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How the Perception of the Inclusiveness of the Learning Environment Predicts Female and Male Students' Physics Self-efficacy, Interest, and Identity in an Introductory Course for Bioscience Majors

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ABSTRACT

Students' physics self-efficacy, interest, and identity in introductory courses can influence their outcomes in that course and their future career aspirations. A lot of work has focused on the role these motivational beliefs play in students' outcomes without attention to the role the perception of the inclusiveness of the learning environment plays in shaping these beliefs. This study used a validated survey instrument to probe the motivational outcomes of 873 students at the end of a two-semester mandatory introductory physics course primarily for bioscience majors, in which women make up 62% of the class. We investigated how the perception of the inclusiveness of the learning environment (perceived recognition, peer interaction, and belonging) predicts male and female students' motivational outcomes, including their physics self-efficacy, interest, and identity. We found that these motivational beliefs were lower for women and the perception of the inclusiveness of the learning environment plays a major role in explaining these motivational outcomes. These findings can be useful in providing support and creating an equitable and inclusive learning environment to help all students excel in algebra-based physics courses for bioscience majors.

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

Introduction and Theoretical Framework

Studies have shown that motivational factors, such as a student's identity, self-efficacy, and interest in a particular field are important for students' career interests (Correll, 2004; Hazari et al., 2013; Ketenci et al., 2020; Stets et al., 2017), learning (Han et al., 2021; Vincent-Ruz & Schunn, 2017), and continuation in science, technology, engineering, and math (STEM) fields (Britner, 2008; Kosiol et al., 2019; Mujtaba & Reiss, 2014; Robinson et al., 2019). For example, students were more likely to take courses or pursue a career in science if they had higher competency belief or self-efficacy (Britner, 2008; Correll, 2001, 2004; Eccles, 1994; Wang & Degol, 2013), display higher interest in science (Benbow & Minor, 1986), or have a higher science identity (Chemers et al., 2011; Robinson et al., 2019; Stets et al., 2017). A gender gap favoring men in motivational factors (Cwik & Singh, 2023; Maries et al., 2020; Maries et al., 2022; Louis & Mistele, 2012; Marshman et al., 2018; Nissen & Shemwell, 2016; Santana & Singh, 2023; Stewart et al., 2020) and conceptual tests (Traxler et al., 2018) have been studied in STEM courses. Specifically, in physics, many studies have been done on calculus-based physics courses, where women are underrepresented, to understand and address the low diversity in the courses.

However, stereotypes about who can excel in physics could affect women even in these physics courses in which they are not underrepresented, e.g., mandatory two-semester physics course sequence for bioscience majors. One common stereotype is that genius and brilliance are important factors in success in physics (Leslie et al., 2015). However, genius is often associated with boys (Upson & Friedman, 2012), and girls from a young age 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 smart* and less likely to choose activities that are made for *brilliant people* (Bian et al., 2017). As these students get older, norms in the science curriculum hold less relevance for girls, since they tend not to represent the interest and values of girls (Archer et al., 2017). All these stereotypes and factors can influence female students' perceptions about their ability to do physics before they enter the classroom. Thus, it is possible that although women are the majority in algebra-based physics courses primarily for bioscience majors, these societal stereotypes can still influence their outcomes in the physics class unless instructors attempt to create a fair and inclusive learning environment.

Students' identity in STEM disciplines has been shown to play an important role in their participation in classes and professional choices (Carlone & Johnson, 2007; Gee, 2000; Hazari et al., 2010; Stets et al., 2017; Tonso, 2006; Vincent-Ruz & Schunn, 2018). However, prior studies have shown that it can be more difficult for women to form a physics identity than men (Archer et al., 2017; Godwin et al., 2016; Lock et al., 2013; Monsalve et al., 2016). Students' physics identity is influenced by their self-efficacy, interest, and perceived recognition (Flowers III & Banda, 2016; Godwin et al., 2016; Li & Singh, 2022; Lock et al., 2013; Potvin & Hazari, 2013; Sawtelle et al., 2012).

