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How Inclusiveness of Learning Environment Mediates the Evolution of Engineering Students' Motivational Beliefs in a Two-Semester Introductory Physics Course Sequence*

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In this study, we focus on engineering students' motivational beliefs and course grades in a two-term college calculus-based introductory physics sequence (physics 1 and physics 2). We investigated how engineering students' perception of the inclusiveness of the learning environment (including their sense of belonging, perceived effectiveness of peer interaction and perceived recognition) predicts their physics course grades and motivational beliefs including self-efficacy, interest, overall physics identity, and overall engineering identity. Using structural equation modeling, we find that students' perception of the inclusiveness of the learning environment statistically significantly predicts their physics grades and motivational beliefs. In particular, students' engineering identity is statistically significantly predicted by engineering students' perception of how they were recognized as a physics person. In addition, we find that the gender differences in students' physics self-efficacy, interest, overall identity, and grades were partially mediated by the different components of students' perception of the inclusiveness of the learning environment. Our findings suggest that instructors' focus on equity and inclusion, and approaches to student recognition, are especially important for supporting students' engineering identity and promoting learning for all students in the classroom.

Keywords: equity; gender; identity; learning environment

1. Introduction

Prior studies have shown that women are often underrepresented in many science, technology, engineering, and mathematics (STEM) courses and disciplines [1–11]. For example, despite women securing a substantial share of all bachelor's degrees awarded in the United States, they continue to be significantly underrepresented in engineering undergraduate programs [12]. In addition, prior studies showed that female students leave engineering fields at higher rates than male students [13]. Moreover, prior studies also show that female students drop out more frequently from engineering than from other STEM fields [14]. These studies suggest that we are largely missing out on the talents of half of the population, which not only hinders the development of engineering fields because of the loss of talent and diversity, but also hinders women from pursuing many great career opportunities. Therefore, efforts to promote participation, achievement, and continuation of women in engineering fields are important for the development of both individuals and the society as a whole. Some prior studies suggest that individuals' academic performance and persistence in a field such as engineering can be influenced by their motivational beliefs such as self-efficacy, interest and identity in that domain [15–24]. Students from underrepresented groups in engineering such as women may not have enough encouragement and role models to help them develop strong motivational beliefs in engineering. In addition, the societal stereotypes and biases in engineering may further undermine their motivational beliefs and lead to withdrawal from engineering courses, majors or careers [9, 10, 25–35]. Thus, investigation of students' motivational beliefs is important for better understanding the underrepresentation of women and minority students in engineering and can be useful for formulating guidelines for developing an inclusive learning environment and promoting diversity and equity in engineering fields.

By inclusive learning environment, we refer to an environment in which all students feel welcome, valued, and supported. By equity in learning, we mean that not only should all students have adequate opportunities and access to resources and have an inclusive learning environment with appropriate support and mentoring so that they can engage in learning in a meaningful and enjoyable manner, but the course outcomes should be equitable. Therefore, inclusiveness is necessary but not sufficient for equity since inclusiveness does not guarantee equitable course outcomes. By equitable course outcomes, we mean that students from all demographic groups (e.g., regardless of their gender identity or race/ethnicity) who have the prerequisites to enroll in the course, on average, have comparable outcomes, which is consistent

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with Rodriguez et al.'s equity of parity model [36]. The course outcomes include student performance and their motivational beliefs at the end of the courses because regardless of the performance, the motivational beliefs can influence students' short and long-term retention in the field such as engineering [37, 38]. We note that adequate opportunity and access to resources, inclusive learning environment and equitable outcomes are strongly entangled with each other. For example, if the learning environment is not inclusive, the outcomes are unlikely to be equitable.Introductory physics courses usually serve as a prerequisite for many engineering courses, and thus for most students who enrolled in an undergraduate engineering program, physics is mandatory in their first year. A study shows that students' grades in introductory physics courses predict their performance in later engineering courses [39]. Moreover, physics is not only important for engineering students' knowledge building but may also affect their attitudes and self-beliefs about being an engineer. For example, studies have shown that students' physics motivational beliefs such as self-efficacy and interest can influence their engineering career agency [40]. However, physics is also one of the most stereotyped domains in the sense that it is a traditionally male-dominated field and has a masculine culture and a masculine public image [41, 42]. In addition, physics is perceived by many people to depend largely on the innate qualities of "brilliance" or "genius", which are also typically attributed to men [10, 43, 44]. These societal stereotypes not only impact female students' physics motivational beliefs but may also dissuade them from pursuing study in physics-related disciplines such as engineering. A prior study shows that physics was the only science subject for which female engineering students had a lower average score than male engineering students [45, 46]. Therefore, the gender difference in physics motivational beliefs may partially explain the underrepresentation of women in engineering disciplines and studying the relationship between students' physics and engineering motivational beliefs may provide new insights into how to improve the recruitment, retention, and diversity within engineering. In this study, we aim to understand how engineering students' perception of the inclusiveness of the learning environment in an introductory physics course predicts their course outcomes and engineering identity at the end of the course.

1.1 Students' Motivational Beliefs Related to Engineering Learning

The Expectancy-Value Theory (EVT) [47, 48] is one of the most prominent approaches to the study of students' motivational beliefs. In the EVT, expectancy refers to students' belief in their ability to succeed in a given task [48]. Value refers to the subjective task value for students, which can be differentiated into four components: intrinsic value, attainment value, utility value, and cost [48]. Intrinsic value refers to students' interest in the task and the enjoyment they experience from performing the task. Attainment value reflects how important students themselves feel it is for them to develop mastery and do a good job in the field [48]. Utility value pertains to students' perception of whether the task can help them achieve some other goals [48]. The last value component is cost, which refers to the assessments of how much effort and time will be taken to engage in the task as well as the amount of opportunity cost and stress caused by the task [48]. In the EVT, students' learning goals, academic engagement and performance, and persistence in a field are impacted by their expectancy of success and the four components of value [48].

The expectancy component of EVT is closely related to the concept of self-efficacy in Bandura's social cognitive theory, which is defined as one's belief in one's ability to succeed in a specific area or accomplish a task [49, 50]. Prior research suggests that self-efficacy is an important motivational belief of students for them to excel in a domain [19, 51–53]. Studies have shown that students' engagement and performance can be influenced by their self-efficacy [17, 54–57]. For example, students who have high self-efficacy tend to see difficulties as challenges and believe that productive struggles can help them improve, so they often choose to take harder courses and ask to do more challenging problems than students with low self-efficacy, who usually see difficulties as threats and obstacles to success [58].

