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Connecting High School Physics Experiences, Outcome Expectations, Physics Identity, and Physics Career Choice: A Gender Study

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Abstract: This study explores how students' physics identities are shaped by their experiences in high school physics classes and by their career outcome expectations. The theoretical framework focuses on physics identity and includes the dimensions of student performance, competence, recognition by others, and interest. Drawing data from the Persistence Research in Science and Engineering (PRiSE) project, which surveyed college English students nationally about their backgrounds, high school science experiences, and science attitudes, the study uses multiple regression to examine the responses of 3,829 students from 34 randomly selected US colleges/universities. Confirming the salience of the identity dimension for young persons' occupational plans, the measure for students' physics identity used in this study was found to strongly predict their intended choice of a physics career. Physics identity, in turn, was found to correlate positively with a desire for an intrinsically fulfilling career and negatively with a desire for personal/family time and opportunities to work with others. Physics identity was also positively predicted by several high school physics characteristics/experiences such as a focus on conceptual understanding, real-world/contextual connections, students answering questions or making comments, students teaching classmates, and having an encouraging teacher. Even though equally beneficial for both genders, females reported experiencing a conceptual focus and real-world/contextual connections less frequently. The explicit discussion of under-representation of women in science was positively related to physics identity for female students but had no impact for male students. Surprisingly, several experiences that were hypothesized to be important for females' physics identity were found to be non-significant including having female scientist guest speakers, discussion of women scientists' work, and the frequency of group work. This study exemplifies a useful theoretical framework based on identity, which can be employed to further examine persistence in science, and illustrates possible avenues for change in high school physics teaching. © 2010 Wiley Periodicals, Inc. J Res Sci Teach 47: 978–1003, 2010

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Although the gender difference in participation in the field of physics has troubled science educators for decades (Clancy, 1962), this difference has persisted to the present (Ivie & Ray, 2005). Unlike the biological sciences where the percentage of females earning U.S. undergraduate degrees has grown from less than 25% in the early 1960s to 62% in 2005, physics has failed to increase women's participation at a similar rate and continues to suffer low female undergraduate graduation percentages (21% in 2005) (National Science Board, 2000, 2008). The problems posed to the physics community by this participation differential are

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compounded by the continued lack of growth in the overall number of physics degrees awarded each year. Whereas the number of bachelor's degrees awarded in all fields increased by 47% between 1983 and 2005, and biological science bachelor degrees awarded increased by 66% in the same time period, physics bachelor's degrees awarded increased by a mere 11% (National Science Board, 2006, 2008). Thus, physics lags behind the overall growth rate of the undergraduate population. The lack of sufficient growth in both female and overall participation makes it imperative to reexamine our approach to the teaching and learning of physics. Physics education researchers interested in representation issues have for some time shifted their focus to affective domains to better understand overall persistence as well as gender differences in physics participation.

This study will focus on factors from high school physics and career outcome expectations that predict how students, especially females, situate themselves with regard to physics. There are several reasons for the focus on this particular educational stage, high school physics, which are elaborated below. Our research is grounded in a theoretical framework centered around students' identity. We believe that this focus provides a basis for understanding students' long-term personal connection to physics and is a more meaningful measure than a general assessment of students' attitudes. The next few sections will first discuss four domains that are relevant to our conceptual framework: interest, recognition, performance, and competence. We discuss how these domains have been linked to students' science-related self-perceptions and their science career choices. The conceptual framework based on identity, which draws from the work of Carlone and Johnson (2007), is then described and shown to be a centralizing framework for the results of many science education studies. The research literature has identified many student experiences/characteristics that are potentially relevant to our framework. Our study examines how several specific experiences from among these, like high school physics pedagogy, influence students' physics identity.

The Role of Interest and Recognition

One of the key areas found to influence persistence in science is affect. Students' interests, motivations, and beliefs about themselves have a far-reaching impact on their persistence and participation in science. For example, Tai, Liu, Maltese, and Fan (2006), using nationally representative longitudinal data, found that while students' eighth grade mathematics achievement was a good predictor of their future chances of receiving a bachelor's degree in the physical sciences, the students' eighth grade career interests in science were an even stronger predictor. At a much later stage, the beginning of college/university, Adams et al. (2006) found that first-year college students' "personal interest" in physics was highly correlated with their subsequent choice of physics as a major. Supporting this finding, a large body of research using the Social Cognitive Career Theory (SCCT) has also found that interest has a large impact on career choices (Bandura, 1986; Fouad & Smith, 1996; Fouad, Smith, & Zao, 2002; Lent, Brown, & Hackett, 1994, 1996). Clearly, when studying students' choice of field, the development of their interests is of critical relevance. It is likely that the link between the development of interest and career choice is mediated by changes in self-perceptions (and identity). For example, Haussler and Hoffmann (2002) found that adapting physics curriculum to address the interests of girls had a significant positive effect on the girls' physics self-concept. Unfortunately, when studying the under-representation of females in physics, the landscape looks stark because females have been found to lose interest in the physical sciences at early ages (Baker & Leary, 2003; Dawson, 2000; Jones, Howe, & Rua, 2000; Weinburgh, 1995). Furthermore, Farenga and Joyce (1999) found that the choices boys and girls aged 9–13 made regarding "appropriate" science courses for themselves and their opposite-gender peers resembled graduate school enrollment distributions by gender. Thus, choices that result in the gendering of physics are already developing in the early school years.

Another factor that repeatedly arises in the literature addressing science career choice is the role of recognition. How others see a student is vitally important to how the student sees her/himself and to her/his subsequent choices. Not surprisingly, several studies have found that parents' perceptions and expectations regarding their child's abilities in mathematics and science influence the child's self-perceptions and expectations (Bleeker & Jacobs, 2004; Jacobs & Eccles, 2000; Smith, 1991; Trusty, 2000; Turner, Steward, & Lepan, 2004). These self-perceptions and expectations can be linked to later career choices. Jacobs and Eccles's (2000) analyses revealed that parental messages are integrated within students' self-perceptions and self-systems, and that ultimately those messages influence future choices such as that of a college major. For example, Turner et al. (2004), applying structural equation modeling to data from 318 sixth-grade students, found that parental support for pursuing mathematics and science predicted students' mathematics self-efficacy, which in turn predicted mathematics and science career interests. "As adults encourage early adolescents to try science and mathematics experiences, these role models may help early adolescents to see themselves as practicing scientists or mathematicians in their new adult identity." (Smith & Hausafus, 1998, p. 123).

More specific to physical science, Bleeker and Jacobs (2004), in a longitudinal study that followed up with students in the sample studied by Jacobs and Eccles (1992) 12 years later at ages 24–25, found that mothers' perception of children's mathematics capabilities in seventh grade was significantly related to their entering a physical science career over a non-science career. For females in the sample, mother's perception was significantly related to their entering a physical science career over both non-science and life science careers. In a slightly contrasting result, Jacobs, Finken, Griffen, and Wright (1998) found in their study of 220 rural girls talented in science that, instead of mother's support, friends' support was a significant predictor of wanting to pursue a physical science profession. Lastly, the relationship between students and teachers has also been found to be influential in physical science persistence for both males and females (Speering & Rennie, 1996; Woolnough et al., 1997). Clearly, the other people in a student's life have a non-negligible influence on how the student sees her/himself with respect to physical science and the subsequent decision to pursue a physical science career. Unfortunately, parents and peers have frequently been found to hold gender stereotypes favoring males when considering males' and females' abilities in science and mathematics (Andre, Whigham, Hendrickson, & Chambers, 1999; Bleeker & Jacobs, 2004; Farenga & Joyce, 1999; Kessels, 2005).

If, as illustrated in the literature reviewed above, most females are already disinterested by the time they reach high school, feel that a career in physics is mismatched with their career goals, and lack recognition in physics, is there anything high school physics teachers can do to change the situation? According to the first and second International Study of Women in Physics carried out by the American Institute of Physics, it was during high school that most female physicists reported that they became attracted to physics and decided to study it further (Ivie, Cuzjko, & Stowe, 2001; Ivie & Guo, 2006). This is an indicator that there may still be a window of opportunity in high school to meaningfully engage some female students who were not previously interested. In any case, there may also be the opportunity to increase interest not only for girls but also for boys who enter with depressed attitudes. This is especially true if the factors that drive students away are false stereotypic images of physics that can be countered in the high school classroom. Although interventions earlier in the educational pipeline would be ideal, it is not "too late" to effect change in high school. In addition, reform has to occur at all levels to ensure sustainable change from one level to the next. For instance, if females become excited about science through innovative reforms in elementary and middle school, there is still the danger that they will be turned off by physical science if their high school physical science courses are not reformed to address affective issues and support their initial interest. In addition, in the United States, high school is usually the first instance when physics is clearly differentiated from the other sciences in the minds of students. This means that high school is the first opportunity for positive engagement specifically in physics and a time when teachers and classroom environments may have a great deal of influence over students' impressions of it.