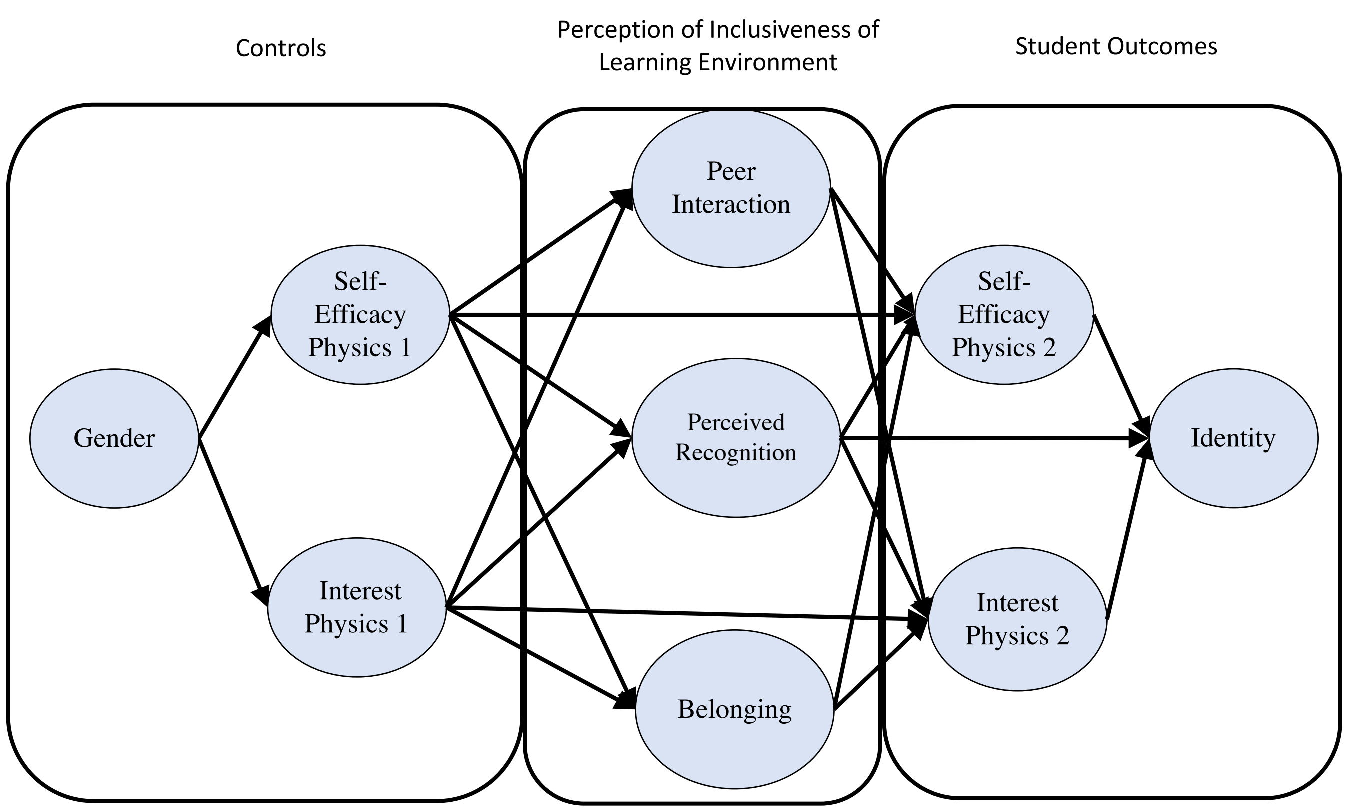
Self-efficacy is a person's belief that they can succeed in a particular activity or course (Bandura, 1977, 1994). Students' self-efficacy in academic courses may be influenced by the classroom environment (Britner & Pajares, 2006; Dou et al., 2018; Gao, 2020; Schunk & Pajares, 2002) and different teaching strategies (Bailey et al., 2017; Fencl & Scheel, 2005; Nissen & Shemwell, 2016). Self-efficacy has been shown to impact students' engagement, learning, and persistence in science courses (Bouffard-Bouchard et al., 1991; Britner, 2008; Cavallo et al., 2004; Correll, 2004; Felder et al., 1995; McKinney et al., 2021; Sawtelle et al., 2012; Dale H Schunk & Frank Pajares, 2002; Vincent-Ruz & Schunn, 2017; Zimmerman, 2000). Similarly, interest in a particular discipline may affect students' STEM career orientation (Lichtenberger & George-Jackson, 2013; Uitto, 2014) and persistence in STEM courses and majors (Harackiewicz et al., 2002; Hidi, 2006; Strenta et al., 1994). One study showed that changing the curriculum to stimulate the interest of female students helped improve all the student's understanding. the end of the year (Häussler & Hoffmann, 2002).

Therefore, it is important to investigate factors that influence students' physics identity, self-efficacy, and interest. Our framework posits that factors in the learning environment can influence students' motivational outcomes including their physics self-efficacy, interest, and identity. Specifically, we investigated students' perception of the inclusiveness of their learning environment, which in this study consists of their interactions with their peers, their sense of belonging, and perceived recognition by others (including friends, family, and their instructors/teaching assistants) and how it predicts their physics self-efficacy, interest, and identity. We investigated these three perceptions of the inclusiveness of the learning environment factors since instructors can influence these factors to help improve the experiences of students in their classes. Additionally, the selection of SEM model is guided by interviews with students (Li & Singh, 2023a; Li & Singh, 2023b). Furthermore, students' sense of belonging in science has been shown to correlate with retention as well as their self-efficacy (Goodenow, 1993; Masika & Jones, 2016); so it is important to investigate how students' sense of belonging predicts their self-efficacy at the end of the semester. Students' positive interactions with peers have been shown to enhance their understanding and engagement in courses (Meltzer & Manivannan, 2002; Rockinson-Szapkiw et al., 2021). Moreover, perceived recognition has been shown to play an important role in a student's identity (Hazari et al., 2010; Kalender et al., 2019; Vincent-Ruz & Schunn, 2018) as well as being an important factor in women's motivation (Goodenow, 1993).

