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Women Have Lower Physics Self-efficacy and Identity Even in Courses in Which They Outnumber Men: A Sign of Systemic Inequity?

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ABSTRACT

The motivational beliefs of students, who were mainly bioscience majors interested in careers in health professions, in mandatory large introductory level algebra-based physics courses were surveyed. Although female students outnumbered male students in these courses, they had lower physics motivational beliefs including self-efficacy and identity at the beginning of the physics course, and this gender gap increased by the end of the course. Moreover, the present study used a slightly modified version of the physics identity framework by Hazari et al. (2010) to investigate whether the relation between gender and physics identity was mediated by other motivational beliefs, including perceived recognition by others, self-efficacy, and interest. The model shows that perceived recognition by others, self-efficacy, and interest mediated students' physics identity and there was no direct path from gender to identity. The increased gender gap in these beliefs measured at the end of the physics courses may signify inequity and the non-inclusive nature of the physics learning environment. These findings related to the gender gap in physics motivational beliefs are valuable because they may signify that classroom representation alone will not change the pernicious effects of systemic gender inequities in physics perpetuated by society and bolstered further by the physics learning environments.

Keywords: equity, inclusion, gender, motivational beliefs, physics, undergraduate

Introduction

While prior research has investigated issues pertaining to women's representation in the science, technology, engineering, and mathematics (STEM) fields (American Institute of Physics, 2020; Blue et al., 2018; Bowling et al., 2017; Brainard & Carlin, 1998; Center, 2015; Harackiewicz et al., 2016; Kost-Smith et al., 2010; Lorenzo et al., 2006; Miyake et al., 2010; Seymour, 2002; Seymour et al., 1997; Tsui, 2007; Vincent-Ruz et al., 2018; Walton et al., 2015; Whitten et al., 2003), most studies in college physics have focused on courses in which women are outnumbered by men. Moreover, in explaining participation and learning in STEM disciplines, student motivational beliefs have been shown to play an important role (Sari et al., 2018; Smith et al., 2013; Stets et al., 2017; Swarat, 2008; Yang, 2016). However women have been shown to have lower motivational beliefs than men (Hanson et al., 2020; Louis & Mistele, 2012; E. M. Marshman et al., 2018; Stewart et al., 2020). In particular, students' identity has been shown to play an important role, not only in students' in-class participation and performance, but also in their choices of future courses and careers (Carlone & Johnson, 2007; Gee, 2000; Hazari et al., 2010; Stets et al., 2017; Tonso, 2006; Vincent-Ruz & Schunn, 2018). Identity in this context (e.g., physics identity) refers to students' views about whether they see themselves as a *physics person* or a person who can excel in physics (Hazari et al., 2017; Hazari et al., 2013; Hazari et al., 2010; Monsalve et al., 2016).

In the present study, a version of the physics identity framework developed by Hazari et al. (2010) was used, which adapted the science identity framework by Johnson et al. (2017). Johnson et al.'s (2007) science identity framework includes three dimensions: competence (I think I can), performance (I am able to do), and recognition (I am recognized by others). Hazari et al. (2010) modified the framework specifically for physics. Competence and performance were defined as students' beliefs in their ability to understand the subject and students' belief in their ability to perform physics tasks. Additionally, recognition was framed as recognition by others as being a good physics student. Lastly a fourth dimension, interest, was added to the framework since students have highly varying levels of interest in physics (Hazari et al., 2017; Hazari & Cass, 2018). In future studies by Hazari for introductory students, performance and competence are combined into one variable (Hazari et al., 2020). In a slightly reframed version of Hazari's physics identity framework by Kalender et al. (2019b), the framework used in the study, performance/competence was framed as self-efficacy (closely related to competency belief). Additionally, recognition was framed explicitly as perceived recognition by students for clarity.

Self-efficacy refers to students' belief in their ability to accomplish tasks or solve problems (Bandura, 1977; 1994). It has been shown to influence students' engagement, learning, and persistence in science courses, in addition to contributing to students' science identity (Britner, 2008; Cheryan et al., 2017; Felder et al., 1995; Lindstrøm & Sharma, 2011; Sawtelle et al., 2012; Schunk & Pajares, 2002; Zimmerman, 2000). For example, when tackling difficult problems, students with high self-efficacy tend to view the problems as challenges that can be overcome, whereas those with low self-efficacy tend to view them as personal threats to be avoided (Bandura, 1994). However, in introductory physics courses in which women are underrepresented, studies have found a gender gap in self-efficacy that widens by the end of the course, even in interactive engagement courses (E. Marshman et al., 2018; Nissen & Shemwell, 2016). Additionally, self-efficacy has been shown to predict students' engagement, learning, and persistence in science courses (Bandura, 1994; Bouffard-Bouchard et al., 1991; Cavallo et al., 2004; Correll, 2004; Fencl & Scheel, 2005; Vincent-Ruz & Schunn, 2017).