Another important motivational belief is interest, which refers to students' curiosity, enjoyment, and engagement in a specific area [59, 60]. Interest is closely related to intrinsic value in EVT. Studies have shown that interest can also influence students' learning [54, 60–65]. For example, one study showed that students' performance can be improved by connecting physics courses to students' daily lives or using evidence-based curricula to make the courses more engaging and interesting [66]. Prior studies (both experimental and correlational) have also shown that interest can be affected by self-efficacy [67, 68]. Some other studies show that interest may also lead to the development of self-efficacy [69, 70].

In addition, students' identity in a specific field such as engineering is another important motivational belief that influences their career decisions [40, 71–77]. In prior research, engineering identity has been studied from several different perspectives [78, 79]. For example, some studies consider engineering identity as the combination of multiple identities such as academic, social, and occupational identities [80–82]. Some other studies identified several cognitive, affective, and performance variables to comprise engineering identity [83–85]. Another widely used definition of engineering identity is how students see themselves with respect to engineering or whether they see themselves as an engineer based on their perceptions and navigation of engineering related experiences [86–88], which is also the most relevant definition to our study. However, studies have shown that many students have very few direct experiences with engineering before they enter college [89]. Thus, due to the interdisciplinary nature of engineering, students' experiences in other engineering related domains such as math and science may play a very important role in the development of students' engineering identity [84]. For example, studies have shown that doing well in math and science courses in high school has a positive impact on students' choice of and persistence in an engineering major and longer-term career goals [90, 91]. Therefore, studying students' motivational beliefs in engineering related domains, e.g., physics, and how they interact with engineering identity may help us develop a better understanding of students' attrition and retention in engineering majors.

1.2 Theoretical Framework

In Carlone and Johnson's science identity framework [92], students' science identity includes three interrelated constructs: competence (belief in one's competence), performance (belief in ability to perform), and recognition (recognition of self and by others as a "science person"). Hazari et al. [93] adapted this model to physics and added interest to this model. In addition, Hazari et al. [93] developed quantitative measures for these constructs and found that competence and performance factored into a single construct. Moreover, they separated recognition of self and by others and used a single item ("I see myself as a physics person") to measure students' overall physics identity [93]. In Hazari et al.'s later studies using structural equation modeling, they found that students' overall physics identity was predicted by interest, competence/performance beliefs, and perceived recognition from other people [40, 84, 94, 95]. This physics identity framework has been used to study physics identity of students in high school physics classes [96, 97] as well as college students with a variety of majors [94, 98–101], and studies have shown that students' physics identity is an important predictor of their engineering identity [40, 84].

The definition of physics competence/performance beliefs is peoples' beliefs about their ability to understand and perform physics [93], which is very similar to the definition of self-efficacy for the purposes of our research which uses validated survey data, and our survey items were adapted from prior studies that use the term self-efficacy [102, 103]. Moreover, prior studies have shown that self-efficacy is also an important predictor of students' overall identity [80, 104]. Therefore, in this study, we will use the physics identity model in which overall physics identity is predicted by self-efficacy, interest, and perceived recognition.

According to the field-specific identity frameworks discussed earlier, individuals' overall identity in STEM fields is not only impacted by their own motivational characteristics but also by their perceived recognition from others. Several studies have shown that female students did not feel that they were recognized appropriately even before they entered college [43, 105, 106]. One stereotypical view of science is that it is for students who are very smart or have a natural gift in science [106]. In general, due to societal stereotypes, being brilliant or exceptionally smart is usually associated with boys [44]. One investigation showed that the gendered notions of brilliance are endorsed by children as young as 6 years old and have an immediate effect on their interest and identity in science [43]. These stereotypes and biases also exist in the university context [107–109]. For example, one study showed that science faculty participants rated men as more competent and would like to offer higher starting salary and more mentoring to male applicants than the (identical) female applicants even though only the names were different in the hypothetical information they were provided [107]. For female students, the experiences of not being recognized as a science person and the gender-based biases may accumulate over time and negatively influence their science and engineering identity.

Moreover, students' interest and self-efficacy have also been found to be connected to their interaction with other people and recognition by them [50, 60]. In the four-phase model of interest development, Hidi and Renninger pointed out that external factors such as group work and tutoring can trigger and maintain people's interest [60, 62, 110]. In addition, according to Bandura's social cognitive theory, an individual's self-efficacy can be shaped by verbal encouragement from others [111, 112]. Prior studies done by Kalender et al. [108, 113] showed that students' perceived recognition not only strongly predicts their overall physics identity, but also predicts their physics interest and self-efficacy.

In addition to perceived recognition, students' sense of belonging and their interaction with peers have also been shown to be important aspects of the inclusiveness of the learning environment [2, 41, 42, 114–118]. For example, if students have a high sense of belonging in class, they may interact with others more and with more positive attitudes, and they may also develop a higher perceived recognition [119]. In our prior studies, we found that students' perceived recognition, sense of belonging, and peer interaction significantly predict their physics motivational beliefs and physics conceptual understanding [120–123]. However, to our knowledge, no prior studies have investigated the roles played by engineering students' perceived recognition, sense of belonging, and peer interaction in a calculus-based physics course sequence, in their course outcomes and engineering identity. Investigating the evolution of engineering students' motivational beliefs in the calculus-based physics course sequence and possible factors that contribute to this change may help us develop a deeper understanding of the underrepresentation of women in engineering and how to develop a more inclusive learning environment in which all students can thrive.

1.3 The Present Study

In this study, we include engineering students' self-reported perceived recognition by others, sense of belonging, and perceived effectiveness of peer interaction as three aspects of students' perception of the inclusiveness of the learning environment. We first studied how students' motivational beliefs evolve in a calculus-based introductory physics sequence (including physics 1 and physics 2) at a large state-related university in the US. Then, we used structural equation modeling (SEM) to investigate the net effect of each construct of students' perception of the inclusiveness of the learning environment on students' course outcomes in physics 2. In this study, we include students' academic performance (measured by course grades) and motivational beliefs (including physics self-efficacy, physics interest, overall physics identity, and overall engineering identity) at the end of the physics sequence as course outcomes. We also took into account the effect of students' high school preparation, which may also predict students' course outcomes. Specifically, we address the following research questions:

RQ1. Are there gender differences in engineering students' academic performance and motivational beliefs and do they change from physics 1 to physics 2?

RQ2. How do the different components of the perception of the inclusiveness of the learning environment in physics 2 (including perceived recognition, sense of belonging, and perceived effectiveness of peer interaction) predict engineering students' academic performance and motivational beliefs in physics 2 (including engineering identity) after controlling for students' gender, high school preparation, and their performance and motivational beliefs in physics 1?

