Comparative analysis of female physicists in the physical sciences: Motivation and background variables

Katherine P. Dabney*
Department of Teaching and Learning, Virginia Commonwealth University, Richmond, Virginia 23284, USA

Robert H. Tai
Curriculum, Instruction, and Special Education, Curry School of Education, University of Virginia, Charlottesville, Virginia 22904, USA

(Received 24 August 2013; published 3 February 2014)

The majority of existing science, technology, engineering, and mathematics (STEM) research studies compare women to men, yet a paucity of research exists that examines what differentiates female career choice within the physical sciences. In light of these research trends and recommendations, this study examines the following question: On average, do females who select physics as compared to chemistry doctoral programs differ in their reported personal motivations and background factors prior to entering the field? This question is analyzed using variables from the Project Crossover Survey data set through a subset of female physical science doctoral students and scientists ($n = 1137$). A logistic regression analysis and prototypical odds ratio uncover what differentiates women in the physical sciences based on their academic achievement and experiences ranging from high school through undergraduate education. Results indicate that females who have negative undergraduate chemistry experiences as well as higher grades and positive experiences in undergraduate physics are more likely to pursue a career in physics as opposed to chemistry. Conclusions suggest that a greater emphasis should be placed on the classroom experiences that are provided to females in gateway physics courses. Analyses show that women are not a single entity that should only be examined as a whole group or in comparison to men. Instead women can be compared to one another to see what influences their differences in educational experiences and career choice in STEM-based fields as well as other academic areas of study.

DOI: 10.1103/PhysRevSTPER.10.010104 PACS numbers: 01.40.-d

I. INTRODUCTION

Science, technology, engineering, and mathematics (STEM) education has become a critical focus in the United States due to recent economic concerns and educational public policy [1,2]. Part of this focus has been an emphasis on encouraging and evaluating career choice and persistence factors among underrepresented groups such as females in STEM [1,3]. Women currently hold less than one-fourth of the jobs among these rapidly growing occupations [4]. Recommendations to change this status include enlarging the pool of female students pursuing degrees and careers in STEM fields [1].

Historically, women have been underrepresented in STEM degrees and fields. Women now almost match men when it comes to attainment of bachelor's degrees in biological and agricultural sciences, chemistry, mathematics, and Earth sciences [5]. Yet women still receive bachelor's degrees at a significantly lower level than men in physics, engineering, and computer science. Furthermore, females remain underrepresented in all doctorates except for biological and agricultural sciences [5]. Specific to these findings, recent educational policy has focused on the difference between female and male representation in doctoral programs such as the physical sciences [3].

The underrepresentation of women in physical sciences doctorate programs indicates a need to evaluate what may influence their career choices and persistence [3]. Women have made gains in the past 40 years with regard to attainment of bachelor's and doctoral degrees within the physical sciences. Specifically, in 1966, women received 18.5% and 4.9% of bachelor's degrees within chemistry and physics, respectively [5]. Most recently, in 2006, women received 51.8% and 20.7% of bachelor's degrees in chemistry and physics, respectively [5]. While women have made gains with regard to doctoral degree attainment in the physical sciences, these increases are nowhere near the growth seen with bachelor's degrees. In 1966, women earned 6.1% of doctorates in chemistry and 1.9% of doctorates in physics [5]. As of 2006, women earned 34.3% of doctorates in chemistry and 16.6% of doctorates in physics, respectively [5]. Research

*Corresponding author.
kdabney@vcu.edu

indicates that female gains in the physical sciences are still slight in comparison to men, especially with regard to physics and the attainment of doctoral degrees. Furthermore, striking differences exist among women in the physical sciences. Female chemists are closing the gender gap at a significantly faster rate than female physicists in regard to both bachelor's and doctoral degrees. Yet there is no comparative research examining why there are differences in representation among females in physical science.

The majority of theories and studies examine variables in doctoral programs that influence persistence, success, and satisfaction while eschewing educational supports prior to entrance into doctorate fields [6–16]. Existing research on female physical scientists compares women to men or examines women as a single entity. Therefore, there is a paucity of work regarding the differences that exist prior to entrance into doctoral programs among females in the field of science. Perhaps in the end the question is not only how women differ from men, but also what differentiates women who choose one field of science instead of another? More specific to these findings, what prior motivation and background factors are associated with and differentiate women that enter and persist in physics as compared to chemistry doctoral programs?

II. LITERATURE REVIEW

This paper will examine motivation and background differences within female physical scientists. Because of gaps in the literature examining and comparing females within doctorates in physics and chemistry, we will provide a comprehensive overview of the factors that are examined in general STEM studies across genders, while also providing a background on the scarcity of literature that does exist about female physical scientists. Specifically, existing STEM research studies pinpoint that motivation and background factors such as academic achievement [17–19], and postsecondary experiences [20,21] may interact with and influence student persistence and career choice.