Another motivational belief that influences physics identity is interest. Interest in a particular discipline may affect students' perseverance, persistence, and achievement (Bailey et al., 2017; Harackiewicz et al., 2002; Hidi, 2006; Lichtenberger & George-Jackson, 2013; Strenta et al., 1994; Tims et al., 2014; Wang & Degol, 2013). One study showed that changing the curriculum to stimulate the interest of female students helped improve all of the students' understanding at the end of the year (Häussler & Hoffmann, 2002). Within expectancy-value theory, interest and self-efficacy are constructs that predict students' academic outcomes and career expectations (Wigfield & Eccles, 1992). In this study the focus is on intrinsic interest, or an individual's personal interest, and enjoyment in engaging with physics concepts in this study.

The third belief, perceived recognition by others, has been shown to play an important role in a student's identity (Vincent-Ruz & Schunn, 2018) and motivation to excel (Goodenow, 1993). In a study on students' perception of support, teacher support was more strongly linked to the motivation and engagement of girls than boys (Goodenow, 1993). However, studies have shown that female students are not recognized appropriately in many STEM disciplines, even before they enter college (Archer et al., 2017; Bian et al., 2017; Kalender et al., 2019a). One study found that science faculty members in biological and physical sciences exhibit biases against female students by rating male students significantly more competent (Moss-Racusin et al., 2012). Moreover, prior research suggests that students' perceived recognition by instructors and teaching assistants (TAs) can impact their self-efficacy and interest in physics and students' physics self-efficacy can impact their interest in physics (e.g., Doucette et al., 2020; Doucette & Singh, 2020).

Prior studies have shown that women have lower physics motivational beliefs, including identity, than men (Archer et al., 2017; Lock et al., 2013; Monsalve et al., 2016). However, most of the studies in the college context concerning physics motivational beliefs are conducted in classes in which women are underrepresented (Hazari et al., 2010; Kalender et al., 2019a). Nevertheless, pervasive societal stereotypes and biases about who can excel in physics that bombard women from a young age could impact their physics motivational beliefs, including their identity, even in physics courses in which they outnumber men, (e.g., introductory physics courses for bioscience majors in which women are not underrepresented). The students' physics motivational beliefs in these courses could influence not only their participation and performance in the physics courses, which is very important in itself, but also in other STEM disciplines in which they are intending to major or may be considering a career. For example, past studies have shown that the factors that influence students' physics identity influence their engineering career choices (Godwin et al., 2016) and predict students' engineering identity (Patrick et al., 2018), when the survey was administered in college English composition courses (where the majority of students were first year students with intentions to major in a variety of disciplines).

Similarly, these physics identity factors could influence students in a physics course for bioscience and pre-health majors. In particular, the focus here is on students who are bioscience majors primarily interested in health-related professions, for whom two physics courses are mandatory. The reason these physics courses are mandatory for students is not only because the foundational knowledge of physics is central to developing deep understanding of bioscience, but also because the kind of reasoning skills students develop in physics can help them in their majors and future careers. In fact, a majority of these bioscience majors are on the pre-health track and want to become health professionals. Higher physics motivational beliefs including an identity as a person who can excel in physics can help them engage and perform better (e.g., on the Medical College Admission Test (MCAT) in which 5-8% of the material consists of physics concepts) to realize their career goals.

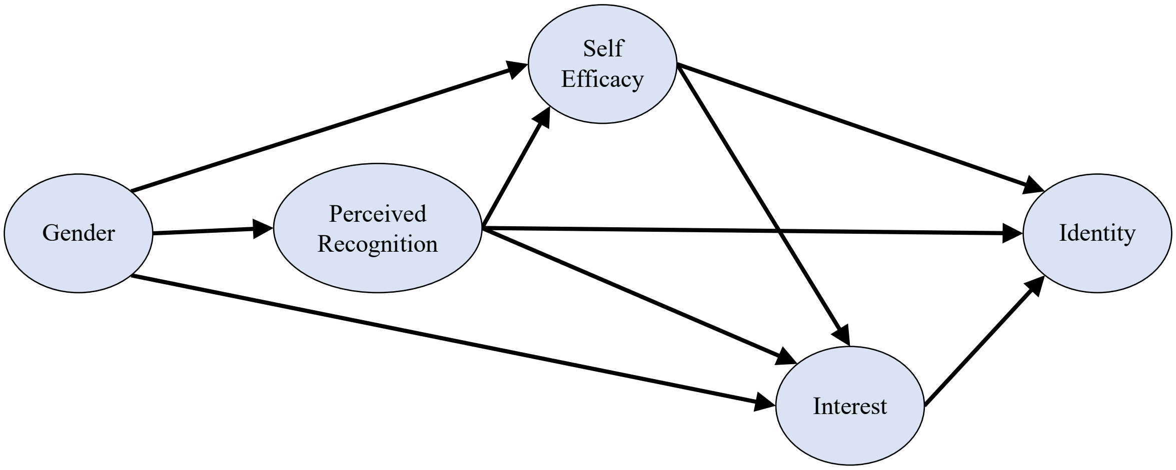
Explicit and implicit societal stereotypes and biases that women internalize about physics could influence their motivational beliefs, including their physics identity. One common societal stereotype is that genius and brilliance are important factors to succeed in physics (Leslie et al., 2015). However, genius is often associated with boys (Upson & Friedman, 2012), and girls from a young age tend to shy away from fields associated with innate brilliance or genius (Bian et al., 2017). Studies have found that by the age of six, girls are less likely than boys to believe they are "really really smart" and less likely to choose activities that are made for "brilliant people" (Bian et al., 2017). These types of stereotypes may continue to negatively impact women from childhood through college physics courses. In formal and informal situations, women are often made to feel that they cannot excel in physics-related fields. Formal situations include K-12 education, in which teachers and counselors often treat men and women differently and give them differential advice about courses to take, and informal situations, which include interacting with family, friends, media and others. Additionally, negative societal stereotypes and biases may lead to a chilly climate for women in science classes, and lack of attention to making science curricula relevant to the interests of many female students (Blickenstaff, 2005). These issues emanating from structural societal inequities pertaining to physics can lower the physics motivational beliefs of women compared to men.