While many studies have investigated gender differences in motivational factors in introductory physics courses where women are underrepresented, most have not taken into account the factors in the students' learning environment. This study examined the difference between male and female students' perceptions of the inclusiveness of the learning environment on their motivational beliefs at the end of the algebra-based introductory physics sequence for bioscience majors in which women are not underrepresented. The perception of the inclusiveness of the learning environment is shaped by experiences students have in the classroom as well as interactions outside of the classroom like office hours, email correspondence with the instructor or TA, and students studying or doing homework together. We control for students' self-efficacy and interest at the end of physics 1 since these are students' beliefs about physics when they enter the class based on prior experiences. The perception of the inclusiveness of the learning environment includes students' perception of their peer interaction, sense of belonging, and perceived recognition (from instructors, TAs, friends, and family). Lastly, we investigated the students' outcomes of physics self-efficacy, interest, and identity at the end of physics 2. An example of our final model is shown in Fig. 1. All paths were considered from left to right in our model, however, only some of the paths are shown in Fig. 1 for clarity.

Figure 1

Schematic representation of the model based on the theoretical framework. From left to right, all possible regression paths were considered. However, only some (not all) of the regression paths are shown.



Research Questions

RQ1 Are there gender differences in students' motivational characteristics including physics self-efficacy, interest, and identity at the end of the course?

RQ2 How does the perception of the inclusiveness of the learning environment (including peer interaction, perceived recognition, and belonging) predict motivational factors at the end of the course?

RQ3 What is the effect of controlling for high school factors (e.g., high school GPA and SAT Math scores) on the motivational factors at the end of the course?

Methodology

Participants

In this study, we analyzed results from 873 students who completed a motivational survey at the end of the semester in introductory algebra-based physics 1 and physics 2 over two years. These courses are typically taken by students primarily on the bioscience track in their junior or senior year of undergraduate studies, with approximately 50%-70% of 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. From the university data, the participants were 38% male and 62% female students. The gender data provided by the university include only binary options of *male* and *female*. We recognize gender as a socio-cultural and nonbinary construct; however, the data provided by the university only included binary options (less than 1% of the students did not provide this information and thus were not included in this study).

Instrument Validity

This study measured students' physics identity, self-efficacy, interest, sense of belonging, perceived recognition, and interaction with their peers for students enrolled in introductory algebra-based physics courses for bioscience majors. 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 context using one-on-one student interviews (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). The *physics identity* questions evaluated whether the students see themselves as a physics person (Hazari, Potvin, et al., 2013). The *physics self-efficacy* questions measure students' confidence in their ability to answer and understand physics problems (Glynn et al., 2011; Hazari, Potvin, et al., 2013; Learning Activation Lab, 2017; Schell & Lukoff, 2010). The *interest in physics* questions measured students' enthusiasm and curiosity about learning physics and ideas related to physics (Learning Activation Lab, 2017). The *sense of belonging* questions evaluated whether students felt like they belonged in the introductory physics classroom (Goodenow, 1993; *PERTS Academic Mindsets Assessment*, 2020). The *perceived recognition* questions measured the extent to which the students thought other people see them as physics persons (Hazari et al., 2013). Lastly, the *peer interaction* questions measured whether students thought that working with their peers was beneficial, e.g., for increasing their confidence and enthusiasm to do physics (Sayer et al., 2016; Singh, 2005). The physics identity instrument only included one question, which is consistent with past studies since it has been difficult to make other questions that factor in this category in exploratory factor analysis (Godwin et al., 2021; Godwin et al., 2016; Hazari et al., 2013; Hazari et al., 2010). The questions in the study were designed on a Likert scale of 1 (low endorsement) to 4 (high endorsement) except for the sense of belonging questions which were designed on a scale of 1 to 5 to keep them consistent with the original survey (Likert, 1932). A lower score was indicative of a negative endorsement of the survey construct while a higher score was related to a positive belief in the construct. Some of the items were reverse-coded.

After performing an EFA to ensure that the items were factored according to different constructs as envisioned, a CFA was conducted to establish a measurement model for the constructs and used in SEM. The squares of the CFA factor loadings (lambda) indicate the fraction of variance explained by the factors. The model fit indices were good and all the factor loadings (lambda) were above 0.6, which indicates good loadings (Cohen, 2013). The results of the CFA model which include the factor loadings are shown in Table 1.

Table 1

Survey questions for each of the motivational constructs along with factor loadings from the Confirmatory Factor Analysis (CFA) result for all students (N = 873). The rating scale for most of the self-efficacy and interest questions was NO! no yes YES! while the rating scale for the physics identity, peer interaction, and perceived recognition questions was strongly disagreed, disagree, agree, strongly agree. The rating scale for the physics belonging questions was not at all true, a little true, somewhat true, mostly true, and completely true. All p-values (of the significance test of each item loading) are $p < 0.001$.