The Role of Performance and Competence

In addition to interest and recognition, other areas might influence gender differences in physics persistence. One might wonder: do females get "weeded" out of physics or other sciences at higher rates because they are not able to perform at levels equivalent to the males? Several studies have found that this is not the case (Hazari, Tai, & Sadler, 2007; Hyde & Linn, 2006; Sadler & Tai, 2001; Tai, Sadler, & Loehr, 2005). For example, Hyde and Linn's (2006) examination of large-scale gender studies and meta-analyses illustrates that gender differences in science achievement (as represented, e.g., in National Assessment of Educational Progress test scores) are small to negligible when considered from an effect size perspective and in most cases represented an overlap of approximately 90% in the score distributions for male and female students. Furthermore, they show that for mathematical skills relevant in science (mathematical conceptual understanding, complex problem solving) there were either no significant gender differences or small effect sizes as well. These negligible differences indicate that mathematics performance and abilities are not the primary reason that females opt out of physics at much higher rates; especially given the high percentage of female bachelor's degree recipients in mathematics—45% in 2006 (National Science Foundation, 2009).

This does not mean that performance plays no role at all in discouraging females from the pursuit of physics. In fact, a more complex story emerges when looking specifically at physics performance, rather than at science and mathematics performance in general, and controlling for prior achievement. Hazari et al. (2007) found that female students came into university physics with better high school mathematics and physics grades but performed at the same level as the males in the course. Although the effects were also small, another study showed that females were out-performed by male counterparts with similar backgrounds in calculus-based physics but not in algebra-based physics (Tai and Sadler, 2001). It is particularly troubling that performance differences, albeit small, are greater in the higher-level physics courses aimed at physical science and engineering majors (e.g., calculus-based university physics, Advanced Placement high school physics) where the representation of females is appreciably smaller (Hazari, Sadler, & Tai, 2008; National Science Board, 2006).

Developing the link between performance and self-perceptions, Marsh, Hau, and Kong (2002) found a reciprocal effect between performance and self-concept; that is, earlier performance affects academic self-concept and prior self-concept affects future performance. In addition, research studies employing the social-cognitive career choice model indicate that performance (often in the form of grades received) influences self-efficacy (individuals' judgments about their ability to successfully perform a task, see Bandura, 1986), which in turn influences career goals and choices (Fouad et al., 1996; Fouad et al., 2002; Lent et al., 1994, 1996). Thus, performance has a direct effect on how students perceive themselves in relation to a field such as physics, and this perception influences their career choices or persistence as well as their future performance. Evidence also suggests that the impact of these self-perceptions may be greater for female students (Shanahan, 2008). Clearly, it is necessary to take performance into consideration as one of the factors that influence self-perceptions and ultimately persistence (Fouad & Smith, 1996).

It is important to recognize as well that despite small to negligible gender differences in performance and achievement, large experiential differences persist. Consistent with historical trends, Jones et al. (2000) found that males reported significantly more extracurricular experiences related to physical science than did females. Similarly, Hazari et al. (2008) found that male students in introductory college physics reported significantly more knowledge of physics from hobbies, media, books, and even from coursework than did female students. These experiential differences may lead to disparities in conceptual understanding. For example, Chambers and Andre (1997) found significant gender differences in college students' conceptual understanding of electricity; however, these gender differences became non-significant once experience and prior knowledge were accounted for. In addition, we must also consider the fact that females may have a depressed view of their capability to understand, that is, depressed self-competency or self-efficacy beliefs. Through the mechanism of a self-fulfilling prophecy, this can lead to lower competency. Cavallo, Potter, and Rozman (2004) found that self-efficacy predicted physics understanding and achievement for both male and female college physics students, and that females tended to maintain significantly lower self-efficacy throughout the course and increased their usage of less meaningful learning strategies, such as memorization, as the course progressed. This makes intuitive sense: if you do not believe you have the capability to understand something, you give up trying to master the underlying concepts and end up simply using memorized terms and algorithms to get through the course. Despite these results, there is evidence that certain teaching choices can help in this domain. In an intervention study where teachers were trained to nurture the self-concept and interests of females in a physics class, Haussler and Hoffmann (2002) found that girls in the treatment group had significant gains compared to the non-treatment group on self-competence ratings.

This type of research, which examines teaching strategies that lessen gender differences in performance, competence, and competency beliefs, is important because of the influence these domains have on the choice to continue studying physics. For example, Jacobs et al. (1998) found that science performance (measured by science GPA) was a significant predictor for the choice of a physical science profession for females age 15–18 even after controlling for family/friend support, science/mathematics activities, physical science interest, and overall grades in the model. Similarly, studies employing the social-cognitive career model consistently find that performance influences career choices, albeit indirectly through self-efficacy development (Fouad et al., 2002). Cleaves (2005) captured this self-efficacy domain in her in-depth interviews with students over a 3-year period when she found that post-compulsory science-taking choices involved a variety of dynamic considerations including not only interest and enjoyment, but competency beliefs such as ‘‘confidence in their own ability to do science’’ (p. 484).

An Identity Framework

In this study, we use an identity framework that encapsulates the above dimensions (recognition, interest, performance, and competence) to examine what can be done in high school physics courses to help students identify with physics. We chose the construct of students' identification with physics because it provides a richer lens that encompasses the four dimensions above rather than focusing on only one. It also provides an understanding of how students see themselves in relation to the field of physics based upon both their perceptions of physics and their negotiation and navigation of everyday experiences with physics (Enyedy, Goldberg, & Welsh, 2006). In addition, identity-based frameworks have proven fruitful in studying persistence. Evidence connecting identity-related measures and persistence/engagement is clear in the work of several research studies (e.g., Barton & Yang, 2000; Basu, 2008; Brotman & Moore, 2008; Carlone & Johnson, 2007; Chinn, 2002; Cleaves, 2005; Gillibrand, Robinson, Brawn, & Osborn, 1999; Hughes, 2001; Lee, 1998, 2002; Morgan, Isaac, & Sansone, 2001; Stokking, 2000). For example, Carlone and Johnson (2007) found that female scientists with ‘‘disrupted scientist identities’’ faced more difficulty in their career paths. In secondary school, Cleaves (2005) found that some students were ‘‘handicapped in the task of constructing their ideas, because they have a hazy picture of what their possible selves in science could be like.’’ (p. 484).

The specific conceptualization of identity that guides this study is outlined in Figure 1. Four components, identified in the above literature review, act as key contributors to students' identification with physics in high school: competence, performance, recognition, and interest. The first three were identified by Carlone and Johnson (2007). Because their participants were practicing scientists, the aspect of general ‘‘interest’’ in science was a given for their participants. Thus, they did not include it in their model but acknowledged its importance—‘‘a satisfactory science identity hinges not only upon having competence and interest in science, but also, critically, upon recognition by others as someone with talent and potential in science’’ (p. 1197). Drawing from the social-cognitive career model (Fouad et al., 1996; Fouad et al., 2002; Lent et al., 1994, 1996) and consistent with our discussion of the importance of interest above, we have added the component of interest, which we consider critically relevant in influencing the decision of who and what a *student* wants to be.

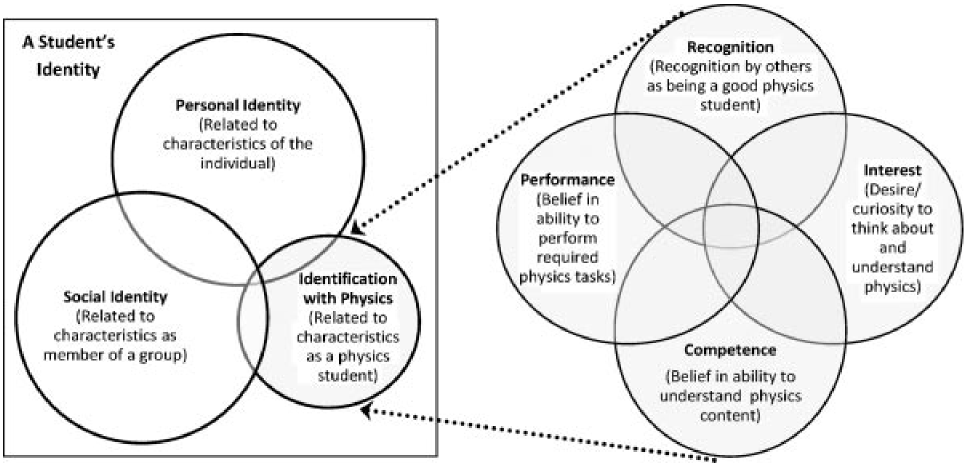

Figure 1. Framework for students' identification with physics.

In using an identity framework, we recognize that identification with physics is only one small part of an individual's identity. As depicted in Figure 1, we concur with Burke's (2003) assessment that when studying identity we need to recognize the complex interplay between the aspects of identity that are: (a) highly individual (personal identity) and defined by the characteristics and experiences that individuals hold to be self-defining (e.g., I am caring, I am shy, I am conscientious), (b) group and collective oriented (social identity) and defined by shared experiences and histories (e.g., I am a member of my family, I am a member of a religious community), and (c) context and role oriented (here, physics identity) that are influenced by expectations and perceptions associated with a situation or area. We recognize that these aspects of an individuals' identity will have continual mutual influence. Thus, a student's sense of self with respect to physics (e.g., I am a physics person because I love learning about relativity) is affected in both positive and negative ways by a student's personal sense of self (e.g., I am a loner and I do not care to interact with lots of people; people who like physics are mostly loners) and their sense of self with regards to the social groups they affiliate with (e.g., I am an athlete and athletes are not nerds; people who like physics are mostly nerds).