Moreover, in prior investigations, researchers have often hinted at the fact that underrepresentation of women in those courses is likely related to their lower physics motivational beliefs and the gender gap increasing from the beginning to the end of those courses (E. M. Marshman et al., 2018). However, it is important to investigate whether a similar gender gap in physics motivational beliefs exist in physics courses in which women are not numerically underrepresented, and whether these gender gaps get worse from the beginning to the end of the courses. In particular, it is important to investigate whether numerical overrepresentation of women (e.g., in physics courses for bioscience majors) would eliminate or significantly reduce the gender gap in physics motivational beliefs at the beginning and end of these courses. If this is not the case, it may signify that classroom representation alone will not change the pernicious effects of systemic gender inequities in physics perpetuated by society and bolstered further by the physics learning environments. It may point to the need to view these gender-gaps as more deep-rooted than simply due to women's underrepresentation in a physics course and speaks to the need to address inequities in physics learning environments that exacerbate these gender gaps. Since physics motivational beliefs can impact student engagement and performance in physics courses and have the potential to impact their career choices, the deterioration of a gender gap in these courses would be markers of inequity that must be addressed.

Thus, this study focuses on the hypothesis that male and female students' physics motivational beliefs, including their identity, may be different even in courses in which women are not underrepresented. The physics learning environment in this situation may also exacerbate the situation and make the gender gap worse. Figure 1 shows the schematic representation of the identity framework for this investigation (identical to the one used for calculus-based introductory physics courses in which women are outnumbered by men (Kalender et al., 2019b)). In the framework shown in Figure 1, the relation between gender and physics identity is mediated by students' perceived recognition, physics self-efficacy, and interest (Flowers III & Banda, 2016; Godwin et al., 2016; Lock et al., 2013; Potvin & Hazari, 2013; Sawtelle et al., 2012). Models which also have a direct path from gender to physics identity were tested and they were not statistically significant. Therefore, that direct path from gender to physics identity is not shown for clarity.

Figure 1

Schematic Representation of the Physics Identity Model



Note. Schematic representation of the physics identity model and how perceived recognition, self-efficacy, and interest mediate the relation between gender and identity. From left to right, all possible paths were considered (including the one from gender to identity, although it is not shown here since it was not statistically significant).

In accordance with the framework, male and female students' self-efficacy, interest, and perceived recognition, and how these motivational beliefs predict identity in introductory physics courses for bioscience majors in which women outnumber men were investigated. Structural equation modeling (SEM) was used to investigate how the motivational beliefs that comprise physics identity relate to each other in this model. As noted earlier, it is not clear in the context of an introductory physics course in which the majority of students are women whether there are gender differences in these motivational beliefs and how perceived recognition, self-efficacy, and interest mediate male and female students' physics identity. From a statistical point of view, SEM can establish correlations among factors but cannot establish causal effects (Tomarken & Waller, 2005). While past models have theorized the directionality between the constructs in Figure 1 in multiple ways (Godwin et al., 2016; Hazari et al., 2020; Kalender et al., 2019a), this model was chosen because it has the ability to empower instructors so that they adopt effective practices, understand their role in empowering students, and recognize and affirm their work. Additionally, physics interest is not fixed and can increase or decrease depending on students' perceived recognition and self-efficacy, which in turn are dependent on how inclusive and equitable the physics learning environment is. The research questions are delineated based upon the framework, then the methodology is described, then results and discussion are provided, and finally, instructional implications and future directions are discussed. The following research questions were answered by analyzing data from a validated survey administered to students in large algebra-based physics courses at a research university in the United States in which women outnumber men and used mediation analysis via SEM:

Research Questions

RQ1 Are there gender differences in the physics motivational beliefs (self-efficacy, interest, perceived recognition, and identity) and how do they change from the pre-test (at the beginning of the course) to the post-test (at the end of the course)?

RQ2 Can gender differences in students' physics identity be explained with gender differences in physics perceived recognition, self-efficacy, and interest at the end of an introductory algebra-based physics sequence?

Methodology

Participants

The participants were students at a large, public research university in the United States The students were administered a validated written survey at the beginning (pre) and end (post) of the first semester of a two-semester sequence in a traditionally taught introductory algebra-based physics course in which women outnumbered men. Data were used from 501 students who completed the survey on paper in the first week and the last two weeks of recitation class. The students completed the posttest in the week preceding the final exam for the course. These courses are typically taken by students primarily majoring in bioscience in their junior or senior year of undergraduate studies, with approximately 50 to 70% of the students expressing a desire to pursue future careers in health professions. The university provided demographic information such as age, gender, and ethnic/racial information using an honest broker process by which the research team received the information without knowledge of the identities of the participants. The gender data provided by the university included only binary options for male and female, although gender is a socio-cultural and a nonbinary construct (less than 1% of the students did not provide this information and thus were not included in this study). Based on the university data from the participants, 35% identified as male and 65% identified as female students. Thus, female students outnumber male students significantly in this physics class.