A. Academic achievement

Academic success in the field of mathematics is seen as essential to persistence and entrance into STEM fields. Historically, female self-confidence and academic success in mathematics was low in comparison to males. Today, females are on an equal footing with males with regard to success in mathematics and numbers of courses in science and mathematics in high school [2]. Specifically, Hyde *et al.* [17] presented, through an analysis of the National Assessment of Educational Progress data of students in grades 2 to 11, that a gender difference no longer exists academically between males and females in mathematics. Men still, however, score higher on standardized tests and take more STEM-related advanced placement exams [22]. Lubinski and Benbow [12] reviewed data from the Study of Mathematically Precarious Youth. Results from a 20-year longitudinal follow up of three cohorts indicated that among the highest scoring students in mathematics, females are making gains in representativeness with regard to SAT scores, a standardized test for college admissions, yet males still outnumber females in this area as well [12,22]. While women are advancing academically when it comes to mathematics, some factors must remain that are preventing them from entering the physical sciences.

One area where extensive research exists is gender-limiting factors such as personal preferences in academic fields [23,24]. Females tend to be more attracted to language arts and humanities, while males are more interested in mathematics and science compared to other fields. One research study examined 111 students, 68 girls and 43 boys, from four classrooms in a midwestern school district [24]. It used a survey based on 45 careers from Hollands' six career codes. Results indicate that differences in career choice begin in early adolescence, where girls are less interested in science and mathematics careers than boys. These findings also exist in studies examining inner-city youth [25] and gifted students [12]. One such study tracked 320 gifted middle school students for 10 years and found that males maintained a preferred interest in mathematics, while females preferred language arts and the humanities [26].

Gender disparities are later reflected in research on vocational choices, where it was discovered that men tend to work more in science and mathematics fields while women prefer people-oriented careers [27]. Specific to the physical sciences, research indicates that females report gender bias and isolation in as early as secondary physics coursework, and that this may later impact their career choice [28]. McDonnell [28] completed a qualitative study of eight girls and nine boys from nine physics classrooms in the Northeast. Females in these results often reported gender stereotyping from males in the classroom and therefore felt that they must conform to the male classroom atmosphere or face isolation from their peers. These findings connect with later research that has indicated that females feel that certain occupations in STEM fields are also less gender appropriate, and therefore they are less likely to pursue them [23,24]. A metaanalysis of stability of vocational interests, from adolescence to adulthood, indicated that STEM vocational interest and beliefs are persistent for both males and females [24]. Interest in a career choice is stable through adolescence and then peaks in early adulthood, where it is constant for the next 20 years. Therefore, research indicates that early interest and beliefs are tenacious, especially with regard to women, and important to career choice in STEM fields.

B. Postsecondary experiences

Factors in postsecondary experiences are critical as to whether students in STEM fields of study remain in or exit the STEM pipeline. Studies have indicated that gender differences may exist in the type of postsecondary STEM experiences that students prefer. Poock and Love [29] examined 180 doctoral students in higher education programs between 1995 and 1996. Males and females were found to be similar in their postsecondary preferences, but women indicated that they preferred rigorous academic institutions that were well accredited. In addition, methods of instruction influence female academic performance in U.S. universities. One such study analyzed the differences among 15 000 college students from 16 universities in physics course achievement based on gender [20]. Findings include that women were higher achievers than men when found to be comparable on their high school algebra, not calculus, background. More importantly, women performed higher than men in slow-paced physics courses that focused on content, while men performed higher in fast-paced courses that had fewer hands-on activities.

Academic performance is necessary for student success in STEM college degrees, but often there is a large rate of attrition of students from these degree programs. Differences exist based on gender as to why females or males may exit a STEM degree. Specifically, Subotnik and Steiner [30] found that women tend to leave STEM postsecondary fields due to an impersonal nature of instruction and overcrowding of classes. Men were more likely, however, to exit because of a lack of challenging content or poor classroom instruction. Universities often vary their courses and content. Research has reinforced that a preferred method of instruction may differ based on the individual student, aside from gender. One study of 1478 students in STEM degree programs from Europe examined components as to why students would persist into STEM fields [31]. Many factors arose as to what influenced students' persistence, and these factors were often associated with the specific type of STEM degree students were obtaining. Students enrolled in chemistry degree programs were positively reinforced by classroom activities, while students enrolled in physics degree programs were positively influenced by their future career options.

Studies of at-risk groups of women have indicated that early development and sustained identity in postsecondary education as a research scientist leads to a greater persistence in the field of science. One qualitative study followed the career path of 15 women with Hispanic, African American, Native American, or Asian American racial and ethnic backgrounds [21]. This longitudinal research spanned undergraduate through graduate studies and ended with these females' selected career choices. Ethnographic interviews were used to gain initial knowledge of the participants' undergraduate experiences and included a sixth-year follow-up interview. What was found is that science identity, manifesting either as a passion for the field of science or the ability to use science in an altruistic manner, accounted for the persistence of these female participants.

C. Limitations of existing research

Existing studies have some major limitations that are relevant to this research study. First, one focus is the examination of motivational and background factors in reference to generalized STEM outcomes. The majority of these articles have looked at both males and females in reference to a combination of one or two variables regarding STEM career choice or persistence. These studies did not separate groups of participants by specific field of study in STEM. Research in this area has included large sample sizes that are generalizable. In contrast, this paper seeks to understand the specific experiences of women doctorates in the physical sciences; there is a lack of research with regard to this specific subpopulation of women.