RQ3. If gender does not moderate any predictive relationship in RQ2 (the regression coefficients among the constructs are not different for women and men), how does gender directly or indirectly predict

(a) students' high school preparation and their academic performance and motivational beliefs in physics 1?
(b) the perception of the inclusiveness of the learning environment after controlling for students' high school preparation and their academic performance and motivational beliefs in physics 1?
(c) students' academic performance and motivational beliefs in physics 2 (including their engineering identity) after controlling for everything else in RQ2?

This study was conducted in a two-term college calculus-based introductory physics sequence (including physics 1 and physics 2) at a large public university. These courses are generally mandatory and taken by students majoring in engineering in their first year of university. Physics 1 mainly includes mechanics, while the main content of physics 2 is electricity and magnetism. In our prior work, we found that students' physics motivational beliefs decreased from the beginning to the end of physics 1, and these changes were mediated by students' perception of the inclusiveness of the learning environment in physics 1 [124, 125]. Students' physics motivational beliefs and their engineering identity may change for better or worse from physics 1 to physics 2 based upon the inclusiveness of the learning environment, e.g., depending on whether students had a high sense of belonging in the course, whether they felt recognized, and whether their interaction with peers was positive. We note that for most students in the calculus-based introductory physics sequence, physics 2 might be their last formal physics course in college, so their motivational beliefs at the end of physics 2 are very important not only for their engagement in the following courses in engineering, but also for their short and long-term academic goals in engineering fields.

Therefore, in this study, we investigated the effect of the perception of the inclusiveness of the learning environment (including students' sense of belonging, perceived effectiveness of peer interaction, and perceived recognition) on students' grades and motivational beliefs (including physics self-efficacy, physics interest, overall physics identity, and overall engineering identity) in physics 2 after controlling for students' gender and pre-college test scores (including high school Grade Point Average (GPA) and Scholastic Assessment Test (SAT) math scores) as well as their self-efficacy, interest, overall physics identity, overall engineering identity, and grades in physics 1. For convenience, perceived effectiveness of peer interaction is shortened to peer interaction in the rest of the paper. We note that the learning environment here is not only the classroom environment but also includes students' experiences outside the class. For example, students may work together on their homework after class, and they could also ask for help during TAs'/instructors' office hours.

As shown in Fig. 1, the sixteen constructs are divided into three groups: what we control for, perception of the inclusiveness of the learning environment, and outcomes. Students' gender, SAT math scores, high school GPA (HS GPA), and their self-efficacy, interest, overall physics identity, overall engineering identity, and grades in physics 1 (Self-efficacy (SE) 1, Interest 1, Physics Identity 1, Engineering Identity 1, and Grade 1) are constructs that we control for. Outcomes include students' self-efficacy, interest, overall physics identity, overall engineering identity, and grades in physics 2 (Self-efficacy (SE) 2, Interest 2, Identity 2, and Grade 2). Perceived recognition (Perceived Recog), peer interaction (Peer Int) and sense of belonging (Belonging) constitute the perception of the inclusiveness of the learning environment. It is expected that students' responses to the motivational survey in physics 1 and physics 2 are correlated because they are students' responses to the same questions pertaining to the same motivational construct at two different time points. However, if students' motivational beliefs changed from physics 1 to physics 2, we want to study whether the perception of the inclusiveness of the learning environment helps to explain the changes and what role is played by each construct in the inclusiveness of the learning environment. In addition, since previous studies suggest that self-efficacy and interest can influence student learning [54, 57, 60, 62], we also model a direct path from self-efficacy and interest to grade in both physics 1 and physics 2.

In this study, we first investigated how students' motivational beliefs changed from physics 1 to physics 2 and whether there were gender differences in the constructs studied. Then, we used Structural Equation Modeling (SEM) to study the effect of the perception of the inclusiveness of the learning environment on students' motivational beliefs including their engineering identity and grades in physics 2 after controlling for students' gender, high school GPA, SAT math scores, and their motivational beliefs and grades in physics 1.

2. Methods

2.1 Participants and Data Sources

The motivational survey data used in this study were collected at the end of each course of a two-term college calculus-based introductory physics sequence (including physics 1 and physics 2) in two consecutive school years at a large research university in the US. These courses are taken mostly by students in engineering school for whom they are mandatory. In this study, we only focus on engi-

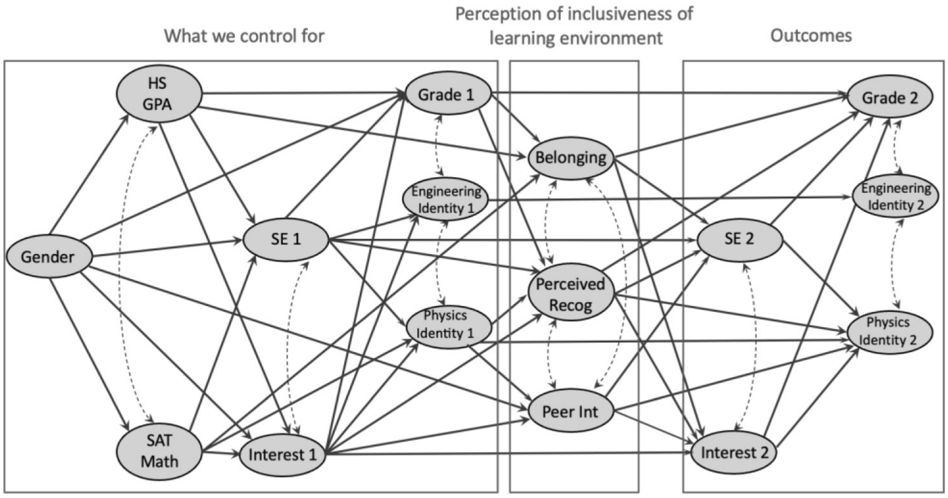

Fig. 1. Schematic representation of the theoretical framework. HS GPA represents high school GPA, SE represents self-efficacy, Perceived Recog represents perceived recognition, and Peer Int represents peer interaction. The solid lines represent regression paths, and the dashed lines represent covariances. From left to right, all possible regression paths were considered, but only some of the paths are shown here for clarity.

neering major students. Physics 1 mainly includes mechanics, while the main content of physics 2 is electricity and magnetism. The paper surveys were handed out and collected by TAs during the last recitation class of a semester. In particular, students' self-efficacy, interest, overall physics identity, and overall engineering identity in physics 1 and physics 2 were measured at the end of each course, and their perceived recognition, peer interaction, and sense of belonging were measured at the end of physics 2. This is because only after the course can students answer the survey questions pertaining to inclusiveness of the learning environment based on their real experience in the course such as their interaction with peers, TAs, and instructors. Table 1 shows when each construct was assessed throughout the course sequence. The demographic data of students – such as gender – were provided by the university. Students' SAT math scores, high school GPA, and course grades in physics 1 and physics 2 were also obtained from the university records. Students' names and IDs were de-identified by an honest broker who generated a unique new ID for each student. Thus, researchers could analyze students' data without having access to students' identifying information.