Instrument Validity

The survey items were constructed from items validated by others (Adams et al., 2006; Glynn et al., 2011; *PERTS Academic Mindsets Assessment*, 2020) and re-validated in our own context using one-on-one student interviews (E. M. Marshman et al., 2018), exploratory factor analysis (EFA), confirmatory factor analysis (CFA) (Cohen, 2013), analyzing the Pearson correlation between different constructs (Cohen, 2013), and using Cronbach alpha (Cronbach, 1951) At the beginning of the survey, students were instructed to answer the questions on the survey with regard to the physics course they were in. The survey items asked about different motivational beliefs at the beginning and end of the course. These motivational constructs included students' physics identity (1 item), self-efficacy (4 items), interest (4 items), and perceived recognition (3 items). The *physics identity* question focuses on whether students see themselves as a physics person (Hazari et al., 2013; Hazari et al., 2010; Shanahan & Nieswandt, 2009). *The physics self-efficacy* questions measure students' confidence in their ability to understand and answer physics problems (Adams et al., 2006; Glynn et al., 2011; Godwin et al., 2016; Hazari et al., 2013; Learning Activation Lab, 2017; Schell & Lukoff, 2010). The *interest in physics* questions measure students' enthusiasm and curiosity to learn physics and ideas related to physics (Learning Activation Lab, 2017). The *perceived recognition* questions measure the extent to which a student believes that other people see them as a physics person (Hazari et al., 2013). The interest questions were adapted from the Activation Lab Survey on science fascination/interest (Learning Activation Lab, 2017). The first self-efficacy question was taken from the Peer Instruction Self-efficacy instrument (Schell & Lukoff, 2010). Three other self-efficacy questions were adapted from Godwin et al.'s (2016) performance/competence questions with minor changes based upon individual interviews during the validation of the survey instrument at our institution. The physics identity and perceived recognition questions were adapted from Godwin et al. with no fine-tuning required based upon interviews as students interpreted the questions as intended (Godwin et al., 2016).

After performing EFA to ensure that the items factored according to different constructs as envisioned, a CFA was conducted to establish a measurement model for the constructs and used in SEM. The square of CFA factor loadings (lambda) indicates the fraction of variance explained by the factor. The model fit indices were good and all of the factor loadings (lambda) were above 0.50, which indicate good loadings (Cohen, 2013). The results of the CFA model are shown in Table 1. The Cronbach alpha was used to measure the internal consistency of the items. The Cronbach alpha is 0.79 for the self-efficacy questions, 0.76 for interest questions, and 0.89 for perceived recognition questions which are considered reasonable (Cronbach, 1951).

Table 1

Survey Questions and Factor Loadings (Lambda) from the Confirmatory Factor Analysis (CFA)

Construct and Item	**Lambda**
Physics Identity	
I see myself as a physics person	1.000
Physics Self-efficacy	
I am able to help my classmates with physics in the laboratory or recitation.	0.587
I understand concepts I have studied in physics.	0.750
If I study, I will do well on a physics test.	0.759
If I encounter a setback in a physics exam, I can overcome it.	0.723
Physics Interest	
I wonder about how physics works.	0.567
In general, I find physics. †	0.751
I want to know everything I can about physics.	0.741
I am curious about recent discoveries in physics.	0.637
Physics Perceived Recognition	
My family sees me as a physics person.	0.889
My friends see me as a physics person.	0.921
My physics instructor and/or TA sees me as a physics person.	0.702

Note. Survey questions corresponding to each of the motivational constructs, along with factor loadings from the Confirmatory Factor Analysis (CFA) for all students (N = 501). The questions in the study were designed on a Likert scale of 1 (low endorsement) to 4 (high endorsement) (Likert, 1932). The rating scale for some of the self-efficacy and interest questions was *NO!, no, yes, YES!* while the rating scale for the physics identity and perceived recognition questions was *strongly disagree, disagree, agree, strongly agree.* All p-values (of the significance test of each item loading) are $p < 0.001$.
† the rating scale for this question was very boring, boring, interesting, very interesting.

Zero-order pair-wise Pearson correlations r are shown in Table 2. These Pearson r values signify the strength of the relationship between constructs. The inter-correlations vary in the strength of their correlation, but none of the correlations are so high that the constructs cannot be considered separate, consistent with prior studies (Kalender et al., 2019b).

Table 2

Pearson Inter-Correlations Between Factors

Pearson Correlation Coefficient				
Observed Variable	1	2	3	4
1. Perceived Recognition	--	--	--	--
2. Self-Efficacy	0.61	--	--	--
3. Interest	0.60	0.60	--	--
4. Physics Identity	0.78	0.59	0.62	--

Note. Pearson inter-correlations are given between all the predictors and outcomes for the post-test in Physics 1. All p-values < 0.001.

