

Women have lower physics self-efficacy controlling for grades even in courses in which they outnumber men

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Self-efficacy has been shown to affect student engagement, learning, and persistence in various science, technology, engineering, and math (STEM) courses and majors. Additionally, prior research has shown that women have lower self-efficacy than men in STEM courses in which women are outnumbered by men. This study examines the self-efficacy of men and women with similar performance in two consecutive algebra-based introductory physics courses in which women make up two thirds of the students. These were mandatory courses at a large public university in the US taken primarily by bioscience majors, many of whom are interested in health professions. Our findings show a gender gap in self-efficacy disadvantaging women when controlling for course grades in both physics 1 and physics 2 both at the beginning and end of the course. Additionally, we find that most of the gender gap in self-efficacy is due to biased perceptions rather than performance in the courses.

I. INTRODUCTION

Many research studies have investigated motivational beliefs, such as self-efficacy and identity in different STEM domains, because they can influence students' continuation in STEM courses, majors, and careers [1-9]. Specifically, in the context of physics, many studies have focused on students in calculus-based courses, in which women are underrepresented [10-14]. These investigations have shown that women often have lower motivational beliefs than men at the beginning of the course sequence, and the self-efficacy gender gap increases by the end of traditionally taught courses [5,15,16]. However, few studies have focused on introductory physics courses for students on the bioscience track in which women outnumber men.

Even though women outnumber men in the introductory algebra-based physics courses for students on the bioscience track, pervasive societal stereotypes and biases about who can excel in physics can impact women's physics self-efficacy. One common stereotype is that genius and brilliance are important factors to succeed in physics [17]. Furthermore, the environment in many science classrooms can negatively impact women, including a pedagogy that favors male students' interests, a "chilly climate" for women, and a lack of female role models [18]. Therefore, although women are not underrepresented in physics courses for students on the bioscience track, these societal stereotypes can still impact their motivational beliefs in those courses.

One important motivational belief, self-efficacy, is a person's belief that they can succeed in a particular activity or course [19,20]. It has been shown to impact students' engagement, learning, and persistence in science courses as well as contribute to students' science identity [1-3,5,21-24]. Students with higher self-efficacy are more likely to embrace challenging goals, take on difficult tasks in their classes, and employ academic skills like goal-setting and self-monitoring [23]. Students with high self-efficacy in a domain are less likely to have anxiety that can rob them of cognitive resources while learning and test taking, since the working memory during problem solving has limited capacity [25]. Self-efficacy can also increase students' persistence in science majors and careers [26].

A self-efficacy gender gap disadvantaging women has been observed in calculus-based physics courses in which women are underrepresented [16,21,27]. These studies have found the gender gap in self-efficacy widens by the end of the course [2,16]. Stereotypes about who belongs in physics and can excel in it run deep in our society, so we must investigate if a similar gap exists when women are not numerical minorities in the classroom.

In this study, we investigate whether there is a similar gender gap in algebra-based introductory physics courses, in which women outnumber men. In particular, we investigated the gender gap in self-efficacy at matched performance

levels. It is important to examine whether physics self-efficacy reflects actual performance differences or whether the self-efficacy gender gap is, e.g., due to pervasive societal stereotypes and biases female students must contend with throughout their lifetime.

We answered the following research questions by analyzing data from a validated survey administered to students at a large public research university in the US in introductory algebra-based physics courses mainly for bioscience majors in which women outnumber men:

- RQ1** Are there gender differences in self-efficacy throughout a two-semester physics course sequence, controlling for student performance?
- RQ2** If there is a self-efficacy gender gap at the beginning of the first physics course, is the gap eliminated by the end of a year-long physics course sequence in which women outnumber men?
- RQ3** If there is a self-efficacy gender gap, is it a reflection of the performance differences by gender, or is there a gender gap beyond what is predicted by course performance, e.g., due to pervasive stereotypes and biases female students must contend with throughout their lifetime?

II. METHODOLOGY

The data were collected using a motivational survey drawing on prior work and validated by our group [16,28]. The survey was administered at a large, public, research university in the U.S. to students in a two-semester introductory physics sequence in which women outnumber men. The survey was administered in the recitation at the beginning (pre, in the first week of class) and end (post, in the last two weeks of classes) of physics 1 and physics 2. These two courses are generally taken in consecutive semesters. We analyzed data across two consecutive academic years from courses that are traditionally taught primarily using lectures with no explicit focus on equity and inclusion. The classes are typically taken as a requirement by students on the pre-health track (mainly students on the bioscience track) primarily in their junior or senior year of undergraduate studies. Both of these courses are mandatory physics courses for all biological sciences majors.