There were 762 students in physics 1 and 629 engineering students in physics 2 participating in the survey. However, in this study, we only focused on 524 students (182 female students and 342 male students) who took the survey in both courses in recommended semesters, i.e., physics 1 in Fall semester and physics 2 in Spring semester because we wanted to track the same group of students' motivational beliefs and academic performance in the two courses in the recommended sequence. Some possible reasons that some students took these courses in the off semesters (not recommended semesters) include students taking Advanced Placement (AP) physics in high school with scores that exempted them from college physics 1 and directly enrolling in physics 2 in their first semester, students repeating physics 1 in the off semester if they did not perform well the first time, and students putting off taking at least one of these courses in the summer semester due to their heavy course load in Fall and Spring semesters. Most of the participants were in their first year of university when the study was conducted.

2.2 Survey Instruments

In this study, our analysis includes three motivational constructs (physics self-efficacy, physics interest, and overall physics identity) and three perception of the inclusiveness of the learning environment constructs (peer interaction, perceived recognition, and sense of belonging). The survey questions for each construct are shown in Table 2. We adapted these questions from existing motivational research [93, 103, 126–128] and revalidated them in our prior work [52, 113, 125–129]. The validation and refinement of the survey involved use of individual interviews with students [52, 130, 132, 134], exploratory and confirmatory factor analysis (EFA and CFA) [135], Pearson correlation between different constructs and Cronbach alpha [136, 137].

Physics self-efficacy represents students' belief about whether they can excel in physics. In our survey, we had four items for self-efficacy [103, 126, 127] (Cronbach's $\alpha = 0.79$ for self-efficacy in physics 1 and $\alpha = 0.81$ for self-efficacy in physics 2 [137]). These items each had four options "NO!, no, yes, YES!", which is a 4-point Likert scale (1–4). We also had four items for physics interest [103, 126] (Cronbach's $\alpha = 0.82$ for interest in physics 1 and $\alpha = 0.84$ for interest in physics 2). For the item "I wonder about how physics works", students can choose from "Never, Once a month, Once a week, Every day". For the item "In general, I find physics", students can choose from "very boring, boring, interesting, very interesting". The remaining two items under interest had a response scale of "NO!, no, yes, YES!". By choosing the four options, students will get a score from 1 to 4 respectively. For example, if a student finds physics very boring, they will get one point for this item. The more interest a student has in physics, the higher score the student will have for this item. We had one item for overall physics identity [93], which corresponds to students' belief about whether they designate themselves as a physics person. We had one item for overall engineering identity, which corresponds to students' belief

Table 1. Time points when different constructs were assessed

Constructs	**When the constructs were assessed**
Gender, SAT Math, High School GPA	Pre-college
Grade 1, Self-efficacy 1, Interest 1, Overall Physics Identity 1, Overall Engineering Identity 1	At the end of Physics 1 (December)
Peer interaction, Perceived recognition, Sense of Belonging	At the end of Physics 2 (April)
Grade 2, Self-efficacy 2, Interest 2, Overall Physics Identity 2, Overall Engineering Identity 2	At the end of Physics 2 (April)

about whether they designate themselves as an engineer. These identity items had response options "strongly disagree, disagree, agree, and strongly agree", which correspond to 1 to 4 points [138].

In addition, perceived recognition, peer interaction and sense of belonging are the perception of the inclusiveness of the learning environment constructs in our study. Unlike self-efficacy, interest, and overall physics identity, these three constructs are directly related to students' experience in the course. Perceived recognition (included in perception of the inclusiveness of the learning environment) included three items (Cronbach's α = 0.86) which represent whether students think they are recognized as a physics person by other people including their instructors or TAs, friends, and family [93, 139, 140]. Peer interaction (which includes four items) [127] represents whether students have a productive and enjoyable experience when working with peers (Cronbach's α = 0.92). Sense of belonging is about students' feelings of whether they belonged in the physics class [116], and it included five items [128] that each had a 5-point Likert scale: "not at all true, a little true, somewhat true, mostly true and completely true" (Cronbach's α = 0.87). Two sense of belonging items ("I feel like an outsider in this class" and "Sometimes I worry that I do not belong in this physics class") were reverse coded, which means that a higher score in these two items represents a lower sense of belonging. Students' score on each construct is the average score of all items in that construct.

2.3 Analysis

First, we calculated the mean score for each construct for each student. Then we used a *t*-test [141, 142] to compare students' responses in physics 1 and physics 2 and to compare responses for female and male students. Then, we conducted Structural

Table 2. Survey items for each construct studied

Construct and Item	**Lambda**	***p* value**
Overall Physics Identity		
I see myself as a physics person.	1.000	<0.001
Overall Engineering Identity		
I see myself as an engineer.	1.000	<0.001
Physics Self-Efficacy (Cronbach's α = 0.81)		
I am able to help my classmates with physics in the laboratory or in recitation.	0.689	<0.001
I understand concepts I have studied in physics.	0.740	<0.001
If I study, I will do well on a physics test.	0.725	<0.001
If I encounter a setback in a physics exam, I can overcome it.	0.709	<0.001
Physics Interest (Cronbach's α = 0.84)		
I wonder about how physics works†	0.677	<0.001
In general, I find physics‡	0.824	<0.001
I want to know everything I can about physics.	0.825	<0.001
I am curious about recent physics discoveries.	0.707	<0.001
Physics Perceived Recognition (Cronbach's α = 0.86)		
My family sees me as a physics person.	0.854	<0.001
My friends see me as a physics person.	0.900	<0.001
My physics TA and/or instructor see me as a physics person.	0.733	<0.001
Physics Sense of Belonging (Cronbach's α = 0.87)		
I feel like I belong in this class.	0.815	<0.001
I feel like an outsider in this class.	0.699	<0.001
I feel comfortable in this class.	0.836	<0.001
I feel like I can be myself in this class.	0.707	<0.001
Sometimes I worry that I do not belong in this physics class.	0.675	<0.001
Physics Peer Interaction (Cronbach's α = 0.92)		
My experience and interaction with other students in this class. . .		
made me feel more relaxed about learning physics.	0.751	<0.001
increased my confidence in my ability to do physics.	0.940	<0.001
increased my confidence that I can succeed in physics.	0.926	<0.001
increased my confidence in my ability to handle difficult physics problems.	0.860	<0.001

The Cronbach alphas and CFA item loadings (Lambda and *p*-values of the significance test for each item loading) shown here were calculated with physics 2 data. ‡ The response options for this question are "Never, Once a month, Once a week, Every day".
† The response options for this question are "very boring, boring, interesting, very interesting".