The highest inter-correlation was between physics identity and perceived recognition (0.78), which is consistent with prior studies in calculus-based courses. Perceived recognition questions ask about external identity (perception of whether other people recognize an individual as a physics person), whereas the physics identity question asks about internal identity (whether an individual sees oneself as a physics person) so there tends to be a high correlation between these constructs. However, the correlation is low enough that they can be considered separate constructs.

In addition, preformed item response theory (IRT) was completed in order to check the response option distances for the survey constructs (Embretson & Reise, 2000). The parametric grades response model using STATA was used to test the measurement precision of the response scale. The two response scales were *NO!, no, yes, YES!* and *strongly disagree, disagree, agree, strongly agree.* The parametric grades item response model calculates the location parameter for each response and calculates the difference between the locations. For the first group (NO!, no, yes, YES!), the response scale discrimination values were 1.54 and 2.08. For the second set of answers (strongly disagree, disagree, agree, strongly agree), the response scale discrimination values were 1.51 and 1.26. The numerical values for the location differences need to be similar, as they are for both of these scales, so the means for these values can be used. In addition, IRT-based domain scores were estimated (Embretson & Reise, 2000). The correlation coefficient between the Likert mean scale values for each observed variable and the IRT-based domain scores were calculated to be 0.99 between interest questions, 0.98 between self-efficacy questions and 0.99 between perceived recognition and identity questions (Embretson & Reise, 2000; Samejima, 1969). Since the factor scores derived from the IRT are so highly correlated with the mean score, using mean values for the scores is acceptable when analyzing the data (De Winter & Dodou, 2010; Embretson & Reise, 2000; Norman, 2010). In particular, because the psychological distance between adjacent response items and across items was approximately similar and complex factor scores derived from IRT or CFA are so highly correlated with the mean scores, it is reasonable to use mean scores (Embretson & Reise, 2000; Samejima, 1969). Moreover, the frequencies of student responses for each question are included in Appendix A.

Analysis

Initially, data was analyzed using descriptive statistics and compared female and male students' mean scores on various constructs for statistical significance using *t*-tests and computed the effect sizes using Cohen's *d* (Cohen, 2013). In general, $d = 0.20$ indicated a small effect size, $d = 0.50$ indicates a medium effect size, and $d = 0.80$ indicates a large effect size (Cohen, 2013). For predictive relationships between different motivational constructs, Structural Equation Modeling (SEM) was used as a statistical tool in R (lavaan package) with a maximum likelihood estimation method (Team, 2013). The SEM is an extension of multiple regression. It conducts several multiple regressions simultaneously between different latent variables (or factors or constructs) in one estimation model and can have multiple outcome variables. This is an improvement over multiple regression since it can calculate overall goodness of fit and it allows for all estimates to be standardized simultaneously. This enables a direct comparison among different structural components, along with calculations of factor loadings for all factors (or constructs or latent variables). The SEM also has an option to handle missing data using the full estimation maximum likelihood, or ML estimation feature which improves both power and generalizability since it imputes missing data so that students only missing some data are not dropped. The model fit for SEM was reported by using the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residuals (SRMS). Commonly used thresholds for goodness of fit are as follows: CFI and TLI > 0.90, and SRMR and RMSEA < 0.08 (MacCallum et al., 1996).

The model estimates were performed using gender moderation analysis to check whether any of the relations between variables show differences across gender by using lavaan to conduct multi-group SEM. Initially, different levels of measurement invariance in the multi-group SEM model were tested with gender moderation. In each step, different elements of the model were fixed to equality across gender and compared the results to the previous step using the Likelihood Ratio Test. Since there was not statistically significant moderation by gender, the theoretical model in a gender mediation analysis was tested, using gender as a variable directly predicting all latent variables to examine the resulting structural paths between constructs.

Results and Discussion

Pertaining to **RQ1**, Table 3 and Table 4 show that women had statistically significantly lower mean values than men for all motivational beliefs in the model. For example, both women's and men's scores were low in physics identity with women scoring below the negative value (2). Additionally, when the scores in the pre-test and post-test as shown in Table 5 are compared, the scores significantly change for women's self-efficacy, interest, and physics identity as well as for men's self-efficacy from when they enter the class until the end of the course. These differences increase throughout the semester and the gender gap widens by the end as evident from the larger Cohen's d values for women in Table 5. This occurs despite the fact that women outnumber men in this course. In addition, in Appendix A, the percentage of men and women who selected each response to the questions are provided. This provides a sense of how students shifted their answers from the pre-test to the post-test. From Tables 6 and 7 in Appendix A, it is found that in general both men and women shift from higher values to lower values for each motivational factor. For example, in the perceived recognition and identity questions, most students selected response 2 in the pretest while most students selected response 2 in the posttest. Additionally from Table 6 and Table 7, for the self-efficacy and interest questions, the overall trend is that the percentage of students who answered 3 or 4 decreased from the pretest to the posttest and the percentage of students who answered 1 or 2 increased from the pretest to the posttest.

Table 3

Mean Pre Predictor and Outcome Values by Gender and Effect Sizes (Cohen's d)

Predictors and Outcomes	**Mean**		**Cohen's *d***
	Men	**Women**	
Perceived Recognition	2.19	2.00	0.32
Self-Efficacy	3.07	2.83	0.58
Interest	2.74	2.45	0.58
Physics Identity	2.16	1.87	0.46

Note. All *p*-values < 0.001.