Second, studies that specifically examine women in the physical sciences are based on qualitative analysis or small sample sizes. In addition to the small numbers of participants, these studies are based on one career outcome in STEM and not a comparative analysis between physics and chemistry, in contrast to the research design used in this study.

Third, the majority of these research studies look at gender-based differences. Specifically, men are compared to women with regard to self-confidence and mathematical ability [17], career choice and gender sterotyping [24,26,28], and, finally, university and instructional preferences [29,30]. The literature predominately focuses on a comparison of men to women, but no studies exist comparing women in the sciences to each other, based on their career choices and persistence factors.

Finally, the resounding message is that there is a lack of relevant research literature about motivational and background factors with regard to female doctorates in the physical sciences. Specifically, none of these studies compares women among themselves in order to find out what is associated with and what differentiates their career choices.

D. Research question

The goal of this paper is to examine the association between background and motivation variables prior to graduate school and female career choice into physics doctoral programs. This study examines the following research question: On average, do females who select physics as compared to chemistry doctoral programs differ in their reported personal motivations and background factors prior to entering the field?

III. DATA AND METHODS

A. The study

Survey data for this study were taken from Project Crossover. Project Crossover is a mixed methods study, containing interview and survey components, developed to examine factors influencing entrance into physical science doctoral programs as well as the transition from graduate students to independent researcher. The Project

Crossover survey was developed from a combination interview data as well as prior research within the field. The survey consisted of 145 scale questions examining background and demographic experiences such as early science interest and motivations, academic achievement, undergraduate and graduate experiences, and career variables following graduation from doctoral programs. Crossover survey questions include categorical, ordinal, multiple choice, numerical, and Likert-scale items that were indicated retrospectively by the participants. Potential participants' names were acquired from the American Chemical Society and American Physical Society. From this list a random sample of 17 500 individuals were mailed hard copies and online versions of the survey in 2007. Of these initial surveys 3600 were nonscience degree holders and therefore determined to not fit the participant group. In addition, 550 of the surveys were returned, as they were undeliverable. Of the final 13 350 qualified possible survey takers, 4285 returned completed surveys for a response rate of 32.1%. The survey sample included chemistry and physics doctoral students, scientists, and individuals holding other doctoral physical science degrees. In order to determine that the data set was nationally representative, the sample was compared to the National Science WebCASPAR data set with a focus on their demographics (gender and race and ethnicity) and employment backgrounds (government agencies, universities, profit, nonprofit, and other). Overall the Project Crossover sample was found to be comparable to the representation of WebCASPAR data based on these backgrounds [16].

B. The sample

The series of analyses presented in this paper focuses solely on data collected from female respondents among physical sciences graduate students and scientists. The Project Crossover survey is particularly relevant to this series of analyses due to its large sampling of females in the physical sciences. Females represent 28.5%, or 1221, of the participants. The final sample for this study consisted of 1137 female participants due to listwise deletion of missing data for 71 participants based on career outcome and 13 participants who had multiple responses for individual control and predictor variables (see Table I). Female proportions in the sample included 80 female physics doctoral students, 234 female chemistry doctoral students, 271 female physics scientists, and 552 female chemistry scientists. Based on the sampling of females in both fields of the physical sciences, the Project Crossover survey provides one of the most extensive data sources to date for female physical scientists' educational experiences prior to elementary school through undergraduate education.

C. Logistic regression analyses

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 physics as compared to chemistry. Differences between females in the physical sciences were not only sought but also included were whether these differences influenced or predicted group membership. Based on the need to differentiate between females in the physical sciences on descriptive background and motivational variables that were dichotomous and continuous, logistic regression analysis is the most accurate method of analysis in order to answer these questions [32]. In addition, logistic regression analysis is more lenient with multivariate assumptions regarding the predictors within each outcome variable group [32–34]. Therefore, due to the ability to account for all predictor and control variables in the model and greater flexibility with multivariate assumptions, the data for this research question was examined through a logistic regression analysis. This logistic regression model was completed with the use of SPSS 19.0, a software package for statistical analysis.

D. Outcome variables: female physicist

When examining female background demographics and motivations in the sciences, studies usually compare females to males rather than in gender comparisons [35,36]. Comparative analysis based on demographic and motivational factors have previously been used as methods to inform educational public policy in the STEM fields [37,38].

Caution should be used in the interpretation of this as a logistic regression outcome variable, as the results are an indication of a correlation and not a causal study. However, as there is a shortage of women in science, especially in the physical sciences [39], this outcome variable could provide educators and educational researchers with ways to better understand female early experiences prior to their entrance into physics.

Question No. 2 from the Project Crossover Survey asked participants whether their doctoral program was in chemistry or physics. 30.9% of sample respondents indicated a career choice in physics and 69.1% of sample respondents indicated a career choice of chemistry.

TABLE I. A summary comparison of the sample of female physical graduate students and scientists.