Equation Modeling (SEM) [143] using the "lavaan" package in software R [144] to study how the perception of the inclusiveness of the learning environment predicted students' motivational and academic outcomes in physics 2 after controlling for students' gender, high school GPA and SAT math as well as their self-efficacy, interest, overall physics identity, overall engineering identity, and grades in physics 1.

The SEM includes two parts: confirmatory factor analysis (CFA) and path analysis. First, we performed the CFA for each construct. The CFA model fit is considered adequate if the Comparative Fit Index (CFI) and Tucker-Lewis Index (TLI) are >0.9 and Root Mean Square Error of Approximation (RMSEA) and Standardized Root Mean Square Residual (SRMR) are <0.08 [145]. In our study, CFI = 0.933, TLI = 0.915, RMSEA = 0.052 and SRMR = 0.038, which represents a good fit. This result provides quantitative support for us to divide the motivational constructs and the inclusiveness of the learning environment constructs as proposed. In addition, as shown in Table 2, all of the CFA item loadings are above 0.6 and most of them are above 0.7, which means that our constructs extract sufficient variance from the items [146].

Before performing the path analysis, we calculated the Pearson correlation coefficients pairwise between each pair of constructs [136]. As shown in Table 3, there are relatively strong correlations among non-academic constructs, while the correlations between non-academic constructs and SAT math or high school GPA are relatively small. Even though these non-academic constructs have strong correlations with each other, the correlations are not so high that SEM cannot examine the constructs separately [147]. We note that in Table 3, there are two very strong correlations. The correlation coefficient between Interest 1 and Interest 2 is 0.85, which means that students' interest in physics 2 is highly related to their interest in physics 1. In addition, the correlation between students' Self-efficacy 2 and sense of belonging is r = 0.81 and the correlation between students' perceived recognition and overall physics identity 2 is r = 0.83 are relatively larger. According to the prior work done by Kalender et al., these constructs are indeed strongly correlated with each other even though they are separate constructs [105, 113].

To analyze the relationships among the constructs, we performed the full Structural Equation Modeling (SEM). Apart from CFA, the path analysis part of SEM estimates the predictive relationships between different constructs. The strength of each relationship is represented by a regression coefficient β. One advantage of SEM is that it simultaneously estimates factor loadings for items and all of the regression links for multiple outcomes, which improves the statistical power compared with other statistical methods such as multiple regression. The level of SEM model fit can also be represented by CFI, TLI, RMSEA and SRMR. We first analyzed the saturated SEM model that includes all of the possible links from left to right between different constructs shown in Fig. 1, and then we removed the most insignificant path line (with the highest p value) and re-ran the model. We used this method to trim one path at a time until all remaining path lines were statistically significant. Next, we used modification indices to improve the model fit. The modification index is the chi-square value, with 1 degree of freedom, by which model fit would improve if a particular path was added back. Modification index bigger than 3.84 indicates that the model fit would be significantly improved, and the p value for the added parameter would be < 0.05 [148, 149]. We added back the paths with modification index larger than 3.84 one at a time (from high to low modification index) to improve the model fit. Finally, we checked the

Table 3. Zeroth order correlation coefficients of the constructs studied

Observed Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1. SAT math	—	—	—		—	—	—	—		—	—	—	—	—	—
2. High school GPA	0.19	—	—		—	—	—	—		—	—	—	—	—	—
3. Overall Physics Identity 1	0.01$^{\text{ns}}$	–0.09*	—		—	—	—	—		—	—	—	—	—	—
4. Overall Engineering Identity 1	–0.01$^{\text{ns}}$	0.00$^{\text{ns}}$	0.28												
5. Grade 1	0.37	0.26	0.33	0.13**	—	—	—	—		—	—	—	—	—	—
6. Self-efficacy 1	0.11*	0.06$^{\text{ns}}$	0.66	0.30	0.52	—	—	—		—	—	—	—	—	—
7. Interest 1	–0.03$^{\text{ns}}$	–0.07$^{\text{ns}}$	0.73	0.30	0.23	0.60	—	—		—	—	—	—	—	—
8. Overall Physics Identity 2	0.04$^{\text{ns}}$	–0.07$^{\text{ns}}$	0.63	0.25	0.31	0.54	0.54	—		—	—	—	—	—	—
9. Overall Engineering Identity 2	0.02$^{\text{ns}}$	0.06$^{\text{ns}}$	0.16	0.47	0.16	0.24	0.17**	0.24							
10. Grade 2	0.31	0.26	0.23	0.14**	0.61	0.30	0.17**	0.30	0.21	—	—	—	—	—	—
11. Self-efficacy 2	0.08$^{\text{ns}}$	0.02$^{\text{ns}}$	0.49	0.29	0.36	0.72	0.47	0.70	0.28	0.42	—	—	—	—	—
12. Interest 2	–0.03$^{\text{ns}}$	–0.05$^{\text{ns}}$	0.58	0.22	0.22	0.43	0.85	0.64	0.18	0.24	0.65	—	—	—	—
13. Perceived Recognition	0.05$^{\text{ns}}$	–0.05$^{\text{ns}}$	0.69	0.27	0.36	0.64	0.62	0.83	0.32	0.34	0.72	0.65	—	—	—
14. Peer Interaction	0.07$^{\text{ns}}$	0.02$^{\text{ns}}$	0.36	0.21	0.25	0.44	0.33	0.49	0.24	0.32	0.71	0.50	0.55	—	—
15. Sense of Belonging	0.07*	0.04$^{\text{ns}}$	0.38	0.21	0.31	0.55	0.33	0.58	0.23	0.38	0.81	0.52	0.60	0.64	—

p values are indicated by ** for $0.001 \leq p < 0.01$, * for $0.01 \leq p < 0.05$, and $^{\text{ns}}$ for $p > 0.05$. All the other correlation coefficients have $p < 0.001$.

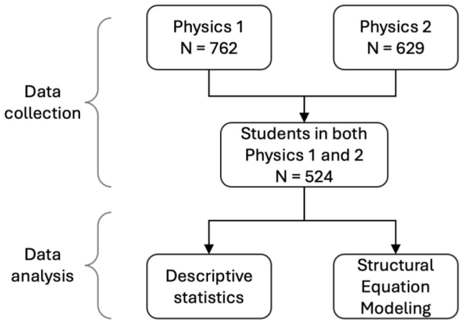

Fig. 2. Flow diagram of the steps in the study.

statistical significance of each trimmed path by adding them back to make sure that all trimmed paths are not statistically significant and all statistically significant paths are kept.