Table 4

Mean Post Predictor and Outcome Values by Gender and Effect Sizes (Cohen's D).

Predictors and Outcomes	**Mean**		**Cohen's *d***
	Men	Women	
Perceived Recognition	2.21	1.92	0.43
Self-Efficacy	2.90	2.55	0.66
Interest	2.66	2.27	0.69
Physics Identity	2.03	1.64	0.59

Note. All *p*-values < 0.001.

Table 5

Cohen's d (d) for Men and Women's Outcomes from the Pre-Test to the Post-Test

Predictors and Outcomes	**Men**		**Women**	
	d	*p-value*	*d*	*p-value*
Perceived Recognition	0.05	0.686	0.13	0.128
Self-Efficacy	0.33	0.005	0.54	< 0.001
Interest	0.15	0.203	0.34	< 0.001
Physics Identity	0.18	0.137	0.34	< 0.001

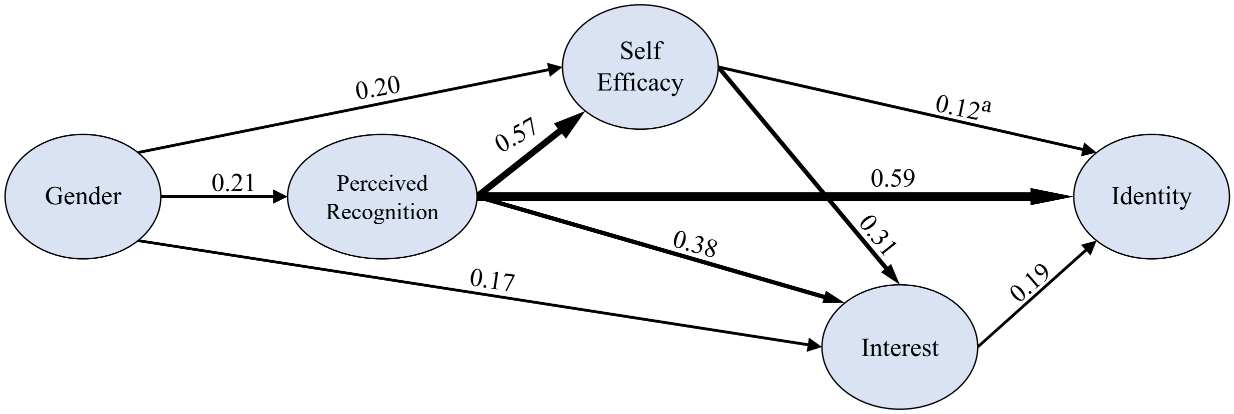
Note. Statistical significance refers to *p*-values.

Pertaining to **RQ2**, SEM was used to investigate the relationships between the constructs and to unpack each construct's contribution to explaining the physics identity of women and men. Initially, gender moderation was tested between different constructs using multi-group SEM (between male and female students) and investigated whether the relationships between the different motivational constructs were different across gender. There were no group differences at the level of weak and strong measurement invariance, including no difference at the level of regression coefficients. Therefore, gender mediation analysis was used to understand how gender mediates physics identity at the end of the semester in the introductory physics course.

The results of the SEM are presented visually in Figure 2. The model fit indices indicate a good fit to the data (acceptable fit thresholds in parentheses): CFI = 0.981 (> 0.90), TLI = 0.974 (> 0.90), RMSEA = 0.043 (<0.08), and SRMR = 0.030 (< 0.08).

Figure 2

Result of the Path Analysis Part of the SEM



Note. Result of the path analysis part of the SEM showing mediation between gender and physics identity through perceived recognition, self-efficacy, and interest. The line thickness qualitatively denotes the relative magnitude of the standardized regression coefficients β shown. All p-values for β are indicated by no superscript for $p < 0.001$ and "a" for $p = 0.013$. Gender does not directly predict physics identity.

All three of the mediating constructs (perceived recognition, self-efficacy, and interest) predict physics identity at the end of the physics course similar to past results (Hazari et al., 2010; Kalender et al., 2019b) in other contexts. Perceived recognition had the largest direct effect (β = 0.59) with smaller effects from self-efficacy (β = 0.12) and interest (β = 0.19).

Additionally, gender predicts perceived recognition, self-efficacy, and interest. However, the relation between gender and physics identity is mediated only by the mediating constructs, and after accounting for these indirect paths, there is no direct path from gender to identity. In other words, women appear to have a lower physics identity because they have lower perceived recognition, self-efficacy, and interest. These results are very similar to those for calculus-based introductory physics courses (Kalender et al., 2019b) in which women are severely underrepresented and the majority of students are engineering majors. In addition, in Appendix B, data are presented for how the factors that predict students' physics identity also predict students' science identity. Although it is not one of the main research questions, Figure 3 in Appendix B shows that physics self-efficacy also predicted students' science idenity.