	$N = 1137$
Physics graduate students	80
Chemistry graduate students	234
Total responding to graduate students	314
Physics scientists	271
Chemistry scientists	552
Total responding to scientists	823

E. Predictor variables

Predictor variables in this study included average grade in high school chemistry (see the Appendix, Fig. 1), average grade in high school physics (Appendix, Fig. 2), average grade in undergraduate chemistry (Appendix, Fig. 3), average grade in undergraduate physics (Appendix, Fig. 4), experiences in undergraduate chemistry (Appendix, Fig. 5), and experiences in undergraduate physics (Appendix, Fig. 6). The literature signifies that early interest, academic success, and academic experiences influence student career choice and persistence in degree programs.

Academic achievement in the physical sciences has been linked to persistence in the field [40,41]. Average grades in high school chemistry, average grades in high school physics, average grades in undergraduate studies in chemistry, average grades in undergraduate studies in physics, experiences in undergraduate chemistry, and experiences in undergraduate physics were examined in this series of analyses as separate predictor variables. Average grades for high school and undergraduate chemistry and physics were each dummy coded based on an A, B, C, or D or lower. In addition, experiences were dummy coded in the model so that a strongly positive or somewhat positive experience was recoded as a positive experience, or a 1, and a strongly negative experience or somewhat negative experience was recoded as a negative experience, or a 0. Participants who did not take an undergraduate course in the physical sciences were represented if respondents indicated a 0 for both a negative and positive response. All undergraduate academic achievement and experience variables were entered into the logistic regression models based on a career choice in physics. Specifically, the model contained undergraduate academic achievement and experiences in physics.

F. Control or demographic variables

The following control or demographic variables from the Project Crossover survey were examined for the outcome variables presented above: racial or ethnic group, year of birth, citizenship status, highest level of education completed by guardians or parents, family interest in science, first interest in general science, and first interest in chemistry or physics. Race and ethnicity was recoded as dummy variables in this series of logistic regression analyses. Citizenship status was also recoded from continuous to dummy variables in this data set. An additional composite variable of highest parent education was created from the highest mother and father education variables due to high Pearson correlations. Finally, family interest in science, first interest in general science, and first interest in chemistry or physics were included as control variables in the logistic regression model.

Decisions about which control variables to include in these statistical analyses were based on the literature surrounding the association of these variables with STEM career interest [37], female participation in the physical sciences [42,38], and time to degree completion [43].

TABLE II. Project Crossover study sample missing-data proportions.

Variable	Percentage missing
Race/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
High school chemistry grade	1.3
High school physics grade	1.7
Undergraduate chemistry grade	1.0
Undergraduate physics grade	0.9
Undergraduate chemistry experience	1.4
Undergraduate physics experience	1.8

G. Missing values

Missing data in any statistical study are a concern. Therefore, all outcome, control and demographic, and predictor variables of the sample were examined for missing values prior to any logistic regression or multiple regression analyses. The missing-data percentages based on the study control and predictor variables are reported in Table II. Missing-data analysis was used to determine whether the data were not missing at random, missing at random, or missing completely at random. Recommendations by Enders [44] and Rubin [45] were then consulted, based on the nature of the missing data, in order to determine an appropriate missing-data procedure.

Specific to these predictor and control variables, mean comparisons of age, highest parent education, citizenship status, general science interest by K5, physical science interest by K5, high school chemistry grade, high school physics grade, undergraduate chemistry grade, undergraduate physics grade, chemistry undergraduate experience, and physics undergraduate experience did not differ based on the outcome variables of career choice in the physical sciences. Therefore, it was determined that there was no systematic bias in the data. This, in addition to the relatively low percentages of missing data, indicated that there was no need to utilize missing-data procedures.

IV. RESULTS AND CONCLUSIONS

A. Female physicist

A logistic regression model was run focusing on female physicist career choice (see Table III). For this model, a career choice as a physicist was coded as an outcome of 1 and a chemistry career choice was coded as an outcome of 0. Because of the coding of this outcome variable, all

TABLE III. Female physicist logistic regression model summary with odds ratio.

	B (coefficients)	Standard errors.	Significance (p values)	Odds ratio
Intercept			Included	
Demographic or background			Included	
High school chemistry grade	−0.103	0.044	*	0.902
High school physics grade	0.063	0.035	not significant	1.065
Undergrad chem grade	−0.399	0.041	***	0.671
Undergrad physics grade	0.526	0.064	***	1.692
Negative undergrad chem experience	1.643	0.234	***	5.169
Positive undergrad physics experience	1.318	0.238	***	3.737

*$p < 0.05$.
**$p < 0.01$.
***$p < 0.001$.

results are reviewed in reference to whether women made a career choice in physics as opposed to one in chemistry. The model indicated a variety of predictor variables that were significant and could differentiate or predict a career choice in physics compared to chemistry. Significant predictor variables included high school grade in chemistry, high school grade in physics, undergraduate grade in physics, and a positive undergraduate experience in physics.

