physics grade	−0.471	0.064	53.400	**	0.625	0.551	0.709
Postsecondary Chemistry grade	0.259	0.048	29.232	**	1.296	1.179	1.423
Negative Postsecondary Physics Exp	1.474	0.251	34.512	**	4.367	2.671	7.141
Positive Postsecondary Chem Exp	2.051	0.246	69.347	**	7.773	4.797	12.595

*$p < 0.01$. **$p < 0.001$.

Logistic Regression Model

Focusing on the model (see Table 3), results indicate a variety of achievement and experience factors that are positively associated with female career choice in the physical sciences. The model summary of this logistic regression analysis shows that the x^2 (df = 16) is 448.302 ($p < 0.001$), and that the pseudo-R^2 (Nagelkerke) is 0.509. This indicates that secondary and postsecondary physical science grades, postsecondary physical science experiences, and demographic/background information together account for an estimated 50% of the variance in whether females enter into chemistry or physics doctoral programs and careers. This regression model when compared to a model with no predictors is significant at the α level of 0.05.

Chemistry career choice was coded as an outcome of 1 and physics career choice was coded as an outcome of 0. Therefore, all results will be reviewed as a career choice predictor of chemistry as opposed to a career choice in physics. Specific predictor variables in the model that were significant, or differentiate between a career choice in chemistry or physics, are secondary grade in chemistry, postsecondary grade in physics, postsecondary grade in chemistry, negative postsecondary experience in physics, and a positive postsecondary experience in chemistry. All of these variables were reported as significant predictors when placed in the model together.

The coefficient is the coefficient of the exponent in logistic regression models; therefore, the value is less straightforwardly interpretable. The odds ratio, which is calculated with the coefficient, is a more manageable form of the outcome. An odds ratio provides the difference in odds between two different outcomes. Therefore, the odds ratio represents the odds that a certain outcome will occur given a certain experience, which is compared to the odds that the outcome will not occur when the experience does not occur. Odds ratios of the significant predictors in the chemist logistic regression model differentiate a female career choice in chemistry as opposed to one in physics. Results indicate that participants with a secondary grade of A as opposed to a B in chemistry had a 1.126 times higher odds of reporting a career choice in chemistry. The postsecondary physics grade had a negative impact on the model, where females with an A as opposed to a B in physics had a 0.625 times odds of going into the field of chemistry. Respondents who achieved an A instead of a B in postsecondary chemistry had a 1.296 times higher odds of reporting a career choice in chemistry as opposed to one in physics. Participants with a general negative postsecondary physics experience had a 4.367 times higher odds of choosing to enter the field of chemistry. What is most striking about this model is that participants reporting a general positive experience in postsecondary chemistry had a 7.773 times higher odds of choosing a career in chemistry as opposed to physics. Therefore, the logistic regression shows that secondary and postsecondary academic achievement and postsecondary experience in chemistry has a positive association with a career choice in chemistry after controlling for background demographic variables.

Next, a series of interactions was developed by crossing background demographic variables with secondary grade in chemistry, postsecondary grade in physics, postsecondary grade in chemistry, a negative postsecondary experience in physics, and a positive postsecondary experience in chemistry in the model. Variables examined in these interactions included age and highest parent education, which were individually incorporated into the chemist logistic regression model. First, age was examined as an interaction with secondary grade in chemistry, postsecondary grade in physics, postsecondary grade in chemistry, a negative postsecondary experience in physics, and a positive postsecondary experience in chemistry respectively, in the model. No appreciable change was found from these interactions with respective outcomes to warrant the added complexity of the model. Next, a series of interaction variables was created among highest parent education with secondary grade in chemistry, postsecondary grade in physics, postsecondary grade in chemistry, a negative postsecondary experience in physics, and a positive postsecondary experience in chemistry. None of these interactions was found to be individually significant in the chemist logistic regression model.

■ DISCUSSION AND IMPLICATIONS

Descriptive Analyses

Descriptive analyses examined the sample of female physical sciences doctoral students and scientists as a whole and then in subsamples based on their field of chemistry or physics. These analyses were used to provide a better understanding of the participants' representation in demographics, interest, academic achievement, and experiences variables examined through later regression analysis.

Demographic variables included race and ethnicity, age, highest parent education, and citizenship. Race and ethnicity distribution of participants showed an equal representation based on chemistry and physics career choice, with the majority of respondents being Caucasian. As a reminder, the Project Crossover survey sample was determined to be representative based on participants' demographics (race and ethnicity and gender) and employment groupings with the NSF's WebCAS-PAR database.[41] The age variable contained a slight negative skew for both chemistry and physics participants. Specifically, 70% of females in chemistry were in the age range of 20−39 and 73% of females in physics were in the age range of 20−49. Therefore, the average chemistry participant was younger, based on year of birth, at the time the Project Crossover survey was taken. This ties in with research showing that the number of females in the physical sciences is slowly increasing, with the majority of growth occurring in the last 40 years.[3] In regard to highest parent education, chemists and physicists showed equal representation; however, there was a slight negative skew, with the majority of respondents' parents having a bachelor's degree or less for their highest level of education. In addition, the majority of participants were U.S. citizens, which was not surprising for a U.S.-based survey.