Summary, Implications, and Future Directions

In this research involving both descriptive and inferential quantitative analyses, gaps in physics motivational beliefs are found that disadvantage women in mandatory introductory physics courses for bioscience majors in which women are not outnumbered by men. This result is similar to what has been found earlier in introductory calculus-based courses in which women are severely underrepresented (Hazari et al., 2010; Kalender et al., 2019b). In particular, prior research in calculus-based courses in which women are underrepresented shows that, compared to men, women have a greater decrease in their motivational beliefs (e.g., about whether instructors and TAs see them as people who can excel in physics) (Kalender et al., 2019b). These findings are true even in algebra-based physics courses in which women are not underrepresented (e.g., both men and women have a mean recognition below the positive lower threshold, i.e., score of 3, and women score significantly lower than men). Tables 3 and 4 show that women had a greater decrease in physics perceived recognition, self-efficacy, interest, and identity compared to men. The inferential analysis using SEM in Figure 2 shows how perceived recognition, self-efficacy and interest mediate students' physics identity. The gender differences in students' perceived recognition, self-efficacy, and interest predict their identity as a person who can excel in physics and the correlations between these motivational beliefs predicting students' physics identity are similar to those in calculus-based introductory courses in which women are underrepresented (Hazari et al., 2010; Kalender et al., 2019b). Moreover, there is no direct path from gender to physics identity, similar to the calculus-based courses (Kalender et al., 2019b).

The model provides support for the physics identity framework in a new context and helps us understand the role of different motivational factors in predicting physics identity of women and men in algebra-based physics courses where women are not underrepresented. This is important since identity in a particular discipline is context-dependent and factors that influence physics identity can relate to each other differently in different contexts. Additionally, the model shows that TAs and instructors could play a critical role to increase students' self-efficacy, interest, and identity in physics. The findings suggest that women feel less recognized by their instructors and TAs than men which influence women's self-efficacy, interest, and identity in physics.

The existence of a gender gap at the beginning of the physics course may be due to a variety of reasons including societal stereotypes, experiences in previous science courses, and lack of female physics role models in media. The exacerbation of the gender gaps in motivational beliefs such as physics perceived recognition, self-efficacy, interest, and identity from the beginning to the end of the physics course for bioscience majors may be a sign of inequity and can disadvantage women in terms of their participation, engagement, and outcomes in the physics courses. These persistent gaps can also impact their choice of majors and future careers in STEM. The increased gender gap in these beliefs at the end of the physics courses may signify inequity and the non-inclusive nature of the learning environment. The trends in the gender gap in physics motivational beliefs are highly troubling. Further investigation of their cause is required because this may signify that classroom representation alone will not change the pernicious effects of systemic gender inequities in physics perpetuated by society and bolstered further by the physics learning environments. For example, the increased motivational belief gaps may at least partly be due to physics instructors and TAs unwittingly reinforcing gender stereotypes about physics and communicating lower expectations for women. If female students are not given the same type of positive feedback as male students, this could have a negative effect on perceived recognition and self-efficacy of women. Changing the narrative, increasing students' sense of belonging (Binning et al., 2020), and making the physics learning environment equitable and inclusive (e.g., by not letting men dominate the conversations in class and affirming students more when they make progress in the course) has the potential to decrease the gender gap in student's perceived recognition and other motivation beliefs.

A limitation of this quantitative study focusing on descriptive and inferential quantitative analysis is that insight can only be found in the relative values of the motivational beliefs of men and women at the beginning and end of the course, and how the relation between gender and physics identity is mediated by physics perceived recognition, self-efficacy, and interest. However, causal effects cannot be established. Therefore, future studies should investigate factors in the physics learning environment that exacerbate gender gaps in motivational beliefs even in these courses in which women outnumber men. In addition, future work can investigate approaches to improving student motivational beliefs in these types of physics courses in which women are not underrepresented and investigate whether approaches that are effective in these courses would also be successful in courses in which women are underrepresented. One potential approach for improving students' motivational beliefs is through brief social-psychological classroom interventions (e.g., mindset/sense of belonging), that have been shown to be effective in boosting women's grades in some science courses (Binning et al., 2020; Harackiewicz et al., 2016; Walton et al., 2015; Yeager & Walton, 2011).

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Appendix A

Percentages of men and women who selected each answer choice for each question are shown. This provides a sense of how students shifted their answers from the pre-test to the post-test.

Table 6

Percentages of Women Who Answered Each Question

	Women							
	Pre-Test				Post-Test			
Question	1	2	3	4	1	2	3	4
Physics Identity								
1	27%	59%	13%	1%	45%	45%	9%	1%
Physics Perceived Recognition								
2	31%	53%	15%	1%	40%	46%	13%	1%
3	30%	55%	13%	2%	38%	46%	13%	3%
4	16%	52%	29%	3%	26%	38%	32%	4%
Physics Self-efficacy								
5	14%	45%	39%	2%	11%	29%	54%	6%
6	4%	19%	68%	9%	6%	29%	59%	6%
7	1%	6%	66%	27%	11%	39%	41%	9%
8	1%	14%	66%	19%	7%	39%	48%	6%
Physics Interest								
9	24%	53%	20%	3%	23%	35%	33%	9%
10	5%	32%	58%	5%	13%	38%	46%	3%
11	5%	44%	45%	6%	18%	54%	26%	2%
12	5%	33%	54%	8%	15%	40%	41%	4%

Note. Percentages of women who answered each question by the options they selected, with 1 being the low value (NO! and strongly disagree) and 4 being the high value (YES! and strongly agree). The rating scale for the self-efficacy and interest questions was *NO!, no, yes, YES!,* while the rating scale for the physics identity and perceived recognition questions was *strongly disagree, disagree, agree, strongly agree.*