Odds ratios of positive significant predictor variables were examined to present how these variables differentiated between a physics career choice when compared to one in chemistry by female scientists. High school chemistry grade had a negative impact on the model where females reported an A, as opposed to a B, in chemistry had 0.902 times odds of going into the field of physics. Females that signified an undergraduate chemistry grade of A instead of B had 0.671 times higher odds of pursuing a career in physics. In addition, participants reporting an undergraduate physics grade of A instead of a B had 1.692 times higher odds of having a career in physics instead of one in chemistry. Undergraduate chemistry experiences were examined in the analysis and females that reported a negative experience had 5.169 times higher odds of pursuing a career in physics. Furthermore, females who said their undergraduate physics course provided a positive experience had 3.737 times higher odds of going into the field of physics. These negative chemistry and positive physics experiences far outweigh all of the other odds ratios combined, therefore indicating the importance of positive female experiences within physical science classrooms. Overall, female physics academic achievement in postsecondary studies and positive experiences in undergraduate physics courses was significant for a career choice in physics after controlling for demographic variables in this physicist logistic regression model.

Next, a series of interactions was run to ensure that the reported predictor variables were influencing the outcomes in the female physicist model. Race, ethnicity, and citizenship status were not examined, as these demographic variables were beyond the scope of this study. Age was the primary demographic variable examined with interactions in these models. Interactions were created by crossing age with high school grade in chemistry, high school grade in physics, undergraduate grade in physics, and a positive undergraduate experience in physics in the model. The four age-based interactions were not found to be independently significant in the physicist logistic regression model.

A series of prototypical odds ratios were created to better understand how the combination of significant physics odds ratios might positively influence a female to enter the field of physics. Four prototypes of female physicists were developed through the multiplication of odds ratios. Prototypes included a lower grade in undergraduate physics and a negative experience in undergraduate physics; a higher grade in undergraduate physics and negative experience in undergraduate physics; a lower grade in undergraduate physics and a positive experience in undergraduate physics; and a higher grade in undergraduate physics and a positive experience in undergraduate physics. The compound odds ratio was developed with a higher grade being an A and a lower grade being a B in high school and undergraduate physical science. Female physicist prototypical odds ratios were calculated by the multiplication of odds ratios from the physics logistic regression model (see Table III) and are reported in Table IV.

Compounded odds ratios depict the connection between female physicists' academic achievement and experiences. A baseline prototype was created of a female in physics with a lower grade in undergraduate physics and a negative experience in undergraduate physics. This individual had

TABLE IV. Female physicist prototypical odds ratio. Higher grades denote an A in undergraduate physics and lower grades denote a B. Negative and positive experiences are in reference to undergraduate physics.

Physicist prototypical odds ratio		
	Negative experience	Positive experience
Lower grades	1.000	3.737
Higher grades	1.692	6.323

1.000 times odds of reporting going into physics. A female who reported a higher grade in undergraduate physics, in addition to a negative experience in physics, had 1.692 times greater odds of being a physicist as compared to a chemist. On the other hand, a female that indicated a lower grade in undergraduate physics and a positive undergraduate experience had 3.737 times higher odds of entering the field of physics. Lastly, a female that reported a higher grade in undergraduate chemistry and a positive experience in undergraduate chemistry had 6.323 times higher odds of entering the field of physics instead of chemistry.

V. DISCUSSION AND IMPLICATIONS

These results are based on women who made a career choice in physics as opposed to chemistry, so it follows that academic achievement in postsecondary classes will indicate a greater likelihood to enter a specific career field. Research has indicated that women are now equal to men in regard to STEM courses taken in high school and subsequent academic success [2]. However, this study indicates that undergraduate academic achievement among women in the physical sciences differentiates and is associated with later career choice. These results, while supporting the hypotheses of this study, are surprising, as it would be expected that women who enter the physical sciences would achieve equally in both chemistry and physics courses due to the academic rigor and requirement necessary to receive a degree in the physical sciences. Prior research on academic achievement has been linked to variables such as interest, environmental factors, and career preferences based on gender [12,24,25,26].

Environmental factors were also taken into account in these models through the examination of experiences in undergraduate physical science. Research has indicated that academic achievement can be promoted through the use of novel and relevant activities [46–49]. This study further supports prior hypotheses by signifying a connection between positive experiences in physics and a differentiation in career choice by females in physics. Project Crossover does not specify what these positive experiences are for females, so it would benefit the education community to further examine what is occurring in physics classrooms that provides a positive experience for females. Previous research has indicated that compared to men, women often report a gender bias or isolation in high school and undergraduate physical science classrooms [23,24,28]. This may influence females to believe that STEM fields are less friendly toward women and therefore choose a career in alternative fields [23,24,28]. However, as this study compares women to women, it can only be conjectured what may influence these negative or positive experiences in the physical sciences. What we do know is that this experience is critical and is strongly associated with the likelihood of a woman's career choice of physics.