At the same time that students' personal and social sense of self is interacting with their development of a physics identity, their physics identity is developing or stagnating in accordance with their physics-related perceptions based on tangible experiences with physics. These perceptions have to do with the level of interest they feel towards physics topics, whether they feel competent in their ability to understand physics, if they feel that performing physics tasks are within their capability, and how much recognition they feel with regards to physics. In summary, according to our framework, the influencing components are: (i) interest (personal desire to learn/understand more physics and voluntary activities in this area), (ii) competence (belief in ability to understand physics content), (iii) performance (belief in ability to perform required physics tasks), and (iv) recognition (being recognized by others as a physics person). These influencing components are developed through experiences with physics, such as learning experiences in the classroom.

Influences on Interest, Recognition, Performance, and Competence

Outcome Expectations

In the area of motivation, the SCCT indicates that outcome expectations, or what individuals expect to achieve as a result of their actions, can strongly influence interest (Bandura, 1986; Fouad et al., 1996; Fouad et al., 2002; Lent et al., 1994, 1996). This relationship is also evident in the expectancy-value model (Wigfield & Eccles, 1992), which finds that the motivation to stay engaged in an academic activity or task is related to the value placed on the task as well as to outcome expectations. We use the term "outcome expectations" in this article to refer to career-related outcome expectations (the outcome expectation items on our instrument are in accordance with Lent et al., 2003). For example, students who have the outcome expectation of making money in their career are more likely to be interested and ultimately choose/persist in a career that they believe will help them achieve that outcome. It is especially pertinent to examine career-related values and expectations when studying the persistence of females in the sciences because many studies have found large gender differences in these values. In a survey of over 400 sixth graders, Jones et al. (2000) found that boys, significantly more than girls, wanted jobs that control others, are easy, make them famous, involved inventing new things, and allow them to make lots of money. By contrast, girls wanted to help others significantly more than did boys. Furthermore, the boys in this study were drawn to physics topics (such as planes, cars, computers, light, electricity, radioactivity, new sources of energy, and X-rays) significantly more than were the girls. At the high school level, Stokking (2000) in a survey of 1,371 secondary school students found that female students were significantly less likely to see physics as relevant to their future or report interest in physics, with future relevance being the main predictor for the students' choice to study physics further. At the college level, Morgan et al. (2001) found supporting results: males reported work goals centering on high pay and high status significantly more often than did females, whereas females reported interpersonal work goals more frequently. In addition, physical science careers were perceived as less likely to afford such interpersonal goals and more likely to afford high pay and status goals compared with other careers. Clearly, it is important to study the effect that outcome expectations have on the interests and eventual career choices of male and female students.

Learning Experiences

The Social Cognitive Career Choice Model also indicates that learning experiences are a strong moderator in the development of interests. In addition, many science education studies highlight measurable/observable experiences and characteristics, especially within the classroom, that influence the four dimensions mentioned above. For example, competence, performance, feeling recognized, and interest in physical science have been found to be influenced by:

- *Curriculum elements or enhancements* (specific pedagogy or content): for example, active learning environments, contextualized scaffolding, technology, labs/demos, writing (Adams et al., 2006; Beichner et al., 1999; Carlone, 2004; Chin & Brown, 2000; Crouch, Fagen, Callan, & Mazur, 2004; Hand, Hohenshell, & Prain, 2004; Harwood & McMahon, 1997; Haussler & Hoffmann, 2002; Labudde, Herzog, Neuenschwander, Violi, & Gerber, 2000; Lawrenz, Wood, Kirchhoff, Kim, & Eisenkraft, 2009; Sadler & Tai, 2001; Tai et al., 2005; Von Secker & Lissitz, 1999).
- *Classroom/school characteristics*: for example, class size, single-sex, private/public, student-centered (Gillibrand et al., 1999; Haussler & Hoffmann, 2002; Labudde et al., 2000; Sadler & Tai, 2001; Wyss, Tai, & Sadler, 2007).
- *Teacher characteristics*: for example, equitable behavior, questioning ability, communication, background (Chin & Brown, 2000; Haussler & Hoffmann, 2002; Labudde et al., 2000; Sadler & Tai, 2001; She & Fisher, 2002).
- *Student characteristics*: for example, SAT scores, math/science achievement, GPA, socio-economic background, motivations, self-perceptions, perceptions about science/scientists (Bonham, Deardorff, & Beichner, 2003; Carlone, 2004; Cavallo et al., 2004; Cleaves, 2005; Farenga & Joyce, 1999; Hazari et al., 2007; Jones et al., 2000; Morgan et al., 2001; Norvilitis, Reid, & Norvilitis, 2002; Sadler & Tai, 2001; Stokking, 2000; Tai et al., 2005).
- *Relationship with peers, family, and other significant adults*: for example, encouragement (Andre et al., 1999; Bleeker & Jacobs, 2004; Cleaves, 2005; Gilbert & Yerrick, 2001; Hatchell, 1998; Hazari et al., 2007; Johnson, 1999; Lee, 2002; Smith & Hausafus, 1998; Tai et al., 2005).
- *Out-of-school experiences*: for example, informal science education, childhood experiences (Chambers & Andre, 1997; Jones et al., 2000; Joyce & Farenga, 1999; Rennie, Feher, Dierking, & Falk, 2003; Stake & Mares, 2001).

Drawing particularly from classroom experiences, this study quantitatively analyzes which experiences predict students' identification with physics. More specifically, we attempt to parse out current practices within high school physics classrooms that might contribute to physics identity formation. Likewise, what career outcome expectations predict physics identity development? Although this cross-sectional large-scale study is limited in terms of depth because it does not afford a psychosocial analysis of individual cases, its design allows for a broad analysis across a representative sample. The strength of this study is its capability to test multiple factors simultaneously to determine their relative effects, and to provide results that are generalizable.

Research Questions

As we have outlined in the introduction, the two major problems that physics education faces in terms of training a sufficiently large new generation of physicists (and other professionals who need a solid grounding in physics) are (1) an overall lack of interest amongst all students to pursue physics and (2) the continued under-representation of females and minorities. In recognition of these issues, we have proposed that an identity framework including the four dimensions of recognition, interest, performance, and competence will make a valuable contribution to understanding student persistence in physics. Based on the literature surrounding these four dimensions, we also propose that student identity (and therefore possibly persistence) is influenced by factors in students' high school physics courses and by their own career outcome expectations. From this perspective, the study therefore examines the following questions:

- How strongly is our physics identity indicator related to the choice to pursue a physics career? (Once we are confident in the robustness of the physics identity measure to predict persistence, we move on to the subsequent two questions regarding what predicts the physics identity measure.)

- What factors from high school physics and career outcome expectations predict students' physics identity indicator? (Which factors contribute the most positively or negatively?)
- How are these factors different for males and females?

In the next few sections, we will introduce the parent study from which this work was drawn, the type of analysis we conducted, how missing values were dealt with, and the key variables in the analysis.

The Study and Data Analyses

The Project

The data used in this study were drawn from the Persistence Research in Science and Engineering (PRiSE) Project, which focused on identifying high school factors that influence the persistence of females in science, technology, engineering, and mathematics (STEM) disciplines. Funded by the National Science Foundation (NSF) and conducted at the Science Education Department of the Harvard-Smithsonian Center for Astrophysics, PRiSE was a large-scale study that surveyed a nationally representative sample of college/university students enrolled in introductory English courses (usually a general education requirement for all college/university students) in the fall of 2007 about their interests and experiences in science. The sampling process included drawing a stratified random sample (by size ranges and student population within those size ranges) from all the colleges and universities in the US. Thus, the results can be generalized to a large population of students—US college students who take college English. Since introductory college English students were surveyed, the project is able to examine the motivations and experiences of a spectrum of students, ranging from those who love science and had good experiences in science to those who hate science, had bad experiences in science, and will take little to no college science. Having this range of views and experiences in the sample is necessary for understanding what drives students towards science careers as well as what drives them away. In other words, by surveying college English, we capture the experiences of physics persisters as well as non-persisters.

The survey included questions on students' demographics, interest, encouragement, and high school physics experiences (the survey can be viewed online at www.cfa.harvard.edu/sed/projects/PRiSE_survey_proof.pdf). The development of the PRiSE survey was guided by three major components: (i) an extensive literature review to extract factors that might influence persistence in STEM fields, (ii) open-ended, free-response questionnaire responses from 259 high school science teachers and 153 scientists on what factors, especially in high school, influence persistence in STEM (over 100 pages of analyzed text), and (iii) an extraction of items from a previous national study (Factors Influencing College Science Success—FICSS—see www.ficss.org for more information) that showed significant gender differences. In terms of reliability and validity, many of the questions were drawn from the FICSS survey, which was previously validated and found reliable with a similar population of students (Tai et al., 2005; Hazari et al., 2007). However, to be confident in the robustness of the PRiSE survey, we conducted independent reliability and validity analyses.