Construct and Item	Lambda
Physics Identity	
I see myself as a physics person	1.00
Physics Self-Efficacy	
I can help my classmates with physics in the laboratory or recitation	0.64
I understand concepts I have studied in physics	0.71
If I study, I will do well on a physics test	0.73
If I encounter a setback in a physics exam, I can overcome it	0.66
Physics Interest	
I wonder about how physics works	0.70
I find physics†	0.81
I want to know everything I can about physics	0.76
I am curious about recent discoveries in physics	0.71
Physics Perceived Recognition	
My family sees me as a physics person	0.91
My friends see me as a physics person	0.91
My physics instructor and/or TA sees me as a physics person	0.68
Physics Belonging	
I feel like I belong in this class	0.80
I feel like an outsider in this class	0.68
I feel comfortable in this class	0.85
I feel like I can be myself in this class	0.69
Sometimes I worry I do not belong in this class	0.61

Physics Peer Interaction	
My experiences and interactions with other students in this class…	
Made me feel more relaxed about learning physics	0.75
Increased my confidence in my ability to do physics	0.95
Increased my confidence that I can succeed in physics	0.94
Increased my confidence in my ability to handle difficult physics problems	0.85

† the rating scale for this question was very boring, boring, interesting, very interesting.

Zero-order pair-wise Pearson correlations are given in Table 2. These Pearson's *r* values signify the strength of pairwise relationships between variables. The inter-correlations vary in strength, but none of the correlations are so high that the constructs cannot be separately examined. The only high inter-correlations were between post-interest in physics 1 and post-interest in Physics 2 (0.89) and between physics identity in physics 2 and perceived recognition in physics 2 (0.82). Prior research has shown there is a high correlation in interest throughout the introductory physics classes (Kalender et al., 2017; Marshman et al., 2018). Perceived recognition questions ask about external identity, whereas physics identity asks about internal identity so there tends to be a high correlation between these constructs. Both correlations are low enough that they should be separate constructs.

Table 2

Pearson inter-correlations are given between all the predictors and outcomes. All p-values are < 0.001.

Pearson Correlation Coefficient								
Observed Variable	1	2	3	4	5	6	7	8
1. Post Self-Efficacy in physics 1	--	--	--	--	--	--	--	--
2. Post Interest in physics 1	0.58	--	--	--	--	--	--	--
3. Perceived Recognition in Physics 2	0.39	0.51	--	--	--	--	--	--
4. Peer Interaction in physics 2	0.36	0.28	0.36	--	--	--	--	--
5. Belonging in physics 2	0.53	0.38	0.45	0.62	--	--	--	--
6. Post Self-Efficacy in physics 2	0.72	0.46	0.58	0.67	0.79	--	--	--
7. Post Interest in physics 2	0.45	0.89	0.58	0.39	0.47	0.60	--	--
8. Physics Identity in physics 2	0.46	0.52	0.82	0.37	0.45	0.58	0.57	--

Analysis

Initially, we compared female and male students' mean scores of the predictors and outcomes for statistical significance using *t*-tests and for the effect size using Cohen's *d* (Cohen, 2013). Cohen's *d* is $d = (\mu_m - \mu_f)/\sigma_{pooled}$, where μ_m is the average score of male students, μ_f is the average score of female students, and σ_{pooled} is the pooled standard deviation for all students. In general, $d = 0.20$ indicates a small effect size, $d = 0.50$ indicates a medium effect size, and $d = 0.80$ indicates a large effect size (Cohen, 2013).

To quantify the statistical significance and relative strength of our framework's path links, we used Structural Equation Modeling (SEM) as a statistical tool by using R (lavaan package) with a maximum likelihood estimation method (Team, 2013). SEM is a statistical method comprising two parts that are completed together; a measurement part that consists of CFA and a structural part that consists of path analysis. Path analysis can be considered an extension of multiple regression analysis, but it allows one to conduct several multiple regressions simultaneously between variables in one estimation model and allows us to predict multiple outcomes simultaneously. SEM also allows us to calculate the overall goodness of fit and for all estimates to be standardized simultaneously so there can be a direct comparison between different structural components. Thus, we can test more complicated models than we would with multiple regression analysis. A full SEM model combines this path analysis with CFA, allowing researchers to test the validity of their constructs (using CFA) and the connections between these constructs (using path analysis) in a single model with a single set of fit indices. We report the model fit for SEM by using the Comparative Fit Index (CFI), Tucker-Lewis Index (TLI), Root Mean Square Error of Approximation (RMSEA), and Standardized Root Mean Square Residuals (SRMR). Commonly used thresholds for the goodness of fit are: CFI and TLI > 0.90, and RMSEA and SRMR < 0.08 (MacCallum et al., 1996).

Initially, we performed gender moderation analysis by conducting multi-group SEM, i.e., the model estimates were performed separately for men and women to check whether any of the relations between variables show differences across gender by using "lavaan" [56]. In particular, our moderation analysis was similar to our mediation model in Fig. 1 but there was no link from gender, instead, multi-group SEM was performed separately for women and men simultaneously.

To explain what moderation analysis means, we start with a simple moderation analysis example. In a simple moderation analysis involving the predictive relation between only two variables, the predictive relationship (the regression path) between those two variables is tested for two or more different groups (e.g., men and women) simultaneously. If the predictive relationship is different for the groups (i.e., the values of the regression coefficients (β) are not the same for the correlation between the two constructs for different groups), then there is a moderation effect in the model. For example, in a study focusing on how smoking predicts lung cancer, if there was a moderation effect by gender, the predictive relation (regression coefficient) between smoking and lung cancer would be different for women and men. However, if the regression coefficients for how smoking predicts lung cancer were the same for women and men, then there is no moderation by gender and one can just focus on mediation analysis by gender (in other words, we need not separately calculate the regression coefficients for women and men since they are equal, and we can introduce gender as an additional categorical variable in the model to do mediation by gender).