Overall, outcomes of the physicist model indicate that content-based undergraduate academic achievement and postsecondary experiences differentiate female career choice in the physical sciences. Pearson correlations present a further connection between academic achievement and positive or negative experiences in undergraduate physical science. Specifically, an undergraduate grade in physics was significantly correlated with a positive experience in undergraduate physics (0.438, $p < 0.01$). In addition, an undergraduate grade in chemistry was significantly correlated with a positive experience in undergraduate chemistry (0.549, $p < 0.01$). Undergraduate experiences and grades in chemistry or physics were not combined, due to their unique representation of date and their ability to paint a more detailed picture in the analyses that followed. In other words, grades and experiences cannot be combined as these two variables are defined and measured differently within the data. In addition, grades and experiences were found to be independently significant within the model further supporting this decision. These findings further reinforce research that signify the connection between gender, academic achievement, classroom experiences, and career choice [12,24,25,26,47,48].

This series of analyses does not answer the question of whether academic achievement influences a student to have a positive experience, or whether positive experiences promote student academic achievement at the postsecondary level. What it does indicate is that there needs to be a greater emphasis on the classroom experiences that are provided to females in gateway physics courses. Females may not be pursuing doctoral degrees in physics due to the experiences that are provided to them in these early undergraduate courses. This raises the question: What forms of classroom instruction and activities lead to a positive experience for women in physics? Prior research indicates that females in STEM, when compared to males or examined as a whole, prefer slower-paced, content-based classes [20], smaller classroom settings [30], and a personal identity as an altruistic research scientist [21]. In addition, studies reported that males and females are motivated to attain physical sciences degrees based on the type of career options in physics [31]. While these studies do not differentiate between women in chemistry or physics, it does provide some perspective as to what may influence female experiences in the classroom based on career choice and what future research could examine.

A. Final thoughts

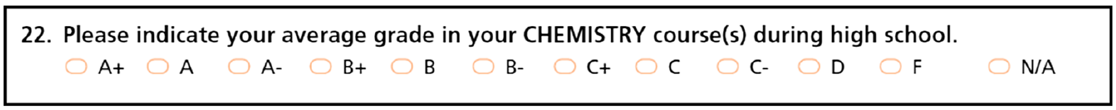
Overall, logistic regression analyses signify that background and early motivational variables differentiate female career choice in physics. Variables were examined, ranging from prior to high school through undergraduate studies, to determine what might better influence entrance into and a long-term career choice in physics. The results of this study indicate that women are not only a single entity that should be examined as a whole group or in comparison to men but also that women can be differentiated in physical science. Women are entering physics at a slower rate than chemistry at both bachelor's and doctoral levels [5]. However, physics and chemistry are closely aligned—as fields within the physical sciences—in their admissions standards, such as prerequisites in science and mathematics, and overall rigor. Based on this similarity of educational training, women could potentially be compared to one another to see what influences their differences in educational experiences and career choice not only in the physical sciences but also in STEM-based fields and other academic areas of study.

ACKNOWLEDGMENTS

Support was received from the National Science Foundation (NSF DRL 1010935, NSF REC 0440002) and the Robert N. Noyce Foundation.

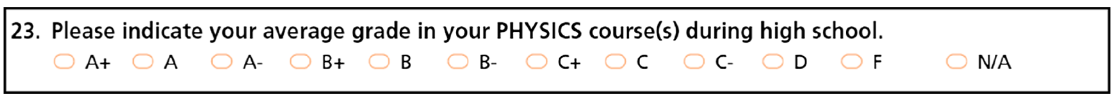
APPENDIX: PREDICTOR VARIABLES

Predictor variables are from the Project Crossover Survey questions below.



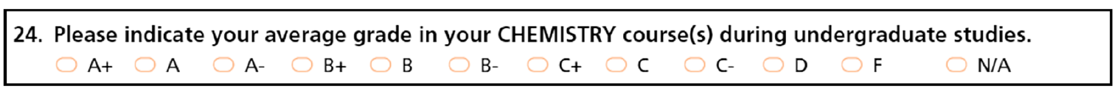
22. Please indicate your average grade in your CHEMISTRY course(s) during high school.
A+ A A- B+ B B- C+ C C- D F N/A

FIG. 1 (color online). Question No. 22 from the Project Crossover Survey on Average Grade in High School Chemistry Course.



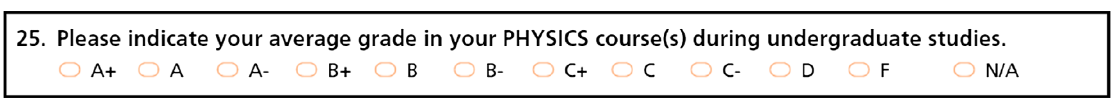
23. Please indicate your average grade in your PHYSICS course(s) during high school.
A+ A A- B+ B B- C+ C C- D F N/A

FIG. 2 (color online). Question No. 23 from the Project Crossover Survey on Average Grade in High School Physics Course.