For reliability, we determined the stability of our items through a test–retest study with 96 students allowing approximately a 2-week interval between administrations. For continuous variables, the correlation coefficient between the test and retest answers served as a measure of reliability; for dichotomous variables, Cohen's kappa was used. By combining these two analogous measures (for both, 1 indicates perfect agreement), the overall mean test–retest reliability of the survey was 0.7. According to Thorndike (1997), in an analysis of groups of 100 participants, a reliability coefficient of 0.5 corresponds to a 0.04% likelihood of a reversal in the direction of an effect. This means that the survey instrument has a high degree of reliability. As discussed in Thorndike (1997), the reason for such a strong reliability stems from the sample size; although the responses of any given individual may vary, overall trends found in large groups tend to be quite stable. Thus, the stability of our instrument was more than acceptable. We also tested the internal consistency reliability for the items that were used to measure our physics identity construct. In this case, Cronbach's alpha was 0.83.

For validity, we established face and content validity for the survey through focus groups with science education experts (researchers and experienced practitioners) and students. In addition, the open-ended free response questionnaires also served to support content validity since we incorporated the breadth of views and hypotheses generated from these questionnaires. To ensure the item choices reflected the variation in experiences of students, we also piloted a draft of the survey with 49 students so that items and scales could be adjusted for the final survey to appropriately capture the natural variability in the sample. Finally, in developing our dependent variable (a physics identity indicator), we established construct validity for our theoretical framework through a factor analysis (described in more detail below).

Since our focus in this study was physics, students were selected for inclusion if they indicated that they had taken at least one high school physics course at any level (i.e., regular, honors, AP, IB, or other advanced). Students were not differentiated by the number of courses, the grade or the course level when they were considered for inclusion. Only the 3,829 who had taken high school physics of the 6,860 students who returned surveys (the overall response rate was 62.5%) were included in the analyses. These students attended 34 randomly selected colleges and universities across the United States; 43% of the students were female and 57% male. Of those who responded to the question about their race (91%), 73% identified themselves as white, 9% as black, 9% as Asian, and the remainder marked less populous racial groups or "other." A Hispanic ethnicity was reported by 12%. Table 1 lists the schools by location, size range, sub-sample size, and percent of total sample.

Table 1
School location, size, sub-sample, and percent of total from amongst students who took high school physics (N = 3,829)

College/University	State	Size[a]	Number in Sample	Percent of Sample
1	AL	Large	189	5
2	AZ	Medium	81	2
3	AZ	Medium	107	3
4	CA	Large	163	4
5	CA	Large	120	3
6	CA	Large	53	1
7	CT	Large	157	4
8	FL	Small	11	<1
9	IL	Small	38	1
10	KS	Small	38	1
11	KY	Small	62	2
12	LA	Large	167	4
13	MD	Small	112	3
14	MI	Small	19	1
15	MN	Small	11	<1
16	MT	Small	2	<1
17	ND	Small	114	3
18	ND	Medium	182	5
19	ND	Small	60	2
20	NJ	Medium	134	4
21	NJ	Small	213	6
22	NY	Large	42	1
23	OH	Small	64	2
24	OH	Small	110	3
25	OR	Medium	144	4
26	SC	Medium	328	9
27	SC	Small	69	2
28	SC	Small	79	2
29	TX	Small	18	<1
30	TX	Large	244	6
31	TX	Small	49	1
32	TX	Large	364	10
33	UT	Large	232	6
34	VA	Small	53	1
Overall			3,829	100

[a]Small—fewer than 5,400 undergraduates; medium—5,400–14,800 undergraduates; large—greater than 14,800 undergraduates.

Main Analysis

Since our primary purpose was to discern the career outcome expectations and high school physics experiences that led students to identify more strongly with the subject, while controlling for alternative hypotheses (e.g., socio-economic status), we chose to employ predictive modeling to analyze the data. Since the data were collected from students in freshman English classes at different institutions, we considered using Hierarchical Linear Modeling (HLM) to account for students being nested within institutions. However, when we constructed a two-level unrestricted means model of our dependent variable (physics identity) that partitioned the variance between the student and the institutional level, we found that only a very small portion of the variance (4.3%) was associated with the institutional level. This result suggested that there would be little benefit in accounting for the institutional-level variance by using HLM rather than a multiple regression model, especially because our interest was focused on students' background and high school experiences, not on their college experience. Furthermore, the possibility that students' career plans (in science or outside of science) might vary by institutional setting has no causal relevance for our study. It would make little sense to assume that the institution has affected the career plans of freshly arrived students. Rather, the choice of institution could be more reasonably interpreted as a consequence or corollary of career intention. (If one finds more incoming students with scientific career intentions at schools with more expansive scientific and technical programs, this does not mean that the schools caused these career intentions after the students arrived. Rather, a more sensible assumption appears to be that students with scientific interests are more likely to attend schools that emphasize science.) Thus, we simplified the analysis to multiple regression models. We also included gender interactions to try to determine which factors have a gender-specific effect on physics identity. To reduce the likelihood of Type I error, we only included predictors in the model whose effects were significant at the $p < 0.01$ level.

Missing Data

In multivariate analysis, the standard procedure for dealing with missing values, called listwise deletion, is to exclude the whole observation ("case") even if only one variable has a missing value for that observation. This often leads to a considerable reduction in the number of cases for analysis (loss of statistical power) and often introduces bias into the results. Our dataset contains relatively few missing values. Of the 136 considered variables, almost all (93.4%) have fewer than 15% missing values; the average percentage of missing values was 9.3%. The average percent missing was 9.9% for non-attitudinal and 7.7% for attitudinal variables for the entire dataset. For students who took high school physics, the missing percentage is even smaller; 95.2% variables have fewer than 15% missing values and the average percentage of missing values was 8.9%. However, because our models considered numerous control as well as predictor variables, the compounded loss of data due to listwise deletion was non-negligible. To avoid this difficulty, we used multiple imputation (Rubin, 1976, 1987, 1996) of missing values for continuous variables. Tabachnick and Fidell (2007) write, "Multiple imputation is currently considered the most respectable method of dealing with missing data . . . and can be used for any form of GLM analysis, such as regression, ANOVA, and logistic regression." (p. 72). This approach creates multiple datasets, each of which is identical to the others as far as non-missing values are concerned. In place of a missing value, however, the method inserts an imputed value. This replacement value is different for each of the datasets, with the distribution of the replacement values representing the uncertainty about the missing value. Thus, the method creates several datasets—each of which is complete, but differs from the others in the values that have replaced the originally missing values. Each of these datasets is then subjected to the desired statistical procedures, which of course produce somewhat different parameter estimates in each case. In the last step, the different parameter estimates are combined to produce final estimates with appropriate standard errors (see Allison, 2002). To carry out the multiple imputation, we used PROC MI and PROC MIANALYZE in the 9.2 release of SAS. The former procedure creates several datasets by multiple imputation; the latter procedure combines the statistical results obtained for each imputation into the final results.

Controls and Predictors

The items from which the control and predictor variables came can be viewed online at www.cfa.harvard.edu/sed/projects/PRiSE_survey_proof.pdf.

Controls. We used control variables for race/ethnicity (dummy variables for Hispanic, African American, Asian), standing in school (most of the sample were freshmen coded as "0"; higher classmen were coded as "1"), parental education (average of both parents' educational levels), community SES (composite of average per capita annual income in the student's home ZIP code and the educational make-up of the adult population in that ZIP code), student's birthplace (foreign-born = 0, U.S. born = 1; note: parental birthplace was non-significant), and family support for science (composite of several variables regarding family science interest, family encouragement to take science, and home environment science support).

Career Outcome Expectations. We asked the participants to rate 15 items in terms of their importance for their future career satisfaction. They were: making money, becoming well known, helping other people, having others work under my supervision, having job security, working with people rather than objects, inventing new things, developing new knowledge and skills, having lots of family time, having lots of time for myself/friends, making my own decisions, having an easy job, having an exciting job, making use of my talents, and working in an area with lots of job opportunities. These were rated on a six-point scale anchored at the endpoints from "Not at all important" to "Very important." Supported by a factor analysis, most of these items could be grouped into four composites (averaging grouped items) with three stand-alone items. The final standardized variables included in our regression analysis were (four composites with constituent items in parentheses followed by three stand-alone):

- extraneous (making money, having others working under one's supervision, having an easy job, and becoming well known);
- intrinsic reward (inventing new things, making use of one's talents/abilities, developing new knowledge and skills, and having an exciting job);
- personal time (time for oneself/friends and time for family);
- people-related (helping other people and working with people rather than objects);
- having job security;
- making one's own decisions;
- working in an area with lots of job opportunities.

High School Physics Experiences. The high school physics variables that were tested in our model included a wide spectrum of pedagogical choices and classroom experiences. Among the items were:

- Overall class features: conceptual understanding (on a scale ranging from "very little" to "a lot"), memorization of facts ("very little" to "a lot"), gender distribution of class ("all female" to "all male"), textbook usage ("not at all" to "followed it closely").
- Classroom environment: frequency of students asking questions, frequency of students answering questions or making comments, frequency of students feeling disrespected.
- Pedagogy: frequency of lecturing, frequency of individual work, frequency of hands-on or lab work, frequency of small group work, gender distribution of groups during group work, frequency of whole class discussions, frequency of teaching classmates.
- Connections: labs address beliefs about the world ("never" to "almost every lab"), frequency of watching science videos, frequency of connections to everyday-life, frequency of connections to other disciplines, frequency of field trips, frequency of guest speakers, female scientist guest speakers, discussion of science career stages, discussion of benefits of becoming a scientist, discussion of under-representation of women, discussion of currently relevant science topics, discussion of ethics related to doing science, teacher relating science experiences/stories.
- Assessment: frequency of tests or quizzes, frequency of in-class or homework problems requiring long written explanations, frequency of in-class or homework problems requiring calculations, test problems requiring calculations, test problems that could be solved without math, test problems drawn from the homework, test problems involving data analysis, test problems requiring long written responses, test problems about earlier material, test problems requiring sketching, test problems requiring memorization, multiple-choice or true–false test questions.
- Out-of-school: amount of time spent studying or doing work for class.