When the model is more complex than the preceding example of smoking and lung cancer as in our SEM model (which has a measurement part involving CFA and a structural part involving path analysis), checking to make sure there are no gender moderation effects involves checking that there are no gender moderation effects for both the measurement and structural parts. For the measurement part, to check for measurement invariance in each step of gender moderation analysis, we fixed different elements of the measurement part of the model to equality across gender and compared the results to the previous step when they were allowed to vary between groups (i.e., for women and men) separately using the Likelihood Ratio Test (Tomarken & Waller, 2005). A non-significant *p*-value at each step indicates that the fit of this model is not appreciably worse than that of the model in the previous step, so the more restrictive invariance hypothesis (when the parameters are set to the same values for women and men) is retained. Therefore, setting those different elements of the measurement part of the model to equality across gender is valid, which means that estimates are not statistically significantly different across groups (i.e., women and men).

First, we tested for *weak* measurement invariance, which determines if survey items have similar factor loadings for men and women. We compared two models, one in which the factor loadings (which represent the correlation between each item and its corresponding construct) for women and men were predicted independently, and the other in which the factor loadings were forced to be equal between the groups (i.e., for women and men). Next, we tested for *strong* measurement invariance, which determines if survey items have similar factor loadings as well as similar intercepts (which represent the expected value of an observed variable when its associated latent variable is equal to zero) for men and women. Similar to weak invariance testing, we compared the models in which these factors were allowed to vary between groups separately for women and men and when they were set equal for women and men. If measurement invariance passes the weak and strong invariance test, i.e., there is no statistically significant difference between models when those parameters for women and men are set equal, then we must check for differences in the path analysis part, i.e., regression coefficients (β) among different latent variables in the model between women and men. This is because differences between the groups could occur at the factor (latent variable) level in regression coefficients (β).

Similar to *weak* and *strong* measurement invariance for the measurement part, when testing the moderation effect in path analysis, the predictive relationship (regression path) between two variables is tested for the two groups (e.g., women and men) simultaneously. If the predictive relationship is different for the groups (i.e., the values of the regression coefficients (β) are not the same for the predictive relationship between the two constructs for women and men), then there is a gender moderation effect in the model. If moderation does not show differences by gender in any of these steps (measurement invariance holds and testing for regression coefficients shows that they can be set equal for women and men), we can utilize a gender mediation model (see Fig. 1). In other words, we can interpret our model the same way for both men and women, and any gender differences can be modeled using a separate gender variable.

In our multi-group SEM model, we found a non-significant *p*-value in each step, and thus measurement invariance holds and the regression coefficients for women and men can be set equal, i.e., there are no moderation effects by gender (for men and women) in our models. Thus, we concluded that our SEM model can be interpreted similarly for men and women and we can use gender mediation analysis (instead of doing moderation by gender). Therefore, we tested the theoretical model in mediation analysis, using gender as a variable (1 for male and 0 for female) directly predicting items to examine the resulting structural paths between constructs (a schematic representation of the path analysis for the gender mediation model is shown in Fig. 1). In the mediation analysis, if there are paths from gender to any of the constructs as we found in our results (Figs. 2 and 3) discussed in the next section, it implies that women and men did not have the same average value for those constructs controlling for all constructs to the left. However, it is important to note that all of the item factor loadings and regression coefficients between the constructs are the same for women and men (as found from the gender moderation analysis which preceded the mediation analysis).

Results and Discussion

Gender Differences in Predictors and Outcomes

We find statistically significant differences in all predictors and outcomes in favor of male students (Table 3). This pattern is similar to what we find in calculus-based physics courses (Kalender et al., 2019) by the end of physics 2 even though in our investigation, women are the majority in the algebra-based courses for bioscience majors (62%). Since a student's physics self-efficacy, interest, and identity can impact not only their performance in that course but also impact students' future career plans, more should be done in the physics classroom to eliminate the gender gap in these motivational factors by creating an equitable and inclusive learning environment.

Table 3

Mean predictor and outcome values by gender and effect sizes (Cohen's d) by gender. The p-values are indicated by no superscript for $p < 0.001$ and superscript "a" for $p = 0.001$.

Predictors and Outcomes (Score Range)	Mean		Cohen's *d*
	Male	Female	
Post Self-Efficacy in physics 1 (1-4)	2.98	2.73	0.49
Post Interest in physics 1 (1-4)	2.81	2.38	0.71
Perceived Recognition in physics 2 (1-4)	2.24	1.98	0.39
Peer Interaction in physics 2 (1-4)	2.94	2.79	0.24[a]
Belonging in physics 2 (1-5)	3.69	3.45	0.28
Post Self-Efficacy in physics 2 (1-4)	2.94	2.73	0.40
Post Interest in physics 2 (1-4)	2.77	2.32	0.73
Physics Identity in physics 2 (1-4)	2.19	1.85	0.45

SEM Path Model

We initially tested moderation analysis between variables using multi-group SEM between female and male students to investigate if any of the relationships between the variables were different across gender. There were no group differences between female and male students at the level of weak, and strong measurement invariance at the level of regression coefficients, so we proceeded to mediation analysis.