Table 7

Percentages of Men Who Answered Each Question

	Men							
	Pre-Test				Post-Test			
Question	1	2	3	4	1	2	3	4
Physics Identity								
1	12%	62%	24%	2%	21%	56%	21%	2%
Physics Perceived Recognition								
2	17%	64%	18%	1%	25%	49%	23%	3%
3	15%	63%	21%	1%	21%	48%	28%	3%
4	8%	52%	35%	5%	12%	41%	39%	8%
Physics Self-efficacy								
5	3%	38%	53%	6%	5%	21%	63%	11%
6	1%	9%	80%	10%	2%	19%	65%	14%
7	0%	2%	54%	44%	5%	14%	57%	24%
8	0%	5%	65%	31%	3%	22%	60%	15%
Physics Interest								
9	13%	42%	37%	8%	10%	26%	51%	13%
10	2%	17%	72%	10%	3%	28%	59%	10%
11	1%	30%	58%	11%	3%	49%	41%	7%
12	3%	17%	68%	12%	5%	31%	56%	8%

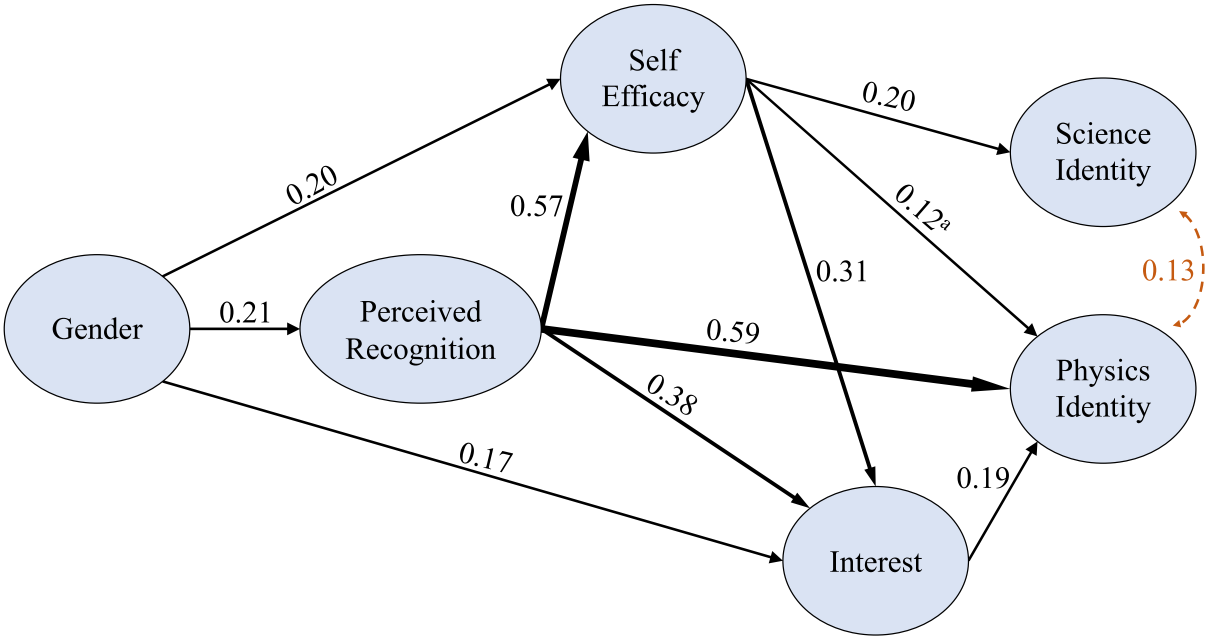
Note. Percentages of men who answered each question by the options they selected, with 1 being the low value (NO! and strongly disagree) and 4 being the high value (YES! and strongly agree). The rating scale for the self-efficacy and interest questions was *NO!, no, yes, YES!,* while the rating scale for the physics identity and perceived recognition questions was *strongly disagree, disagree, agree, strongly agree.*

Appendix B

Below, the path analysis part of the SEM for how the factors that predict physics identity also predict students' science identity is provided. The science identity question on the survey asked students whether they "strongly disagree, disagree, agree, strongly agree" with "I see myself as a scientist". The survey item was adapted from the survey by Godwin et al. (2016) and was re-validated in our own context. The results of the SEM are presented visually in Figure 3. The model fit indices indicate a good fit to the data (acceptable fit thresholds in parentheses): CFI = 0.978 (> 0.90), TLI = 0.971 (> 0.90), RMSEA = 0.043 (<0.08), and SRMR = 0.033 (< 0.08). All three of the mediating constructs (physics perceived recognition, self-efficacy, and interest) predict physics identity at the end of the physics course similar to Figure 2. The mediating constructs of physics self-efficacy also predict science identity at the end of the physics course.

Figure 3

Result of the Path Analysis Part of the SEM with Science Identity



Note. Result of the path analysis part of the SEM with mediation between gender and science/physics identity through physics perceived recognition, self-efficacy, and interest. Each line thickness qualitatively denotes the relative magnitude of the standardized regression coefficients β shown. The dashed lines indicate covariance. All p-values for β are indicated by no superscript for $p < 0.001$, "a" for $p = 0.015$, "b".