Dependent Variable

One principal concern when attempting to model the relationship between physics identity and other variables is how to measure physics identity in the first place. A person's identity, even in the context of a specific role (e.g., physics student), is complex not only in the depth at which it can be described but also in the fluidity of elements that interact to influence its development. Although a complex concept like physics identity cannot be directly measured, just as physics learning cannot be directly measured, what can be measured are indicators or observables that the researcher hypothesizes to be empirically correlated with the latent variable (physics identity in this case). Just as conceptual questions on a specific topic are combined and used as an indicator for the latent variable of understanding of that topic (i.e., being able to answer conceptual questions correctly is not a 100% guarantee of understanding; however, good conceptual questions that have been rigorously validated are likely related to understanding, especially when comparing large groups of people), we propose using self-identification measures to develop an indicator of students' physics identity (note: this study does not employ a latent variable analysis; we measure and model only the indicator). Predicting this physics identity indicator with experiential variables (e.g., high school physics pedagogy) will then allow us to begin to elaborate concrete suggestions for teachers and researchers as to what pedagogy on a national scale might be influencing physics identity development.

One focal item on the PRiSE questionnaire asked students ''Do you see yourself as a physics person?'' and was rated on a scale of 0–5, with 0 being ''No, not at all'' and 5 being ''Yes, very much.'' This item was labeled ''physics person'' and was adopted from an instrument developed by Shanahan (2008). Conceptualizing identity through self-perceptions as a ''type of person'' has been common in the science education literature and beyond (e.g., Carlone, 2004; Pugh, 2004; Rahm, 2007; Rahm & Ash, 2008). In making a case for identity as an analytic lens for educational research, Gee (2000) describes identity development as people winning, losing, gaining, rejecting, and grasping for recognition as certain types of people. In addition to reflecting a common conceptualization in the literature, this item also reflects a way in which students themselves understand and express their beliefs about identity. Qualitative data collection conducted to provide the foundation for another instrument revealed this as a common phrasing used by students (Shanahan, 2007). For example ''All in all, a 'science person' is more likely to be expected to function with care'' and ''I'm just not a 'science person'.''

We justified using the ''physics person'' variable to examine the framework constructs because we had substantial evidence from Shanahan (2007, 2008) that the ''physics person'' variable was related to physics identity. As an initial test of our theoretical framework, we investigated whether all the questionnaire items we hypothesized to be connected to the constructs of recognition, performance, competence, and interest were actually related to the ''physics person'' measure. The correlations, summarized in Table 2, strongly support the framework proposed. The variables that our theoretical identity model anticipated to be connected to students' seeing themselves as a physics person indeed correlated strongly. By contrast, other variables that we would assume not to be part of the construct (e.g., grade in last high school English class, score in non-mathematical portions of SAT or ACT, watching animal behavior, planting seeds) were found to correlate much less strongly if at all. Very similar pictures emerged when looking at male and female students separately.

Factor analyses (for the whole sample and separately by gender) confirmed that the variables from Table 2 indeed aligned according to the theoretically postulated identity dimensions. This supported the formation of the following composite variables by averaging the appropriate standardized original variables (see last column in Table 2 for factor associations). The variable ''recognition'' is composed of the original variables ''Parents/relatives/friends see you as a physics person'' and ''Science teacher see[s] you as a physics person.'' The variable ''performance/competence'' comprises the variables ''middle school science grade,'' ''middle school mathematics grade,'' ''grade in most advanced math course,'' ''grade in first physics course,'' ''score on mathematics portion of SAT or ACT,'' ''middle school confidence in science abilities,'' and ''middle school confidence in mathematics abilities.'' The ''interest'' dimension of the construct was divided into three sub-dimensions, as suggested by the factor analyses. The first, ''physics interest,'' pertains to interests that are specifically focused on physics topics: interest in ''mechanics,'' ''optics/waves,'' ''electromagnetism,'' ''relativity/modern physics,'' ''history and people of physics,'' and an experience in ''tinker[ing] with mechanical devices.'' The second sub-dimension, ''science interest,'' pertains to more

Table 2
Correlations of recognition, performance, competence, and interest variables with seeing oneself as a "physics person" and factors that emerged from the factor analysis to confirm theoretical dimensions

	r	Sig.	*N*	Factor Analysis Composites
Recognition				
Parents/relatives/friends see student as physics person	0.82	***	3,201	Recognition
Science teacher sees student as physics person	0.70	***	3,187	Recognition
Performance				
Middle school science grade	0.23	***	3,211	Perf/comp
Middle school mathematics grade	0.20	***	3,231	Perf/comp
Grade in most advanced HS mathematics course	0.18	***	3,124	Perf/comp
Grade in first high school physics course	0.29	***	2,815	Perf/comp
SAT or ACT score (mathematics portion)	0.30	***	2,645	Perf/comp
Competence				
Science ability confidence in middle school	0.28	***	3,176	Perf/comp
Math ability confidence in middle school	0.25	***	3,222	Perf/comp
Interest				
General interest in mechanics	0.57	***	3,162	Phy. interest
General interest in optics/waves	0.54	***	3,153	Phy. interest
General interest in electromagnetism	0.56	***	3,148	Phy. interest
General interest in relativity/modern physics	0.57	***	3,149	Phy. interest
General interest in the history of physics	0.38	***	3,146	Phy. interest
Experience tinkering with mechanical devices	0.21	***	3,034	Phy. interest
General interest in conducting own experiments	0.38	***	3,204	Sci. interest
General interest in understanding natural phenomena	0.39	***	3,204	Sci. interest
General interest in understanding everyday-life science	0.38	***	3,191	Sci. interest
General interest in explaining things with facts	0.40	***	3,182	Sci. interest
General interest in using mathematics	0.46	***	3,195	Sci. interest
General interest in telling others about science concepts	0.49	***	3,184	Sci. interest
General interest in making scientific observations	0.48	***	3,181	Sci. interest
General interest in wanting to know more science	0.51	***	3,189	Sci. interest
Participated in science clubs	0.24	***	3,140	Sci. activity
Participated in science/math competitions	0.25	***	3,140	Sci. activity
Engaged in personal science hobbies	0.37	***	3,108	Sci. activity
Read/watched non-fiction science	0.27	***	3,117	Sci. activity
Read/watched science fiction	0.22	***	3,078	Sci. activity

Note. Factor Analysis Composites form the basis for the dependent variable.
***$p < 0.001$.

general scientific interests: interest in "conducting [one's] own experiments," "understanding natural phenomena," "understanding everyday-life science," "explaining things with facts," "using mathematics," "telling others about science concepts," "making scientific observations," and "wanting to know more science." The third sub-dimension, "science activity," bundles certain science-related behaviors and activities: "participat[ion] in science groups/clubs/camps," in "science/math competitions," "personal science hobbies," reading or watching "non-fiction science," and "science fiction." Gee (2000) categorized these types of activities as affinity interests or outcomes related to an affinity identity.

Although, as discussed earlier, mathematics performance differences are generally small to negligible between male and female students, mathematics interests and achievement do have an impact on, or relationship with, identity and persistence. In an exploration of how students perceived the identity-expectations of school science (Shanahan, 2008), students identified mathematics ability as a key aspect of intelligence as they defined it in relation to science. In addition, Hazari et al. (2007) found that for both male and female students, mathematics-related factors (high school grades, mathematics SAT scores, and calculus enrollment) were the strongest predictor of university physics performance. Based on the position of mathematics (a) in students' perceptions of identity-related expectations and (b) as a strong predictor of physics performance, mathematics-related variables were regarded as an important part of the physics identity composites.

All composite variables were correlated with the students' view of themselves as a physics person. The closest correlate ($r = 0.82$) is recognition; the furthest is performance/competence ($r = 0.35$), as can be seen in Figure 2 which is a plot using multi-dimensional scaling (MDS) where closeness indicates strength of correlation. MDS maps the proximity of variables onto a multi-dimensional space (reduced to two dimensions in this plot) based on the similarities between the variables (in this case correlation).

The factor analysis composites, plus the standardized variable of seeing oneself as a physics person, were averaged to form our dependent variable—a "physics identity" indicator based on our theoretical framework. We created this indicator because it is more robust and captures more of the complexity in physics identity than would a single questionnaire item. Although the "physics person" item could have been used as the dependent variable, it did not on its own evenly encapsulate all the theoretical dimensions. This is portrayed in the MDS picture in Figure 2, where the "physics person" measure is most closely linked to the recognition composite. On the other hand, the summary "physics identity" indicator occupies a central position within the physics identity nexus. It is strongly correlated with all the physics identity-related items (from $r = 0.59$ with performance/competence to $r = 0.83$ with viewing oneself as a physics person). This physics identity variable was standardized, with a mean of 0 and a standard deviation of 1. The extreme values are 3.0 (highest) and -3.4 (lowest). A technical advantage of using this physics identity measure as the dependent variable in regression models is that it has an approximately normal distribution, which contributes to the accuracy of the regression estimates.