Then we used mediation analysis to investigate the extent to which gender differences in students' outcomes at the end of the introductory physics courses (self-efficacy, interest, and physics identity) were mediated by differences in students' initial self-efficacy, interest, and perception of the inclusiveness of the learning environment of the course.

Model 1

In Model 1 (Fig. 2), the students' perceived recognition, peer interaction, and sense of belonging were part of the learning environment in the class that mediated student outcomes. The model fit indices indicate a good fit to the data: CFI = 0.937, TLI = 0.929, RMSEA = 0.051, SRMR = 0.047. In this model, we found no direct effects from the gender on any of the student outcomes: self-efficacy, interest, and identity in physics 2. We found that gender only had direct connections to self-efficacy ($\beta = 0.27$) and interest ($\beta = 0.37$) in physics 1. To expand further, the statistically significant path from gender to self-efficacy in physics 1 means that men are predicted to have higher mean values in their self-efficacy than women. The reason that there is no direct path from gender to students' identity in physics 2 is that the gender differences in students' physics identity (Table 3) are statistically non-significant when controlling for the other constructs in the model.

In this model self-efficacy, interest, and perceived recognition influence physics identity at the end of physics 2 directly, with perceived recognition having the largest direct effect ($\beta = 0.70$). This is consistent with past models in calculus-based physics courses (Hazari et al., 2010; Kalender et al., 2019). In addition, the total indirect path for physics identity was found by adding all of the indirect paths together. For example, there are two indirect paths from peer interaction to identity. The first path goes from peer interaction → self-efficacy physics 2 →to identity (0.26*0.13 = 0.03). The second path goes from peer interaction →interest physics 2 →to identity (0.15*0.10 = 0.02). So the total indirect path from peer interaction to identity is 0.03 + 0.02 = 0.05. Additionally, identity has a total indirect path from belonging of 0.02 and a total indirect effect from perceived recognition of 0.03.

Women may have negative experiences in perceived recognition from instructors and TAs. In Table 3, we observe that both women and men have a mean recognition below the positive threshold (score of 3). Furthermore, women also have lower scores in identity than men.

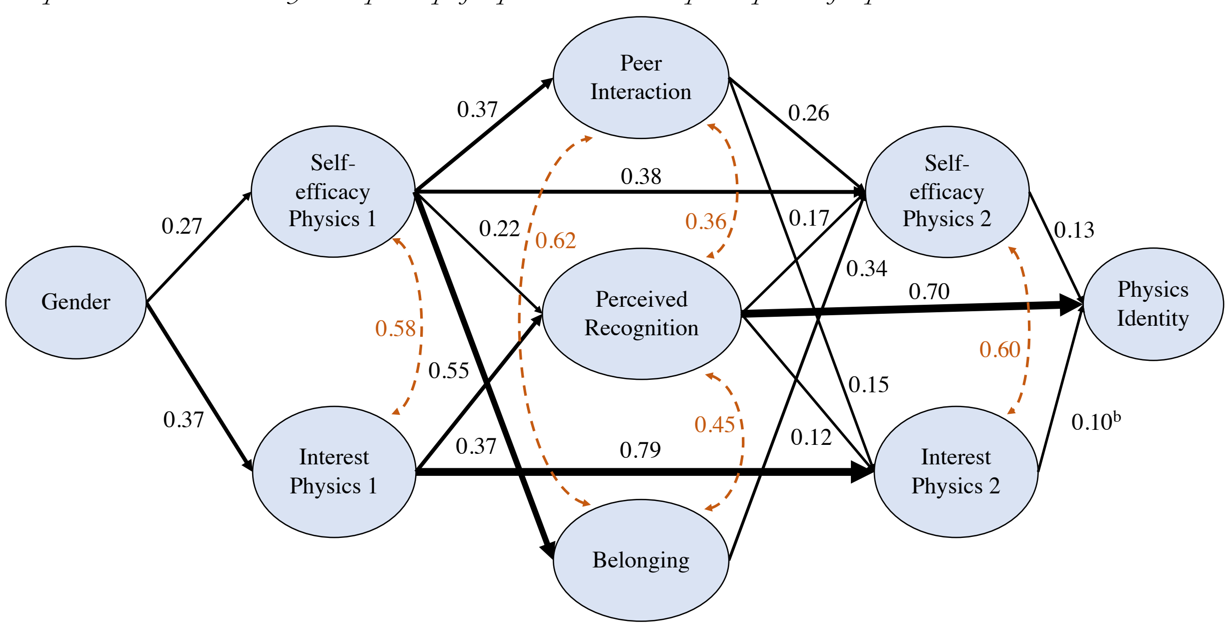
Interest in physics 2 has the largest direct from an interest in physics 1 ($\beta = 0.79$) with smaller direct effects from peer interaction ($\beta = 0.15$) and perceived recognition ($\beta = 0.12$). Although interest in physics 2 is mainly correlated with interest in physics 1, it does not mean that interest can not be changed throughout these courses. Instructors may be able to positively influence students' peer interaction and perceived recognition, which predict students' interest in physics at the end of the course. One possibility to improve students' interest in physics is to provide more problems in class that relate to students' interests and career paths.