Predictor variables included interest, academic achievement, and experiences. Parent interest was reported by the majority of participants ranging from no support to at least two types of science-based support at home. General interest in science prior to fifth grade was almost equal to interest that developed after fifth grade for all respondents. The majority of participants reported initial interest in the physical sciences after the fifth grade, which makes sense, as these subjects are often first taught in high school. Both female chemists and physicists were equally represented based on average grade in high school chemistry; however, a higher grade in high school physics was reported by a greater number of female physicists. This distribution of representation grew in postsecondary education, where female chemists reported a higher grade in undergraduate chemistry and female physicists reported a higher grade in undergraduate physics. In addition, 28% of female physicists reported that they did not receive a grade in undergraduate physics. This could be potentially due to advanced high school placement courses. Most obvious of all in these descriptive analyses is the experience in undergraduate chemistry or physics as reported by female chemists and physicists. Overall, female chemists reported greater positive experiences in undergraduate chemistry, whereas female physicists reported greater positive experiences in undergraduate physics. This leads to the question: Could females' academic achievement and experiences be associated with their career choice in the physical sciences?

Logistic Regression

Although research shows that women are now on equal footing with men regarding academic success and STEM courses taken,[2] this study shows that secondary and postsecondary academic achievement of women in the physical sciences is associated with a career choice of chemistry. This is of interest to the educational community, as entry level chemistry and physics courses would be predicted to provide a similar degree of challenge for females that are receiving a degree within the physical sciences. Previous gender-based research has indicated the association of academic achievement to interest and career outcomes.[58,59,22,60]

Experiences in postsecondary physical science also play a large role within these models. Both negative physics and positive chemistry postsecondary experiences are shown to differentiate women into the field of chemistry. This is not to say that the field should encourage negative experiences in one field but not another in order to encourage career entrance but that we need to better examine what causes a negative or positive experience in these fields so that we can encourage and develop these positive experiences overall for women in STEM. The Project Crossover survey does not indicate what experiences for these females may be deemed negative in postsecondary physics and positive in postsecondary chemistry. Therefore, it would behoove the educational community to produce further research to examine these different experiences among women in chemistry. Research of female chemists in doctoral programs and academic careers has examined the valuable experience of a horizontal mentoring network and work−life balance as well as the negative impact of a chilly climate, lack of job opportunities, and unfair experiences.[17,18,33,34] However, there is a paucity of research examining what these positive and negative experiences are among women in the chemistry prior to doctoral programs. As we now know that these experiences are strongly associated with female career entrance into doctoral chemistry programs; further examination of some of these doctoral factors among secondary and postsecondary groups of women would benefit the educational research community.

In the end, secondary and postsecondary academic achievement and postsecondary experiences differentiate a female career choice of chemistry. Pearson correlations were used to uncover a connection among academic achievement factors and postsecondary experiences. Positive postsecondary experiences correlated with a higher postsecondary grade in chemistry ($p < 0.01$). These variables were not combined because of their distinct representation of the data. It should also be noted that this set of variables remained significant regardless of their simultaneous placement within the logistic regression model.

Although this analysis does not show whether positive experiences influence student achievement or vice versa, it does indicate a greater focus on classroom experiences and academic achievement of women in entry-level chemistry courses. Negative chemistry classroom experiences may be deterring women from succeeding in entry-level secondary and postsecondary courses and pursuing chemistry doctorates, whereas positive experiences may encourage them to both succeed and enter the field. This further lends the case for forming positive classroom experiences and encouraging academic achievement across all STEM fields for women. Prior gender-based postsecondary research has shown that women in STEM prefer small classrooms,[35] slower-paced lessons,[12] and viewing their role in the field as a scientist with an altruistic focus.[13] However, these studies do not differentiate women based on their STEM career choice of chemistry. These findings may also lend to future research that examines what specific types of activities and instruction cause women to have a positive academic achievement in entry-level chemistry courses. Researchers and academics in STEM fields such as chemistry and physics could work together to examine what factors may positively encourage females in individual STEM-based doctoral fields to succeed and persist.

Finally this logistic regression analysis shows that women can be differentiated into a physical science career choice of chemistry based on background and motivational variables such as academic achievement and experience. This further reinforces that women may be compared to one another, instead of only in comparison to men or viewed as a separate entity, to gain a deeper understanding of what influences them to enter one STEM career field as opposed to another.[50]

■ LIMITATIONS

Limitations of this study are reviewed in regard to not only the data set and analyses but also the generalizability of these findings to females in the U.S. education system. The primary limitation of this research is the implications of its findings. All results examined were associative and not causal. Therefore, academic achievement and positive experiences in chemistry were associated with female career choice, but was not causal. Although these findings are not causal in nature, they provide a better picture of what is happening in the U.S. education system today when it comes to women entering and persisting in chemistry. These results can also inform future research regarding what differentiates women in STEM-based research.

Second, when using any survey as a tool to analyze data, there are limitations to the detail that such as survey can provide. The Project Crossover survey had a rich data set of females in the physical sciences and included the following factors: demographic, interest, academic achievement, and experiences prior to elementary school through postsecondary education. This made the Project Crossover data set invaluable to this study and its series of analyses. Data showed the association of academic achievement and positive experiences with female career choice in chemistry. Yet what influenced females in terms of positive academic achievement and experiences were beyond the scope of this survey. This study also does not tell us anything about women who do not choose STEM careers, only about the difference between women who choose chemistry versus physics careers. Future research can build on findings from the Project Crossover survey to examine the factors that influence female academic achievement and experiences in secondary and postsecondary chemistry.

Finally, the Project Crossover survey provides a wide variety of variables that may differentiate and be associated with female career choice and persistence. This study examines a smaller and specific portion of these demographic and motivation factors. The results from this study and the work left to be done can serve as an inspiration to move forward with a research agenda in regard to what influences and differentiates women in STEM.

ASSOCIATED CONTENT

Supporting Information

Detailed tables describing the descriptive analyses. This material is available via the Internet at http://pubs.acs.org.

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Notes

The authors declare no competing financial interest.

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