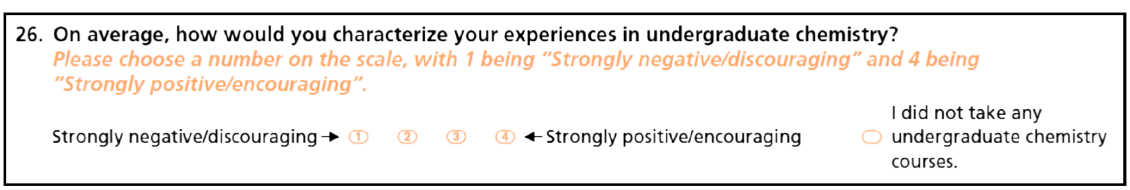
24. Please indicate your average grade in your CHEMISTRY course(s) during undergraduate studies.
A+ A A- B+ B B- C+ C C- D F N/A

FIG. 3 (color online). Question No. 24 from the Project Crossover Survey on Average Grade in Undergraduate Chemistry Course.



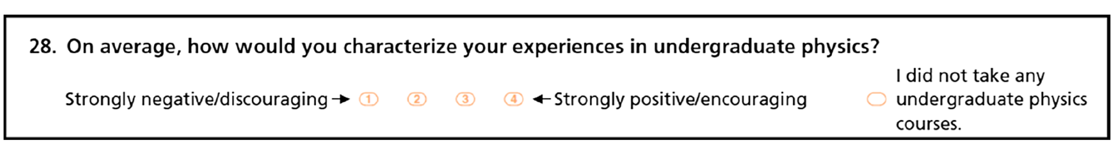
25. Please indicate your average grade in your PHYSICS course(s) during undergraduate studies.
A+ A A- B+ B B- C+ C C- D F N/A

FIG. 4 (color online). Question No. 25 from the Project Crossover Survey on Average Grade in Undergraduate Physics Course.



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.

FIG. 5 (color online). Question No. 26 from the Project Crossover Survey on Experiences in Undergraduate Chemistry Course.



28. On average, how would you characterize your experiences in undergraduate physics?
Strongly negative/discouraging → 1 2 3 4 ← Strongly positive/encouraging
I did not take any undergraduate physics courses.

FIG. 6 (color online). Question No. 28 from the Project Crossover Survey on Experiences in Undergraduate Physics Course.

[1] National Academy of Sciences, "*Rising Above the Gathering Storm: Energizing and Employing America for a Brighter Future*,"http://www.nap.edu/catalog.php?record_id=11463.

[2] The Secretary of Education's Commission on the Future of Higher Education, *A Test of Leadership: Charting the Future of U.S. Higher Education* (U.S. Department of Education, Washington, DC, 2006).

[3] C. Hill, C. Corbett, and A. St. Rose, http://www.aauw.org/resource/why-so-few-women-in-science-technology-engineering-and-mathematics/

[4] National Science Board (NSB), *Science and Engineering Indicators 2008* (National Science Foundation, Arlington, VA, 2008), Vols. 1–2 [http://nsf.gov/statistics/seind08/].

[5] National Science Foundation (NSF), Division of Science Resources Statistics, NSF Report No. 08-321, www.nsf.gov/statistics/nsf08321/pdf/nsf08321.pdf

[6] S. Acker and G. Feuerverger, Doing good and feeling bad: The work of women university teachers, Cambridge J. Educ. **26**, 401 (1996).

[7] B. Barres, Does gender matter?, Nature (London), **442**, 133 (2006).

[8] M. Ferreira, The research lab: A chilly place for graduate women, *J. Women Minorities Sci. Eng. 8, 85 (2002).*

[9] J. Girves and V. Wemmerus, Developing models of graduate student progress, J. Higher Educ. **59**, 163 (1988).

[10] R. Gunter and A. Stambach, Differences in men and women scientists' perceptions of workplace climate, J. Women Minorities Sci. Eng., **11**, 97. (2005).

[11] S. Kleinman, Women in science and engineering building community online, J. Women Minorities Sci. Eng. **9**, 73 (2003).

[12] D. Lubinski and C. P. Benbow, Study of mathematically precocious youth after 35 years: Uncovering antecedents for the development of math-science expertise, Perspectives on Psychological Science, **1**, 316 (2006).

[13] R. J. Menges and W. H. Exum, Barriers to the progress of women and minority faculty, J. Higher Educ. **54**, 123 (1983).

[14] S. Prentice, The conceptual politics of chilly climate controversies, Gender Educ. **12**, 195 (2000).

[15] I. H. Settles, L. M. Cortina, J. Malley, and A. J. Stewart, The climate for women in academic science: The good, the bad, and the changeable, Psychol. Women Q. **30**, 47 (2006).

[16] Z. Hazari, G. Potvin, R. Tai, and J. Almarode, For the love of learning science: Connecting learning orientation and career productivity in physics and chemistry, Phys. Rev. ST Phys. Educ. Res. **6**, 1 (2010).

[17] J. S. Hyde, S. M. Lindberg, M. C. Linn, A. B. Ellis, and C. C. Williams, Gender similarities characterize math performance, Science **321**, 494 (2008).

[18] F. Pajares, Self-efficacy beliefs and mathematical problem-solving of gifted students, Contemp. Educ. Psychol. **21**, 325 (1996).

[19] F. Pajares, in *Gender Differences in Mathematics: An Integrative Psychological Approach*, edited by A. M. Gallagher and J. C. Kaufman (Cambridge University Press, Boston, 2005), pp. 294–315.