We also tested measurement invariance (which tests whether the survey items were interpreted in a similar manner by male and female students) and performed gender moderation analysis using multi-group SEM (which tests whether the regression pathways were different across gender). Results showed that strong measurement invariance holds for our model, and regression pathways among the constructs do not have differences across gender (see the Appendix for detailed results of testing measurement invariance and multi-group SEM analysis). Therefore, we concluded that our SEM model can be interpreted similarly for men and women, and any gender differences can be modeled using a separate gender variable (1 for male and 0 for female) as an exogenous variable as in Fig. 1. If there are statistically significant paths from gender to any of the constructs in the model, it implies that women and men did not have the same average value for those constructs controlling for all constructs to the left. This is the gender mediation SEM model, which we will discuss in more detail in the results section. A broad view of the steps in our study is shown in the flowchart in Fig. 2. As depicted in Fig. 2, we first collected data from students in the introductory physics course sequence, physics 1 and physics 2. We then matched students from physics 1 and physics 2, and subsequently conducted descriptive statistics (e.g., *t*-test) and Structural Equation Modeling.

3. Results

3.1 Gender Differences in Motivational Characteristics and Grades

Table 4 shows the descriptive statistics of students' motivational characteristics and their perception of

Table 4. Descriptive statistics of female and male students' motivational characteristics and their perception of the inclusiveness of the learning environment in physics 1 and physics 2

	Self-efficacy		**Statistics**		**Interest**		**Statistics**	
Gender	**physics 1**	**physics 2**	***p* value**	**Cohen's *d***	**physics 1**	**physics 2**	***p* value**	**Cohen's *d***
Male	3.0409	2.9102	<0.001	0.26	3.1065	2.9675	<0.001	0.29
Female	2.8173	2.6593	<0.001	0.33	2.7225	2.5939	<0.001	0.27
p value	<0.001	<0.001			<0.001	<0.001		
Cohen's *d*	0.46	0.46			0.66*	0.61*		
	Perceived Recognition		**Statistics**		**Peer Interaction**		**Statistics**	
Gender	**physics 1**	**physics 2**	***p* value**	**Cohen's *d***	**physics 1**	**physics 2**	***p* value**	**Cohen's *d***
Male	2.7278	2.7196	0.946	0.00	3.0894	2.9367	<0.001	0.21
Female	2.3630	2.2637	0.026	0.17	2.7935	2.6319	0.005	0.23
p value	<0.001	<0.001			<0.001	<0.001		
Cohen's *d*	0.52	0.67			0.47	0.46		
	Sense of Belonging		**Statistics**		**Overall Physics Identity**		**Statistics**	
Gender	**physics 1**	**physics 2**	***p* value**	**Cohen's *d***	**physics 1**	**physics 2**	***p* value**	**Cohen's *d***
Male	3.8997	3.7742	0.005	0.15	2.73	2.67	0.160	0.08
Female	3.5400	3.4055	0.017	0.18	2.25	2.18	0.183	0.10
p value	<0.001	<0.001			<0.001	<0.001		
Cohen's *d*	0.46	0.45			0.59	0.61		
	Overall Engineering Identity		**Statistics**					
Gender	**physics 1**	**physics 2**	***p* value**	**Cohen's *d***				
Male	3.55	3.45	0.005	0.15				
Female	3.43	3.47	0.440	–0.06				
p value	0.031	0.780						
Cohen's *d*	0.20	–0.03						

N = 182 for female students N = 342 for male students. Cohen suggested that typically values of $d = 0.2$, 0.5 and 0.8 represent small, medium and large effect sizes.

the inclusiveness of the learning environment in physics 1 and physics 2. We note that women had significantly lower scores in self-efficacy, interest, overall physics identity, perceived recognition, peer interaction, and sense of belonging in both physics 1 and physics 2 than men, and the effect sizes are all in the medium range [142]. These results indicate that, in the current learning environment, female students reported less benefit from peer interaction and also felt a lower sense of belonging than male students. Moreover, female students' average scores pertaining to perceived recognition and overall physics identity indicate that on average, female students did not think other people see them as a physics person, and they did not see themselves as a physics person either. Furthermore, the gender differences in students' perceived recognition increased from physics 1 to physics 2. We note that in physics 1, women had a statistically significantly lower overall engineering identity than men, whereas there is no gender gap observed in physics 2.

When we compared students' perception of the inclusiveness of the learning environment and motivational characteristics in the two courses, we found that, from physics 1 to physics 2, there was no statistically significant change in both women and men' overall physics identity, while women' perceived recognition decreased. Even though both male and female students' self-efficacy and male students' interest, peer interaction and sense of belonging significantly decreased from physics 1 to physics 2, the effect sizes are relatively small compared with the effect sizes of the gender differences in these constructs. Additionally, we note that male students' overall engineering identity decreased significantly from physics 1 to physics 2, while there was no statistically significant change in women's overall engineering identity.

Table 5 shows students' high school GPA, SAT math scores, and grades in physics 1 and physics 2. We note that even though female students had significantly lower grades than male students in both physics 1 and physics 2, there was no statistically significant gender difference in SAT math scores, and female students even had a higher average high school GPA than male students.

3.2 Perception of the Inclusiveness of the Learning Environment Mediation Models Using SEM

In this section, we show the predictive relationships among the constructs using Structural Equation Modeling (SEM). We ran the full SEM model in which perceived recognition, peer interaction and sense of belonging constitute the perception of the inclusiveness of the learning environment to study how these inclusiveness of the learning environment constructs predict students' motivational beliefs including their engineering identity and grades in physics 2 after controlling for students' gender, high school GPA, SAT math scores, and their motivational beliefs and grades in physics 1. The results of the SEM model are presented visually in Fig. 3. The model fit indices suggest a good fit to the data: CFI = 0.925 (>0.90), TLI = 0.916(>0.90), RMSEA = 0.051 (<0.08) and SRMR = 0.044 (<0.08).