Results

Research Question 1: Connection between the Physics Identity Indicator and Physics Career Choice

Consistent with the mentioned prior studies that stressed the importance of the students' identity concepts for their career choices, we found our indicator for physics identity to correlate strongly with the students' reported likelihood of choosing a career in the physical sciences (on a 6-point rating scale ranging from "not at all likely" to "extremely likely"; $r = 0.54$). Moreover, the students who said that, at the end of

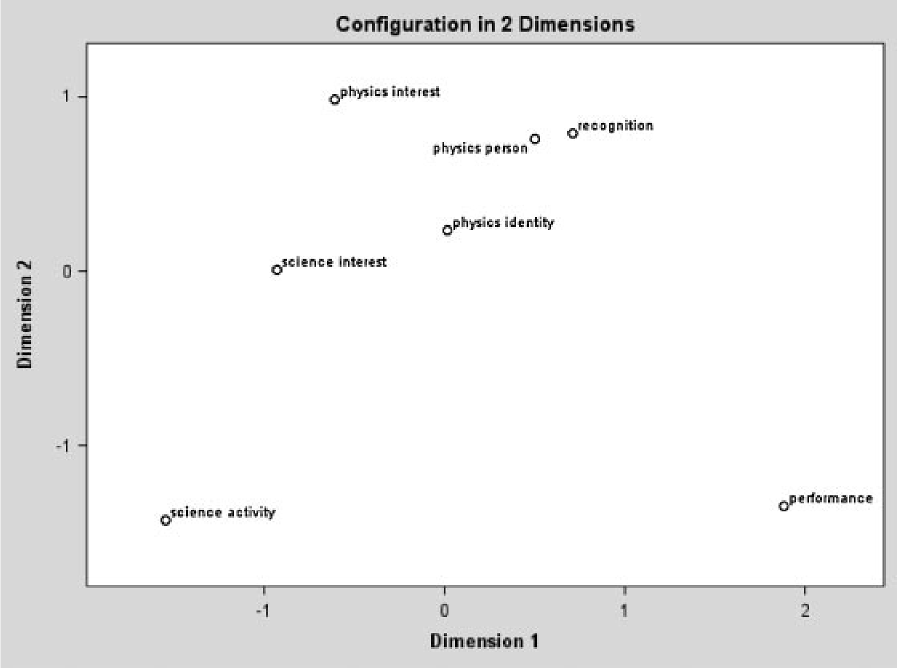

Figure 2. Plot using multi-dimensional scaling to illustrate the strength of relationships between the composites as well as the appropriate central position of our physics identity dependent variable.

high school, their career plan was to become a physicist scored, as a group, 1.1 standard deviations higher on the physics identity composite than did those who did not mention a career plan in physics. In a logistic regression predicting a career plan in physics at the end of high school with students' physics identity, the parameter estimate for the physics identity indicator was 1.12. This corresponds to an odds ratio of 3.1:1. In other words, an increase in physics identity by 1 standard deviation boosts the odds of planning a career in physics more than threefold.

Research Question 2: Predictors of Physics Identity

Two regression models predicting our physics identity indicator appear in Table 3. Model I, which includes demographic predictors and background variables, explains 27% of the variance in the physics identity measure. Note that males have a significantly higher physics identity indicator than their female counterparts by about half a standard deviation. Model II adds career outcome expectations and high school physics experiences to Model I and explains an additional 16% of the variance in the physics identity indicator. Thus, Model II explains a total of 43% of the variance. This model highlights career outcome expectations that correlate with physics identity as well as options high school physics teachers might employ with a good chance to impact the development of a physics identity and reduce gender differences. The one outcome expectation that is *positively* related to physics identity is intrinsic fulfillment. *Negatively* related to

Table 3
Regression models predicting physics identity measure with gender interactions

	Models ($N = 3{,}829$)					
	I			II		
Parameters	Estim.	Sig.	SE	Estim.	Sig.	SE
Intercept	−0.02	ns	0.06	−0.17	**	0.05
Demographics and background controls						
Race		Included			Included	
Parental education and SES		Included			Included	
Sophomore or higher in college		Included			Included	
Born in the US[a]	−0.29	***	0.06	−0.23	***	0.05
Family support for science[b]	0.44	***	0.02	0.30	***	0.02
Gender (0 = Female, 1 = Male)	0.49	***	0.03	0.39	***	0.03
Career outcome expectations						
Intrinsic reward[b]				0.18	***	0.02
Personal time[b]				−0.06	***	0.02
People-related[b]				−0.10	***	0.02
High school physics predictors						
Conceptual understanding class focus[b]				0.13	***	0.01
Labs address belief about world[b]				0.11	***	0.02
Student comments/answers questions[b]				0.11	***	0.02
Student teaches classmates[b]				0.09	***	0.02
Distribution of male students in the class[b]				0.06	***	0.02
Teacher encourages to take science[a]				0.21	***	0.03
Discussion of currently relevant science[a]				0.11	***	0.03
Discussion of benefits of being a scientist[a]				0.14	***	0.03
Discussion of female under-representation[a]				0.20	***	0.06
Interaction: Discuss under-rep. × gender				−0.22	**	0.08
R^2	0.27			0.43		

Note. ns, not significant.
**$p < 0.01$.
***$p < 0.001$.
[a]Dichotomous variable: No = 0, Yes = 1.
[b]Standardized variable: mean = 0, standard deviation = 1 (the estimates for these variables indicate how much, in standard deviation units, the dependent variable changes when the predictor increases by 1 standard deviation).

physics identity are the availability of personal time and working with/for others. The high school physics experiences that are *positively* related to physics identity for all students are: the frequency of labs that address students' beliefs about the world, the frequency of students commenting and answering questions, the frequency of students teaching classmates, a greater percentage of male students in the class, teacher encouragement to take science, discussion of the benefit of being a scientist, and discussion of currently relevant science topics.

Research Question 3: Gender Differences

There is also a significant gender interaction in Model II. It illustrates that explicit discussion of under-representation of women in science has a positive impact on physics identity for female students but no impact for male students. This interaction effect is visually represented in Figure 3. For males, the discussion of under-representation makes no difference. For females, physics identity is significantly higher for those who experienced a discussion of under-representation in their high school classes. As a result, for those who reported this type of discussion in their high school physics classes, the difference between males and females in terms of identity is smaller. Notably, several variables that were hypothesized to be important, based on the literature and from preliminary interviews with female teachers and scientists, proved to be non-significant. They include high school physics experiences such as female scientist guest speakers, discussion of women scientists' work, and the frequency of group work. Finally, although there is only one interaction effect and most of the effects are the same for males and females, there were still some crucial gender differences in the reported frequencies of high school experiences. Females were significantly less likely to indicate that their high school physics class focused on conceptual understanding ($p < 0.05$), had labs that addressed their beliefs about the world ($p < 0.001$), discussed currently relevant science topics ($p < 0.001$), or discussed the benefits of being a physicist ($p < 0.001$), despite the fact that all of these factors were significant positive main effects for the physics identity indicator for *both* males and females. However, females were more likely to report teacher encouragement ($p < 0.01$). (Note: the first two comparisons were results of a *t*-test, since those variables were continuous, and the last three were results of a Mann–Whitney test, since those variables were dichotomous.)

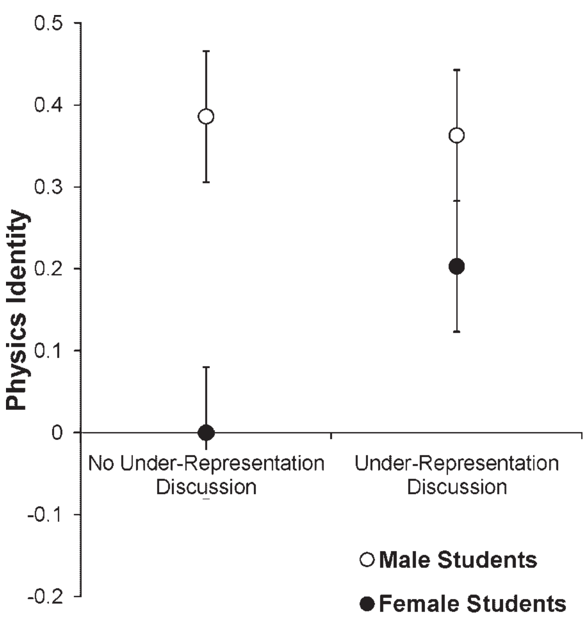

Figure 3. Interaction of gender and discussion of under-representation in high school physics as predicting physics identity. (Note that the location of the horizontal baseline is arbitrary: we chose to set it to female students who had a high school physics class where under-representation was not discussed.)