In this study, we analyzed 474 matched students (students who took the survey at both time points in physics 1 and physics 2). The university provided demographic information such as age, gender, and ethnicity/race 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 matched participants were 34% male and 66% female

TABLE I. The self-efficacy survey item along with factor loadings from the Confirmatory Factor Analysis (CFA) for all students (N = 474) in introductory algebra-based physics 1 and physics 2.

Self-Efficacy Survey Question	physics 1	physics 2
I am able to help my classmates with physics in the laboratory or in recitation.	0.581	0.672
I understand concepts I have studied in physics.	0.769	0.760
If I study, I will do well on a physics test.	0.730	0.762
If I encounter a setback in a physics exam, I can overcome it.	0.771	0.703

students. Thus, female students significantly outnumbered male students in these courses. We note that the data provided by the university only include binary options of male and female. We recognize that gender is not a binary construct and that students may identify differently by the time they are in this class. However, we are limited to the binary data here (less than 1% of the students did not provide this information and thus were not included in this study).

This study focused on students' responses to the physics self-efficacy survey items [4,29-31] in the motivational survey which included other items on other motivational beliefs such as physics perceived recognition, interest, identity, etc. The items in the study were designed on a Likert scale of 1 (low endorsement) to 4 (high endorsement) [32]. A lower score was indicative of a negative endorsement, while a higher score was related to a positive endorsement. The items for different motivational beliefs including self-efficacy were adapted from previously validated surveys [15,29,33-36] and re-validated in our own context using one-on-one student interviews (to ensure that students interpreted the survey items correctly), Exploratory Factor Analysis (EFA), Confirmatory Factor Analysis (CFA), [15], and Cronbach alpha [37]. Interviews with students suggest that they interpreted the items correctly. To ensure that items measured self-efficacy coherently and separately from other motivational constructs in the survey at the end of physics 1 and physics 2, an EFA was conducted. Additionally, we conducted a CFA with five motivational constructs in the broader survey. Since this study focuses only on the self-efficacy construct, the survey items and factor loadings for each self-efficacy item from the CFA are given in Table I. The Cronbach alpha was used to measure the internal consistency of the items. The Cronbach alpha is 0.78 for physics 1 and 0.82 for physics 2, which is considered reasonable by the standards of test design [37].

We obtained students' final grades in each course from the university and linked those to students' gender and self-efficacy via the honest broker process discussed earlier. For analysis, we grouped students into bins by grade ranges (i) C, C+; (ii) B-, B, B+ (iii) A-, A, A+. For convenience, we labeled these bins C, B, and A, respectively. We excluded students who received a C- or below since those grades are considered insufficient to move on to the next course for this mandatory course for students on the bioscience track.

We first compared female and male students' mean self-efficacy scores by grade bins for statistical significance using *t*-tests and for the effect size using Cohen's *d* [38]. Next, to determine whether there are gender differences in

self-efficacy controlling for grade, we performed a linear regression in which the dependent variable was students' average post self-efficacy score in physics 1 or physics 2 and the independent variables were the students' gender and grade at the end of the course [39].

III. RESULTS AND DISCUSSION

RQ1 Are there gender differences in self-efficacy throughout a two-semester physics course sequence controlling for student performance?

From Table II, we find that women have lower (for A and B grade bins) or comparable (for the C bin) average self-efficacy scores compared to men at the beginning and end of the course. Furthermore, Table II shows that women receiving A's have about the same self-efficacy as men who receive between a C and a B at the beginning of the course in physics 1. By the end of the course, women with A's have roughly the same self-efficacy as men with B's at the end of the course. Table II also shows that women's and men's average self-efficacy scores were stable (did not significantly change by the end of the semester) for the students who received A's in the course, i.e., the self-efficacy gender gap was maintained from the beginning to the end of the course. However, the average self-efficacy scores of both men and women decreased for those students who received B's or C's in the physics 1 course. The differences range from a large effect size (*d* greater than 0.50) to a medium effect size (*d* greater than 0.30) [38]. While the gender gap increased for students in the C bin, it was not statistically significant and therefore it would be important to do this study with more years of data.

Table III shows that women had lower self-efficacy scores than men in all grade bins at both the beginning and end of physics 2, but the gender difference was not statistically significant for students who received a C grade. By the end of physics 2, the only statistically significant difference in self-efficacy occurred for women and men in the A range with a medium to large effect size (Table III). This finding is different from a similar study in the calculus-based introductory physics courses (in which women are severely underrepresented) in which the physics self-efficacy gender gap increased from the beginning to the end of the course [16].