As shown in Fig. 3, students' course outcomes at the end of physics 2 are statistically significantly predicted by the perception of the inclusiveness of the learning environment. In particular, students' self-efficacy and interest in physics 2 are predicted by peer interaction and sense of belonging, Grade 2 is predicted by sense of belonging, and overall physics identity in physics 2 is predicted by perceived recognition. Fig. 3 shows that Self-efficacy 1 directly predicts Grade 1, while the direct effect of Self-efficacy 2 on Grade 2 is not statistically significant after controlling for Grade 1 and sense of belonging. In addition, Fig. 3 shows that overall physics identity in physics 1 does not directly predict self-efficacy and interest in physics 2 after controlling for self-efficacy and interest in physics 1 as well as students' perception of the inclusiveness of the learning environment in physics 2. We note that the regression coefficient from sense of belonging to Self-efficacy 2 is 0.40, which is larger than the effect of Self-efficacy 1 on Self-efficacy 2 ($\beta = 0.34$). In addition, consistent with prior work of Godwin et al. and Kalender et al. [40, 108], Fig. 3 shows that overall physics identity is predicted by self-efficacy, interest and perceived recognition. Moreover, Fig. 3 shows that students' engineering identity in physics 2 is statistically significantly predicted by their perception of how others see them as a physics

Table 5. Descriptive statistics of students' high school GPA, SAT math, and grades in physics 1 (Grade 1) and physics 2 (Grade 2)

Grades (Score Range)	Mean		*p* value	Cohen's *d*
	Male	Female		
High School GPA (0–5)	4.24	4.39	<0.001	–0.39
SAT Math (400–800)	719.8	719.6	0.964	0.01
Grade 1 (0–4)	2.89	2.71	0.003	0.27
Grade 2 (0–4)	2.72	2.52	0.004	0.27

N = 182 for female students N = 342 for male students. The minus sign indicates female students have higher scores than male students.

person (β = 0.19) even after controlling for their engineering identity in physics 1.

As shown in Fig. 3, gender directly predicts students' self-efficacy and interest in physics 1 as well as the three inclusiveness of the learning environment constructs. These results are consistent with the descriptive statistics shown in Table 4, which shows that there were statistically significant gender differences disadvantaging women in these constructs. Although there were also significant gender differences in students' grades, self-efficacy, interest and overall physics identity in physics 2 as shown in Tables 4 and 5, gender does not directly predict these constructs in the SEM model. Thus, Fig. 3 reveals that the gender differences in these outcome constructs were partially mediated by the different components of the perception of the inclusiveness of the learning environment. Moreover, even though Table 4 shows that there was a statistically significant gender gap disadvantaging women in students' overall engineering identity in physics 1, Fig. 3 shows that gender does not directly predict overall engineering identity. Instead, this gender difference is mediated through self-efficacy and interest in physics 1. In addition, we note that gender predicts high school GPA with a negative regression coefficient (β = –0.17), which means that female students actually had a higher average high school GPA than male students. This is consistent with the results shown in Table 5.

To further understand how much variance in students' course outcomes is explained by our model, we calculated the coefficient of determination R^2 (fraction of variance explained) for each of the four outcome constructs. According to our results, the R^2 value of Grade 2 is 0.43, which means that the model explains 43% of the variance in Grade 2. For the motivational outcomes, there is 81% of the variance in Self-efficacy 2, 76% of the variance in Interest 2, 71% of the variance in Overall Physics Identity, and 25% variance in Overall Engineering Identity explained by the model.

4. Discussion

Prior studies have shown that students' motivational beliefs such as self-efficacy, interest and identity can influence their persistence and retention in STEM fields such as physics and engineering [19, 52, 54, 57, 58, 61, 136, 150]. In this study, we focused on engineering students' motivational beliefs and academic performance in a calculus-based introductory physics sequence and investigated the role played by students' perception of the inclusiveness of the learning environment (including sense of belonging, peer interaction and perceived recognition) in predicting their motivational beliefs (including self-efficacy, interest and overall physics identity, and overall engineering identity) and academic performance (measured by grades) at the end of this course sequence.

We found that there were statistically significant

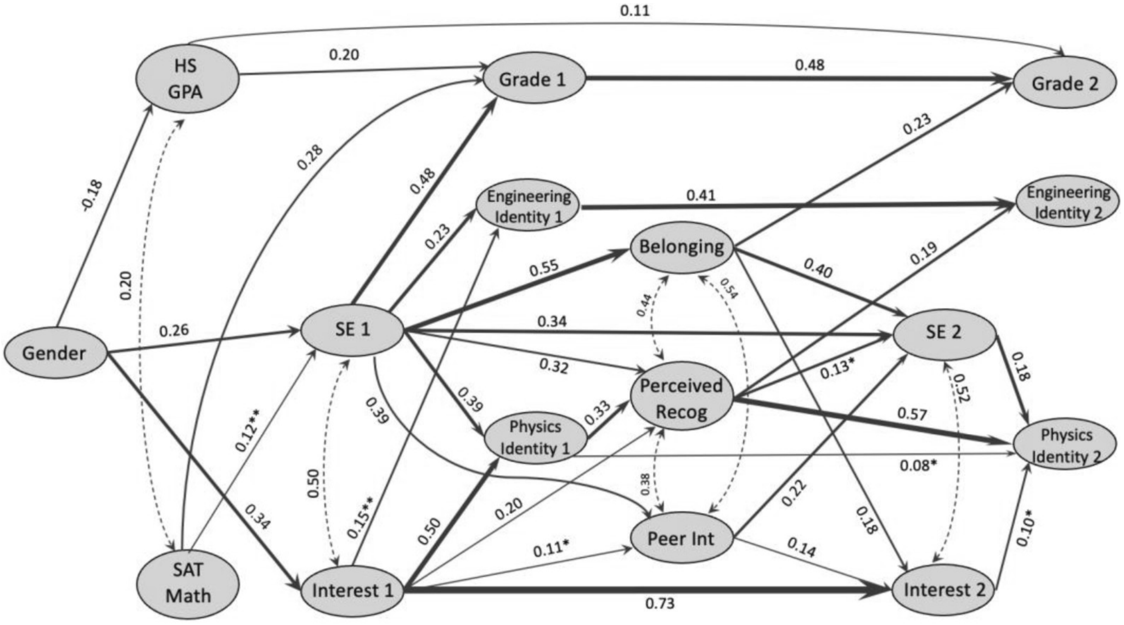

Fig. 3. Schematic diagram of the path analysis part of the SEM model. HS GPA represents high school GPA, SE represents self-efficacy, Perceived Recog represents perceived recognition, and Peer Int represents peer interaction. The solid lines represent regression paths and the dashed lines represent residual covariances. The regression line thickness corresponds to the magnitude of β value (standardized regression coefficient) with $0.01 \le p < 0.05$ indicated by * and $0.001 \le p < 0.01$ indicated by **. Other regression lines show relations with $p < 0.001$.