Discussion

Research Question 1: Physics Identity and Physics Career Choice

Consistent with the work of several other researchers (e.g., Barton & Yang, 2000; Carlone & Johnson, 2007; Chinn, 2002; Cleaves, 2005; Shanahan, 2007), we found a strong link between physics identity and physical science career choices. This link supports the suitability of the identity framework as a critical lens of analysis for studies interested in STEM persistence. We further hypothesize that identity analyses will be useful in predicting longer-term persistence. This supposition is supported by the results of Tai et al. (2006) who, using data from the National Educational Longitudinal Study (NELS), found that science career aspirations in eighth grade (i.e., early identification) strongly predicted physical science bachelor's degree attainment several years later. Further longitudinal research that looks at the longer-term impact of science identity development over the schooling years is critically needed.

Research Question 2: Predictors of Physics Identity—Career Outcome Expectations

"Even in the midst of fulfilling his various roles as worker, friend, spouse, and parent, the scientist is characterized as a person who prefers 'to be left to himself, to be left alone with his mind and his books.'" (Parsons, 1997, p. 758).

Amongst the career outcome expectations variables, the strongest predictor of physics identity is the desire to pursue a career that would result in intrinsic fulfillment through working with knowledge, skills, or products. The fact that this motivation is strongly related to physics identity carries both positive and negative connotations. We want students to be internally driven and to feel motivated simply by the enjoyment of learning and working with physics concepts. Anyone who has a physics background or has worked with physicists knows that there is truth to the claim that the physics culture promotes "physics for the sake of physics." The benefit of this cultural standard is that those who end up participating usually love the theoretical basis of what they do. This internal drive is important for motivating the large amount of dedication needed to become a cutting-edge physicist who pushes the boundaries of our knowledge. However, there is a fundamental imbalance in this norm because mainly those who come from backgrounds with the luxury of affording knowledge-based motivations will opt into physics. Others who have additional motivations, like socio-economic concerns, will need to have a passion for physics above and beyond the norm in order to disregard such concerns and opt into physics. This issue is captured, albeit unintentionally, in a quote of the African American astronomer Neil deGrasse Tyson:

> You've got to be so deeply in love with your subject that when curve balls are thrown, when hurdles are put in place, you've got the energy to overcome them. I can think of no greater, more important need than this, because when I look behind me, I don't see all that many [young minority scientists] coming after me. (NOVA, 2004)

Perhaps if the physics community promoted and supported more balanced motivations, physics would be more successful in attracting members of under-represented groups.

The motivational imbalance becomes more evident from our result that personal time and people-related motivations are negatively related to physics identity. It is true that to be a successful physicist requires some abandoning of personal time, but this is no more so than in other fields. Yet, other areas, such as the humanities, do not carry the stereotype that you have to give up your "life" to be successful. In terms of being people related, one could argue that modern physics is a highly collaborative enterprise, as evidenced by the fact that single-author articles are becoming less common (Greene, 2007). In addition, physics discoveries and innovations have contributed in countless ways to bettering people's lives. Nonetheless, other studies have also found that motivations of having personal time and being related to people are negatively associated with an interest in physics. For example, Morgan et al. (2001) found that college students perceived physical science careers as less likely to afford interpersonal goals. In terms of gender, this is especially problematic because females tend to be more motivated by interpersonal goals (Jones et al., 2000; Morgan et al., 2001; Mullis, Mullis, & Gerwels, 1998) and more interested in careers that will allow them to maintain multiple roles (Curry, Trew, Turner, & Hunter, 1994; Eccles, 1987; Fiorentine, 1988), including that of family caretaker. A high school physics teacher can play an active role in countering some of these perceptions so that developing a physics identity will become consistent with multi-dimensional career motivations. Our results suggest that discussing the many benefits of becoming a scientist might be one way of doing this.

Research Question 2: Predictors of Physics Identity—High School Physics Experiences

Five of the factors in our model are under the direct control of high school physics teachers. They are: focusing the class on conceptual understanding, conducting labs that address students' beliefs about the world, discussing currently relevant science, discussing the benefits of being a scientist, and encouraging students to take science classes. The first finding, that a conceptual understanding focus is positively related to physics identity, dovetails with a host of other research that finds a link between physics conceptual understanding and performance (e.g., Eryilmaz, 2002; Hazari et al., 2007; Willson, Ackerman, & Malave, 2000), reasoning ability (e.g., Cavallo et al., 2004; Chin & Brown, 2000), self-efficacy (e.g., Cavallo et al., 2004), and interest (e.g., Otero & Gray, 2008). These latter domains are embedded in our theoretical framework for physics identity. The focus on conceptual understanding is particularly important for females who enter physics classes with deficits in conceptual understanding (Cavallo et al., 2004; Chambers & Andre, 1997; Engelhardt & Beichner, 2004), often due to lack of prior experience (Chambers & Andre, 1997). However, this focus might prove particularly difficult for teachers because some females, especially academically motivated ones, have been found to resist active reform-based physics teaching focused on conceptual understanding due to the threat it poses to their academic standing (Carlone, 2004). One strategy that might help ease this difficulty is to include relevant real-world contexts. Stadler, Duit, and Benke (2000) found that girls think they understand a physics concept only when they can apply it to familiar real-world situations. In support, Huffman (1997) found that females who solved physics problems using a method that was explicitly designed for thinking about real world, context-rich problems had higher conceptual understanding than did females who used a standard textbook method. It is not surprising, then, that real-world connections also crop up in our study as being related to physics identity (for female and male students). In particular, we found that having labs that address students' beliefs about the world and discussion of currently relevant science topics predict our physics identity indicator.

The next factor returns us to the discussion of career expectations. Specifically discussing the benefits of being a scientist might help students realize a lack of dissonance between their career expectations and the characteristics of physics professions. In other words, such discussions might help them see themselves pursuing physics along with what they want to accomplish for themselves (e.g., having a social life, having a family life, being creative, making a stable living). This concordance may not be apparent to students who have highly stereotyped or naive views of what a physicist is/does—that is, especially to students who, in their familial and social environments, have not encountered anybody who works as a physicist or, more generally, as a scientist. These stereotyped and naive viewpoints towards physics typically include perceptions of masculinity, difficulty, and heteronomy (lack of opportunity for individuals to develop or express their own ideas, creativity) (Kessels, Rau, & Hannover, 2006). Countering these viewpoints has been found to improve students' attitudes and lessen the association between such viewpoints and physics (Kessels et al., 2006).

Favorable factors in terms of developing physics identity are not limited to pedagogy and content; the affective domain is also important. Thus, teachers who encouraged their students in science had students with higher scores on our physics identity indicator. In addition, the family support control variable played a substantial role. It had the largest main effect on physics identity after the gender of the student. This is not surprising because research highlights the importance of support and encouragement by significant adults for persistence in studying STEM (Cleaves, 2005; Ratelle, Larose, Guay, & Senecal, 2005; Turner et al., 2004), particularly for females in physics (Hazari et al., 2008).

Two of the significant predictors in our model require greater action on the part of the student. Thus, although teachers can implement and facilitate these approaches, the success of the approach depends on the willingness of the student to take an active role greater than merely going through the motions of traditional class-work. The first is answering questions and making comments. Students who reported answering questions and making comments more frequently had a significantly higher physics identity indicator. It is not hard to see the connection. Students who actively volunteer responses and comments are more secure in themselves and their knowledge, which enables them to feel confident and empowered enough to contribute to the class. In addition, by voluntarily answering a question or making a comment, a student automatically takes on the role of an authority. This translates into a greater physics-related self-perception, especially if their answers and comments are acknowledged by the teacher. For example, in their description of the science identity formation of a minority female sixth grader over the course of a school year, Tan and Barton (2008) document her identity transformation after she had passed the first half of the year in a relatively quiet subdued state with low science self-efficacy. Among the critical transforming events were her taking on the role of an ‘‘expert’’ and amusing the class in two science presentations, as well as her volunteering answers to the teacher's questions in subsequent science lessons. The work of Olitsky (2007) in an eighth grade physical science class also demonstrates that feeling empowered enough to answer questions and to participate actively contributes to identity building in science. Similarly, Basu (2008) found that for five minority physics students, expressing their voice in class ‘‘described and/or altered their identities, particularly in how they discussed lesson design as connected with their career goals, intellectual identity, social identity, and beliefs about science.’’ Thus, expressing their voice helped them build connections with other parts of their identity. How can teachers encourage this type of voluntary participation by students that is critical for identity development? The work of several qualitative researchers (Barton & Tan, 2009; Basu, 2008; Olitsky, 2007; Tan and Barton, 2008) provides meaningful examples: allowing students the opportunity to express their own voice through presentations, establishing a respectful/encouraging classroom atmosphere that minimizes the anxiety of public expression, positively acknowledging students' views, allowing students to see the ‘‘backstage’’ learning struggles (that even a teacher faces) rather than presenting the material from an elite transfer perspective, and, in general, creating hybrid spaces within classrooms.