Self-efficacy in physics 2 has direct effects from self-efficacy in physics 1 ($\beta = 0.38$), belonging ($\beta = 0.34$), peer interaction ($\beta = 0.26$), and a small effect from perceived recognition ($\beta = 0.17$). Self-efficacy is important for students' persistence in class and future careers. Since the learning environment can influence students' self-efficacy, it is important for an instructor to try and improve student belonging, peer interaction, and perceived recognition.

While many studies have investigated gender differences in students' self-efficacy, interest, and identity in introductory physics courses where women are underrepresented (Hazari et al., 2010; Kalender et al., 2019), most have not taken into account the factors in the student's perception of the inclusiveness of their learning environment. From the model, we find that students' perceived recognition directly predicts students' identity, self-efficacy, and interest at the end of the physics 2 courses. Additionally, students' belonging and peer interaction directly predict students' self-efficacy and interest while indirectly predicting students' identity. Thus instructors may be able to improve this perception of the inclusiveness of the learning environment factors in the classroom that predict student motivational outcomes.

Figure 2

Result of the path analysis part of the SEM showing mediation between gender and motivational outcomes in physics through various mediating factors. The line thickness is a qualitative measure of the relative magnitude of β values. All p-values are indicated by no superscript for p <0.001 and superscript "a" for $p = 0.003$.

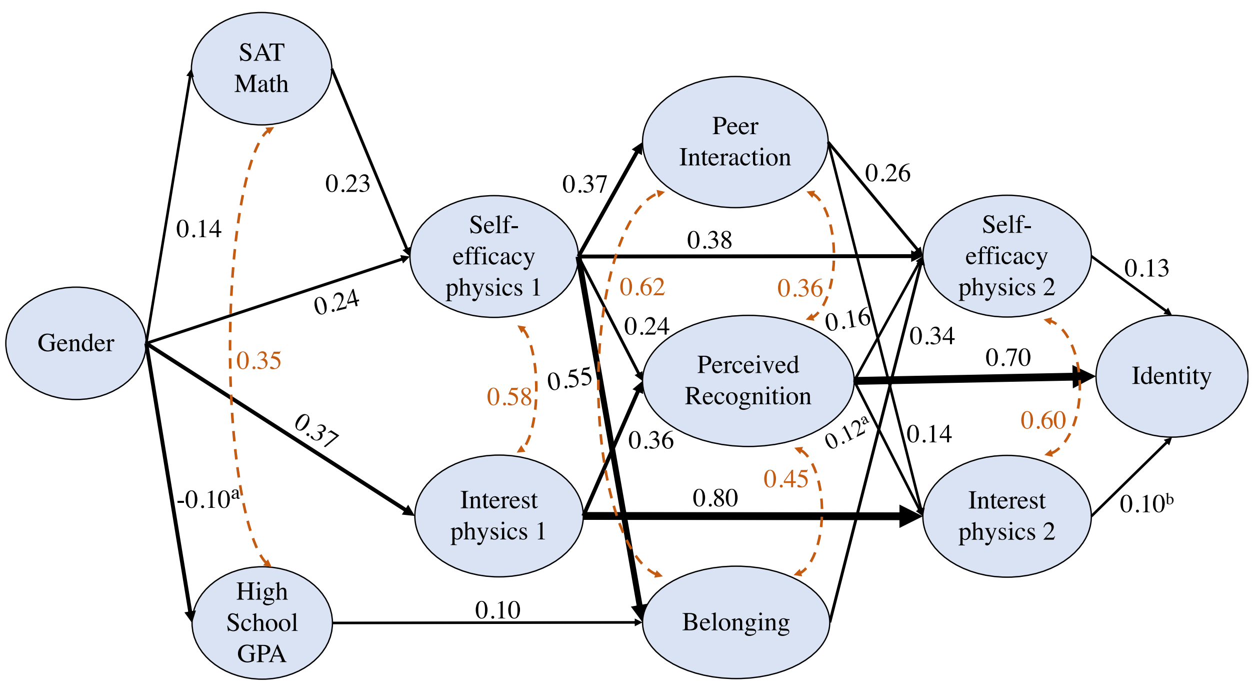


Adding in High School Factors

We also analyzed a model to investigate if additional aspects of student motivational outcomes can be explained by their prior high school academic measures provided during college admissions. In this model visually represented in (Fig. 3), we added students' SAT math scores and high school GPA as control factors. Gender has a small direct effect on both SAT Math ($\beta = 0.15$), and high school GPA ($\beta = -0.11$), which means women have a slightly higher high school GPA than men while men have a slightly higher SAT Math score than women. SAT Math only has a direct effect on self-efficacy in physics 1 ($\beta = 0.23$) whereas high school GPA only has a small direct effect on belonging in physics 2 ($\beta = 0.10$). Almost all other direct effects (and indirect effects) stayed the same from the first model with some minor changes in the value of the direct effect (for instance, the line from self-efficacy in physics 1 → perceived recognition went from 0.24 in the first model to 0.22 in this model). Thus, we conclude that these additional academic factors do not have a significant influence on student motivational outcomes. We can analyze it more clearly when we look at the variance explained in each outcome (Table 4).