[20] R. Tai and P. Sadler, Gender differences in introductory undergraduate physics performance: University physics versus college physics in the USA, Int. J. Sci. Educ. **23**, 1017 (2001).

[21] H. B. Carlone and A. Johnson, Understanding the science experiences of successful women of color: Science identity as an analytic lens, J. Res. Sci. Teach. **44**, 1187 (2007),

[22] D. F. Halpern, C. P. Benbow, D. C. Geary, R. C. Gur, J. S. Hyde, and M. A. Gernsbacher, The science of sex differences in science and mathematics, Psychol. Sci. Publ. Interest **8**, 1 (2007).

[23] P. J. Hartung, E. J. Porfeli, and F. W. Vondracek, Child vocational development: A review and reconsideration, J. Vocat. Behav. **66**, 385 (2005).

[24] K. S. D. Low, M. Yoon, B. W. Roberts, and J. Rounds, The stability of vocational interests from early adolescence to middle adulthood: A quantitative review of longitudinal studies. Psychol. Bull. **131**, 713 (2005).

[25] S. L. Turner, J. L. Conkel, M. Starkey, R. Landgraf, R. T. Lapan, J. J. Siewert, A. Reich, M. J. Trotter, E. R. Neumaier, and J. Huang, Gender differences in Holland vocational personality types: Implications for school counselors, Professional School Counseling **11**, 317 (2008).

[26] D. Lubinski, R. M. Webb, M. Morelock, and C. P. Benbow, Top 1 in 10,000: A 10-year follow-up of the profoundly gifted. J. Appl. Psych. **86**, 718 (2001).

[27] J. L. Holland, Exploring careers with a typology: What we have learned and some new directions, Am. Psychol. **51**, 397 (1996).

[28] F. McDonnell, Why so few choose physics: An alternative explanation for the leaky pipeline, Am. J. Phys. **73**, 583 (2005).

[29] M. Poock and P. Love, Factors influencing the program choice of doctoral students in higher education administration, Journal of Student Affairs Research and Practice **38**, 183 (2001).

[30] R. Subotnik and C. Steiner, Adult manifestations of adolescent talent in science, Roeper Review **15**, 164 (1993).

[31] B. Woolnough, School effectiveness for different types of potential scientists and engineers, Res. Sci. Technol. Educ. **13**, 53 (1995).

[32] E. J. Pedhazur, *Multiple Regression in Behavioral Research: Explanation and Prediction* (Wadsworth Publishing, Belmont, CA, 1997), 3rd ed..

[33] *Reading and Understanding Multivariate Statistics*, edited by L. G. Grimm and P. R. Yarnold (American Psychological Association, Washington, DC, 1995).

[34] B. G. Tabachnick and L. S. Fidell, *Using Multivariate Statistics* (Harper Collins, New York, 1996).

[35] M. Stewart, Gender issues in physics education, Educ. Res. **40**, 283 (1998).

[36] L. Whitelegg, in *The Gender and Science Reader* edited by M. Lederman and I. Bartsch (Routledge, New York, 2001), pp. 373–382.

[37] R. H. Tai, C. Q. Liu, A. V. Maltese, and X. Fan, Planning early for careers in science, Science **312**, 1143 (2006).

[38] Y. Xie and K. A. Shauman, *Women in Science: Career Processes and Outcomes* (Harvard University Press, Boston, 2003).

[39] National Center for Educational Statistics (NCES), 2009. http://nces.ed.gov/pubs2009/2009161.pdf.

[40] D. J. House, Academic background and self-beliefs as predictors of student grade performance in science, engineering and mathematics, *Int. J. Instr. Media* **27**, 207 (2000).

[41] P. Zeegers, Student learning in higher education: A path analysis of academic achievement in science, Higher Educ. Res. Dev. **23**, 35 (2004).

[42] J. J. Jacobs, L. L. Finkens, N. L. Griffin, and J. D. Wright, The career plans of science-talented rural adolescent girls, Am. Educ. Res. J. **35**, 681 (1998).

[43] Y. deValero, Departmental factors affecting time-to-degree completion and completion rates of doctoral students at one-land grant university, J. Higher Educ. **72**, 341 (2001).

[44] C. K. Enders, *Applied Missing Data Analysis. Methodology in the Social Sciences* (The Guildford Press, New York, 2010).

[45] D. B. Rubin, *Multiple Imputation for Nonresponse in Surveys* (J. Wiley & Sons, New York, 1987).

[46] C. Ames, Classrooms: Goals, structures, and student motivation, J. Educ. Psychol. **84**, 261 (1992).

[47] C. S. Hulleman and J. M. Harackiewicz, Promoting interest and performance in high school science classes, Science **326**, 1410 (2009).

[48] M. Resnick, F. Martin, R. Berg, R. Borovoy, V. Colella, K. Kramer, and B. Silverman, Digital manipulatives: New toys to think with, Chi '98 Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, 18 (1998).

[49] S. Tobias, Interest, prior knowledge, and learning, Rev. Educ. Res. **64**, 37 (1994).