The second significant predictor in our model which requires students to take an active role is teaching classmates. Students who more frequently reported teaching their classmates had a significantly higher physics identity indicator. However, peer-learning situations in general, such as small group work, were not significant. This seems plausible because it is probably the role in the group work that is critical rather than the group work itself. Specifically, taking on the role of an expert through teaching others might make students feel like they belong to the expert group. In a meta-analysis of peer-assisted learning interventions in elementary school, Ginsburgh-Block, Rohrbeck, and Fantuzzo (2006) found that such interventions focused on academics can positively influence self-concept outcomes. However, their analysis does not clearly separate out the findings for science or for cases where the student specifically plays the teaching role, and also excludes the stage of secondary education. Unfortunately, much of the research in science education and physics education looks at the influence of peer-assisted learning at the group level (Springer, Stanne, & Donovan, 1999), that is, it is difficult to distinguish whether it was the student with the teaching role or the student with the learning role who benefited more. Research on peer tutoring, on the other hand, provides more comparable results. For example, in a review of the literature on tutoring in mathematics for minorities, Robinson, Schofield, and Steers-Wentzell (2005) found that the vast majority of studies examining how tutoring peers and younger students affected minorities showed gains in feelings of belonging/social acceptance, social skills, and/or academic self-concept, and that no studies reported decreases in self-concept. In addition, several psychological theories, such as role theory, have posited the possibility of manipulating self-perception and intrinsic motivation through taking on particular roles (Allen & Feldman, 1976; Bandura, 1986; Bem, 1972; Cate & Durning, 2007; Ryan & Deci, 2000).

Perhaps the most difficult effect in our model to interpret is the significance for *all* students of having a greater percentage of male students in the class, especially given the literature on the benefit of single-sex physics education for females (Gillibrand et al., 1999; Haussler & Hoffmann, 2002). We put forward a hypothesis: since males have higher interest levels and self-concepts in relation to physical science, having more of them in the class helps create an environment that will foster excitement in the average high school physics class; or females' disinterest may be reinforced by other disinterested females in a typical physics classroom. Recall, that our national sample is not representative of reform-based physics classrooms, but of the typical classrooms. The overwhelming majority of American students are educated in a gender-integrated environment. Only 4.8% of our female participants reported ‘‘all females’’ in their physics classes, and only

6.0% of the males reported "all males." Thus, the results from this study are not comparable to the single-sex studies that find gains for females. Moreover, those studies often incorporate a reformed curriculum that fosters girls' interest or nuanced behavior on the part of the few teachers participating in the study (Gillibrand et al., 1999; Haussler & Hoffmann, 2002). In fact, Haussler and Hoffmann (2002) emphasize that educators and researchers recognize "that separating girls and boys in physics classes is probably ineffective when not supported by a girl-friendly curriculum and a gender-fair teacher." (p. 885). Our results further elaborate the complexity of the issue. To say having more girls in physics classes is good for girls or bad for girls is naïve when it is so highly dependent on the teacher, the curriculum, and the classroom environment. More empirical research, especially that which rigorously addresses possible confounding factors and alternative explanations, is needed before we can parse out not only what our finding means, but how gender-based quorums influence socio-emotional outcomes in particular classroom situations.

Research Question 3: Gender Differences

The one predictor that has a different effect for males and females is the discussion of female under-representation in their high school physics class. Discussion of female under-representation is positively related to the females' physics identity indicator, while having no effect on males' physics identity indicator. This is, perhaps, one of the most interesting and important findings of this study, especially because other pedagogical and content aspects related to women in science, such as examples of female scientists and females scientist guest speakers, had no significant influence on females' physics identity indicator. Students' thinking and choices may be more sophisticated than what many policy makers seeking band-aid solutions would lead us to believe. Showing girls pictures of female scientists or even live examples is not enough for them to want to participate in science for themselves. Mimicking is not the culmination of how we learn and make choices. For example, Gilmartin, Denson, Li, Bryant, and Aschbacher (2007) found that the percentage of female science faculty in a high school "did not have an effect on multiple components and mediators of [male or female] students' evolving science identities" in a study of over a thousand tenth grade students (p. 1000). Their results revealed that "students responded to male and female science teachers who are caring, challenging, engaged, passionate, fair, and/or linked to the 'actual' practice of science in some concrete way" (p. 1001). These findings support several of our results including the effect of teacher encouragement, real-world connections, and, in the case of females, discussion of under-representation. For the latter result, the explicit discussion of under-representation issues, such as gender-bias and the "state of affairs" for women scientists, presents the situation in a more realistic and complex light that may prompt female students to re-assess their own biases, pre-dispositions, and choices, thereby influencing a change in their self-perceptions with respect to physics. A good example of this effect subconsciously taking hold can be extrapolated from the work of Dar-Nimrod and Heine (2006). The authors found that explicitly reading or hearing (prior to taking a math exam) that experiential differences were the cause of gender differences in mathematics performance actually reduced stereotype threat and increased mathematics performance for women.

Finally, although there were five experiences that were in the direct control of teachers which had a positive effect for *both* female and male students, these five experiences were reported at significantly different rates by female and male students. Female students reported significantly less focus on conceptual understanding, labs addressing their beliefs about the world, discussing currently relevant science topics, or discussing the benefits of being a physicist. Thus, sitting, on average, in the same types of classes, females perceived less of a conceptual focus and less contextual relevance with the real world than did their male counterparts, even though these associations were equally beneficial to the smaller number of females who reported them. These findings are mirrored in the results of other research which find that conceptual understanding and contextual relevance are two key areas that need to be focused on when narrowing the gender gap in physics (Cavallo et al., 2004; Chambers & Andre, 1997; Engelhardt & Beichner, 2004; Hazari et al., 2008; Haussler & Hoffmann, 2000). On a positive note, unlike past work on gender reporting that males often dominate by taking the most active roles in science classes (see Guzzetti & Williams, 1996), our sample did not show such a result. There were no significant gender differences in students who reported taking an active role in class (answering questions and making comments, teaching classmates).

Conclusions

There are clearly some current practices in high school physics teaching that are positively related to physics identity development. Extrapolating and understanding these practices is important because of the strong link we found between physics identity and physical science career choice. Our results emphasize some ways in which high school physics teachers might be able to influence positive physics identity development in students: namely, focusing on conceptual understanding, making real-world connections, countering stereotypes that physics is a one-dimensional pursuit that requires giving up other desires, getting students to take on active expert roles (answering questions, making comments, teaching others), and encouraging students. For females, it may be particularly important to focus on conceptual understanding and real-world/contextual relevance since they experienced these connections significantly less than their male counterparts. In addition, explicit discussion of women's under-representation in science had a positive effect for females without detriment to the males.

This study has several broader implications for both physics education practice and research. First, it presents a salient theoretical framework that provides a centralizing structure through which we can think about a wide range of research results focused on persistence in science. To expound on what we mean, recall research findings like: performance influencing persistence; interest influencing persistence; performance influencing interest via self-efficacy, which then influences persistence; perception of others influencing self-perception, which then influences persistence; and so on. To make sense of all these findings simultaneously, a unifying framework is necessary. Building on results from the literature, we propose a framework in which fundamental constructs such as performance, perceptions of competency, perceptions of others, and interest all influence a focal construct—physics identity. Because the fundamental constructs (performance, competency, recognition, and interest) are so highly collinear and influence one another in different directions depending on the situation, it makes sense to synthesize them into the grand total effect they have on a person's overall self-perception with regard to science. The second important implication of this work draws attention to the specific constructs, many of which teachers should be aware of. In other words, it is not enough for teachers to prepare students for performing required tasks or making the subject interesting. Teachers need to also provide opportunities for recognition, recognize students themselves, and focus on practices, such as conceptual understanding, that will not only increase competency but also feelings of competency.

Clearly, physics identity and, more generally, science identity provide fruitful directions for new research. Future work should delve not only into testing the theoretical framework we put forth but also understanding the nuanced ways in which specific pedagogical devices that are currently in use influence identity development. Although we have drawn explanations and support for our results from other findings in the literature, this work is unable to make causal linkages or extract deeper meaning. Thus, in addition to focused experimental or quasi-experimental quantitative studies, explanatory qualitative and case-study work is a necessary follow-up to this study. Such efforts will help us understand not only the ways in which these pedagogies are carried out in the classroom, but also the underlying mechanisms that link certain pedagogical choices and identity development, especially as mediated by the four dimensions in the theoretical framework. For example, qualitative work can help us unravel what *specific* techniques/lessons (both content and pedagogy) connect with something particularly relevant to female students' lives and how that relevance connects to interest or feelings of competence thereby impacting physics identity development.

Furthermore, our initial intent to find factors that influence females differently than males proved to be somewhat unsuccessful. Although we tested many gender interactions, we found only one that had a strong enough effect to survive in our model at the $p < 0.01$ level. Our results shed light on factors that generally might influence physics identity, regardless of gender. The gender difference occurs at a more nuanced level; different students perceive and make connections with the same pedagogy and content in different ways. In other words, even though conceptual understanding and contextual relevance might be equally beneficial for males and females, females perceive experiencing these attributes significantly less. Thus, the question for physics educators to ask is, what content and pedagogy would facilitate females making these more meaningful and sustainable connections with physics? Clearly the gender issue is an important one because there still is a large gender main effect (negative for females). As Chinn (2002) writes, "It took me a long time to understand the little everyday ways that gender, ethnicity, and culture shaped the way decisions were made about women." (p. 306). We push this idea further by asking about the little everyday ways, especially inside the classroom, that shape females' decisions for them by not including their perspectives and what is meaningful to them.

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