Figure 3

Result of the path analysis part of the SEM showing mediation between gender and motivational outcomes in physics through various mediating factors. The line thickness is the relative magnitude of β values. All p-values are indicated by no superscript for $p < 0.001$, superscript "a" for $p = 0.002$, and superscript "b" for $p = 0.003$.



Variance explained by the models

After constructing the models, we calculated the coefficient of determination (adjusted R^2), which allows us to analyze the proportion of variance explained by each factor (Table 4). This allows us to analyze if adding additional academic outcomes explains more variance in the student outcomes for self-efficacy, interest, and identity in physics 2. We found that adding high school factors explained the same amount of variance in post-self-efficacy in physics 1 (from 0.06 to 0.11), perceived recognition (0.26 to 0.27), and belonging (0.29 to 0.31). It did not explain any more of the variance in any of the student outcomes (self-efficacy, interest, or identity in physics 2). This is important since these motivational factors could not only influence students' performance in the course but also their future career choices. Since high school academic measures don't predict student motivational outcomes, the learning environment factors that instructors can influence are central in predicting the outcomes.

Table 4

Adjusted coefficients of determination (Adjusted R^2) for all variables in the two models on the impact of the learning environment. Model 1 is from part an above and the other model (+ H.S. Factors) is from part b above. H.S. refers to high school. All p-values are < 0.001

Variable	Adjusted R^2	
	Model 1	+ H.S. Factors
High School GPA	-	0.00
SAT Math	-	0.01
Post Self-Efficacy in physics 1	0.06	0.11
Post Interest in physics 1	0.12	0.12
Perceived Recognition in Physics 2	0.26	0.27
Peer Interaction in physics 2	0.12	0.13
Belonging in physics 2	0.29	0.31
Post Self-Efficacy in physics 2	0.82	0.82
Post Interest in physics 2	0.82	0.82
Physics Identity in physics 2	0.69	0.69

Implications and Future Directions

In this research involving both descriptive and inferential quantitative analyses, we find gender gaps in physics motivational beliefs disadvantaging women in mandatory introductory physics courses for bioscience majors in which women are not outnumbered by men, 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., 2019). Our SEM models show that perception of the inclusiveness of the learning environment factors (perceived recognition, peer interaction, and belonging) are important to help explain student outcomes of physics self-efficacy, interest, and identity at the end of physics 2. Instructors can influence these learning environment factors to help improve the experiences of women in their classes. These factors influence each other as well, so if an instructor can improve students' peer interaction, possibly by allowing students to work in groups during class such that there is positive interdependence, it could influence students' sense of belonging as well. Thus, if instructors can provide support for the factors they can control, they have the potential to change student outcomes for the better and make their classrooms more equitable and inclusive in the process.

The motivational belief gaps may at least partly be due to physics instructors and teaching assistants unwittingly reinforcing gender stereotypes about physics and communicating lower expectations for women. They must recognize that what is important is not what their intentions are but the impact they are having on the students. Therefore, professors, instructors, and TAs need to create a learning environment that emphasizes recognizing their students positively, allowing for positive peer interactions, and providing a space where all students can feel like they belong in physics.

From our results, each of these factors plays an important role in predicting students' self-efficacy, interest, and identity in physics. We note that the learning environment does not only consist of what happens in the classroom. Student interactions with each other while their doing homework, students' experiences in an instructor or TA's office hours, interactions between students and the instructor over email, and other circumstances all contribute to students' learning environment. All of those interactions can affect students' identity, self-efficacy, and interest in physics by the end of the semester.

There are a variety of ways that TAs/instructors can improve student interactions and the learning environment in the courses. Instructors can influence students' peer interaction with each other by providing time for the students to work together in class and making sure all voices are heard equally when discussing problems as a whole group. One strategy physics instructors can use to encourage equal contribution in group work is to assign each student a role that rotates throughout the course. It is also important for instructors to emphasize that struggling is normal during the learning process, and it is the stepping-stone to learning new things. Therefore, students should embrace their struggles. Additionally, short interventions, e.g., sense of belonging and mindset interventions, have been shown to eliminate gender performance gaps (Kalender et al., 2020; Walton et al., 2015) and have lasting effects beyond the class in which they are implemented (Yeager & Walton, 2011).

The courses in this study were traditionally taught lecture-based courses. It would be important to investigate these models in evidence-based active-engagement courses (e.g., studio courses). In the future, it will also be useful to investigate other student outcomes, e.g., whether students' perceptions of their peer interaction depend on the groups they were interacting with (same-sex groups vs mixed groups vs working alone) and how different evidence-based active engagement classes affect these findings.

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https://sites.google.com/site/professorsinghswebpage/

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