RQ2 If there is a self-efficacy gender gap at the beginning of the first physics course, is the gap eliminated by the end of a year-long physics course sequence in which women outnumber men?

At the beginning of physics 1, women who receive A's have lower self-efficacy than men who receive B's (Table II). By the end of the course sequence, women with A's have the same self-efficacy as men with grades between B and A (see Table III). Table II and Table III show that the self-efficacy gender gap was not eliminated by the end of a year-long course sequence. The gender gap is maintained for students who received an A grade and the self-efficacy scores decreased for students in the B and C bins.

These findings suggest that there is a need to make the physics learning environment equitable and inclusive in order to improve the self-efficacy over the course of the semester in both physics 1 and physics 2 and close the gender gap. It is important to note that women had lower self-efficacy scores than men in many of the grade bins (as evidenced by both the pre and post-tests scores) even though they outnumber men in the course. We hypothesize that this disparity is due to the deep-rooted societal stereotypes and biases about who can excel in physics that women must contend with from an early age starting long before they step into the college physics classroom.

RQ3 *If there is a self-efficacy gender gap, is it a reflection of the performance differences by gender, or is there a gender gap beyond what is predicted by course performance, e.g., due to pervasive stereotypes and biases female students must contend with throughout their lifetime?*

We investigated the fraction of the self-efficacy gender gap that is related to students' course performance versus other factors. First, we controlled for students' self-efficacy in each course with multiple variable regression, including an interaction effect between grade and gender (see Eq. (1)). The interaction effect (β_3) between gender and grade was not a significant predictor for self-efficacy in either physics

$$\text{Post self-efficacy} = \beta_1 \times (\text{gender}) + \beta_2 \times (\text{grade}) + \beta_3 \times (\text{grade} \times \text{gender}) + \text{const} \quad (1)$$

1 ($\beta_3 = -0.08, p = 0.221$) or physics 2 ($\beta_3 = 0.02, p = 0.299$) and thus was omitted in subsequent analyses.

In physics 1, a significant overall regression correlation was found ($F(2,471) = 47.96, p < 0.001$) for post self-efficacy scores with main effects from both gender, $\beta_1 = 0.21$ ($p < 0.001$), and final grade, $\beta_2 = 0.33$ ($p < 0.001$) [38]. Additionally, in physics 2, a significant overall regression correlation was found ($F(2, 471) = 34.78, p < 0.001$) for post self-efficacy scores with main effects from gender, $\beta_1 = 0.15$ ($p = 0.003$), and final grade, $\beta_2 = 0.23$ ($p < 0.001$). Gender is coded 0 for female students or 1 for male students, and grade is reported continuously from 1-4. Both gender and grade were significant predictors of students' average self-efficacy in both physics 1 and physics 2 even though women make up a numerical majority in these introductory physics courses.

Next, we found the raw average post self-efficacy differences between women and men to be 0.28 ($p < 0.001$) in physics 1 and 0.20 ($p < 0.001$) in physics 2 in favor of men. Then we compared the raw post self-efficacy differences to the mean values of the gender gap in self-efficacy (β_1 , from the multiple linear regression). The mean values of the gender gap were lower than the raw post self-efficacy differences in physics 1 (0.21 vs 0.28, respectively) and physics 2 (0.15 vs 0.20, respectively). Thus, while a small portion of the gap in self-efficacy can be attributed to performance in the course, the self-efficacy gender gap mainly comes from factors other than performance in the class: 75% in both physics 1 and physics 2 (see Fig 1). Our theoretical framework suggests that the factor may be women's biased perceptions of how well they can do similar to the findings in calculus-based introductory courses in

TABLE II. Self-efficacy scores in physics 1 by grade bin for female and male students. N = number of students, Pre = mean pre self-efficacy score, Post = mean post self-efficacy score, along with Cohen's d and p -values for the gender differences in pre and post scores for each grade bin (all statistically significant gender differences have been bolded).

Physics 1 Self-Efficacy by Grade									
	C			B			A		
	Pre	Post	N	Pre	Post	N	Pre	Post	N
Men	2.78	2.65	15	3.07	2.92	52	3.09	3.10	95
Women	2.79	2.43	37	2.76	2.58	143	2.90	2.96	131
Cohen's d	-0.01	0.36		0.65	0.60		0.40	0.30	
p-value	0.966	0.252		<0.001	<0.001		0.003	0.027	

TABLE III. Self-efficacy scores in physics 2 by grade bin for female and male students. N = number of students, Pre = mean pre self-efficacy score, Post = mean post self-efficacy score along with Cohen's d and p -values for the gender differences in pre and post scores for each grade bin (all statistically significant gender differences have been bolded).