gender differences disadvantaging women in most motivational beliefs studied, which is consistent with prior studies [45, 53, 125]. Moreover, we found that, in the current learning environment, female students felt a lower sense of belonging and perceived recognition by their instructors/TAs than male students, and they also reported less benefit from peer interaction than men. However, we did not find gender difference in students' SAT math scores and female students actually had a somewhat higher average high school GPA than male students. Although female students had lower average grades in both physics 1 and physics 2, the gender differences in students' motivational beliefs and perception of the inclusiveness of the learning environment are much more pronounced than the gender differences in their course grades. This result is consistent with a prior study finding that in introductory physics courses, female students had significantly lower physics self-efficacy than their equally performing male peers [53]. Therefore, our study suggests that the largest gender differences were in students' motivational beliefs, rather than in actual physics performance. There could be several possible reasons for this phenomenon. For example, students' motivational beliefs can be impacted by how society sees the connection between gender and STEM achievement [27, 30, 31, 151]. One stereotype about physics is that only students who are very smart or have natural ability can do well in physics. This may make people think of physics as a masculine subject because, due to societal stereotypes, the words "brilliant" or "genius" are usually associated with men [44]. These negative stereotypes may deteriorate female students' physics self-efficacy and identity, and they may think they need to put more effort than men to succeed in physics [151]. In addition, some prior studies have shown that instructors may teach and interact with women and men in different ways, which may lead to gender disparity in course outcomes [107]. For example, if instructors do not call on female students to answer questions or do not express the same expectation and recognition as they do for male students, female students' motivational beliefs such as perceived recognition and sense of belonging may be negatively impacted.

In this study, we found that engineering students' academic performance and all motivational beliefs outcomes investigated (including the engineering identity) were statistically significantly predicted by at least one component of students' perception of inclusiveness of learning environment. In particular, out of the three inclusiveness of the learning environment constructs, sense of belonging is the major predictor of students' grades and self-efficacy at the end of the two-semester introductory physics sequence. One possible explanation for this result is that when students do not feel that they belong in the class, they may not fully participate in learning and discussions with others because they may not feel safe to share their ideas, which may influence their learning outcomes. Moreover, the lack of sense of belonging may also result in anxiety [152], which can rob students of their cognitive resources and reduce their level of cognitive engagement while learning. In addition, we found that engineering students' perceived recognition from others in the physics course not only predicts students' physics identity but also their engineering identity at the end of the course. This result suggests that the validation and acknowledgment received from peers and instructors in physics courses are instrumental in shaping a student's engineering identity, which is crucial for their persistence and success in the field of engineering. Moreover, we found that both male and female students' physics self-efficacy decreased from physics 1 to physics 2 and these decreases were partially mediated through the inclusiveness of the learning environment constructs, which indicates that the current learning environment may not positively help students develop their physics motivational beliefs. These results suggest the importance of an inclusive learning environment in developing students' motivational beliefs and improving their academic performance.

Our findings suggest that an inclusive learning environment is very important for equitable outcomes. As educators and instructors, we should make intentional efforts to develop an inclusive learning environment that emphasizes recognizing students for making progress, promoting positive peer interactions, and providing a space where all students can feel that they belong and students from all demographic groups can equally excel. For example, instructors can explicitly recognize students by directly acknowledging their work and expressing faith in their ability to excel. They can also implicitly recognize students by valuing students' opinions and assigning a leadership position or a challenging task to students in small groups that makes them feel excited [153]. In addition to positive recognition, instructors should be careful not to give unintended messages to students, e.g., praising some students for brilliance or intelligence as opposed to their effort since it may convey to other students that they do not have what is required to excel. In addition, belonging interventions that focus on improving the sense of belonging of underrepresented students in STEM courses have been found effective [154, 155]. Instructors can also tailor these short interventions in their classes to help all students develop positive motivational beliefs and learn physics equitably.

5. Conclusions

In this study, we investigated engineering students' motivational beliefs and course grades in a two-term college calculus-based introductory physics sequence (physics 1 and physics 2). We found that female engineering students' motivational beliefs and grades in the physics courses were statistically significantly lower than male engineering students. Our study shows that engineering students' perception of the inclusiveness of the learning environment plays an important role in predicting their grades and motivational beliefs (including engineering identity) and explaining the gender differences in these course outcomes. We found possible signatures of non-inclusive learning environment in that female students perceived significantly lower level of recognition and had lower sense of belonging. Thus, the instructor's focus on equity and inclusion, and approaches to recognizing students is vital in supporting women and promoting learning for all students in the classroom. Our study can be valuable for formulating guidelines for creating an inclusive learning environment in which all students can excel.

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APPENDIX: Multi-Group SEM Analysis

We conducted a multi-group analysis to examine whether the survey items were interpreted in a conceptually similar manner by female and male students, and whether the strength of relationships given by the standardized regression coefficients between any two constructs in the models differ for women and men.

We first tested for measurement invariance. In other words, we looked at whether the factor loadings, intercepts, and residual variances of the items are equal across gender in the model. To test measurement invariance, we ran a set of increasingly constrained models and tested the differences between these models. First, we examined the configural invariance model, in which the number of constructs and the correspondence between constructs and items are the same across gender groups, but all parameters can vary freely in each group. The result indicated that configural invariance holds (CFI = 0.909, TLI = 0.900, RMSEA = 0.056, SRMR = 0.055). Second, to test for "weak" measurement invariance, we ran the model in which the item loadings were constrained to be equal across gender groups, but intercepts and residual variances were allowed to vary between groups. According to a likelihood ratio test, there was no statistically significant difference between the weak invariance model and the configural invariance model, so the weak measurement invariance holds (Chi-square difference $\Delta\chi^2 = 17.712$, degree of freedom difference $\Delta dof = 21$, $p = 0.667$). The third step is testing for "strong" measurement invariance. We ran the model in which both the item loadings and intercepts were constrained to be equal across gender groups, but the residual variances were allowed to differ. A likelihood ratio test shows that there was no statistically significant difference between the strong invariance model and the weak invariance model ($\Delta\chi^2 = 21.613$, $\Delta dof = 21$, $p = 0.422$) or the configural invariance model ($\Delta\chi^2 = 39.324$, $\Delta dof = 42$, $p = 0.589$), so strong measurement invariance holds. Therefore, since strong measurement invariance holds for this model, we proceeded on to test for structural invariance.

Next, we ran a multi-group SEM in which all regression coefficients were constrained to be equal across gender groups in addition to the item loadings and intercepts. The model fit parameters for this model were acceptable (CFI = 0.908, TLI = 0.904, RMSEA = 0.055, SRMR = 0.065). According to the results of likelihood ratio tests, this model was not statistically significantly different from either the configural invariance model ($\Delta\chi^2 = 96.555$, $\Delta dof = 85$, $p = 0.184$) or the strong invariance model ($\Delta\chi^2 = 57.231$, $\Delta dof = 43$, $p = 0.072$). Thus, the regression pathways among the constructs do not have statistically significant differences across gender.

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