Physics 2 Self-Efficacy by Grade									
	C			B			A		
	Pre	Post	N	Pre	Post	N	Pre	Post	N
Men	2.88	2.64	26	3.00	2.74	51	3.10	3.10	79
Women	2.69	2.50	68	2.73	2.68	117	2.89	2.88	117
Cohen's d	0.40	0.27		0.56	0.10		0.51	0.50	
p-value	0.085	0.244		<0.001	0.561		<0.001	<0.001	

Physics 1 & 2

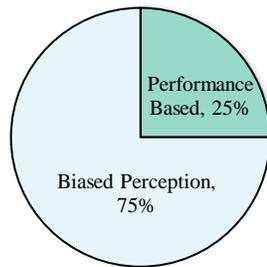


FIG. 1 Relative contributions of performance and biased perception to the post self-efficacy gender gap in physics 1 and physics 2 for bioscience majors in which women outnumber men.

which women are severely underrepresented [16]. In particular, even in these algebra-based courses where women make up the majority of the students, we theorize that biased beliefs about who can excel in physics that are pervasive in our society can affect women's self-efficacy.

IV. IMPLICATIONS AND FUTURE DIRECTIONS

The physics self-efficacy gender gap we found at equal grade levels may appear unexpected since women are not underrepresented in these introductory physics courses for students on the bioscience track (for whom both these physics 1 and physics 2 courses are mandatory). However, we hypothesize that the societal stereotypes and biases about who can excel in physics that women from a young age are bombarded with and how they are treated in both formal and informal environments pertaining to these issues are at the heart of the gender gap in physics self-efficacy in these courses. In particular, not only are female students exposed to gendered views of physics in informal situations growing up e.g., from shows such as the Big Bang Theory or their family and friends [40], they are also often treated differently and given differential advice by K-12 educators and guidance counselors [41].

Our finding is important because it shows that issues related to gender differences in physics self-efficacy are systemic and should not only be attributed to women being outnumbered in a physics class. Furthermore, the physics learning environment even in a course in which women outnumber men does not close the self-efficacy gender gap at the end of the course. This issue needs to be addressed since self-efficacy has been shown to affect students' persistence and long-term outcomes [23]. In particular, a student's lower self-efficacy can cause anxiety and deteriorate their performance, which can then weaken their self-efficacy further. However, there appears to be some benefit to having a large cohort of women in these introductory physics courses for students on the bioscience

track compared to calculus-based introductory physics courses in which women are underrepresented. We find that the percent of the gender gap attributed to biased perception does not change significantly from physics 1 to physics 2 (Fig. 1). However, the percent of the gender gap in introductory calculus-based physics courses in which women are severely underrepresented attributed to biased perception started lower in physics 1 and gets worse in physics 2 [16]. Nevertheless, since women still have lower self-efficacy than men in these courses controlling for grade, there is an urgent need to create an equitable and inclusive learning environment to bridge the self-efficacy gender gap.

In particular, evidence-based equitable and inclusive pedagogical strategies are necessary to eliminate the gender gap in self-efficacy and raise the self-efficacy of all students. However, some active learning pedagogies could decrease women's self-efficacy if they are not implemented with equity and inclusion as central constructs. For example, in one study in engineering, women working in mixed gender cooperative groups tended to be undermined by their male classmates and played a less active role in those groups [22]. In another study, students in physics courses that utilized active engagement strategies performed better than students in lecture-based courses; however, the gender gap in performance on conceptual surveys persisted and even became worse in some cases [42]. In relation to self-efficacy, some interactive engagement physics courses have been shown to decrease women's self-efficacy [2] whereas others have been shown to improve women's self-efficacy [43]. Therefore, the instructor/TA needs to ensure that all students feel like they belong, have a high self-efficacy, and can contribute equally. One strategy physics instructors can use to encourage equal contribution in a group is to assign each student a role that rotates throughout the course. However, this approach in itself is unlikely to be effective in eliminating the self-efficacy gender gap if the learning environment is otherwise not equitable and inclusive.

A field-tested strategy to make the learning environment equitable and inclusive is through classroom interventions [44-46]. In particular, social-psychological classroom interventions, e.g., sense of belonging and mindset interventions, have been shown to eliminate gender performance gaps [45,47]. At the same time, these interventions can help students develop positive feelings of being recognized by their peers, TAs, and instructors. These types of interventions are not very time consuming but require instructors to develop the mindset that all their students have the potential to excel in physics if they create an inclusive learning environment. These interventions could be adapted and their effectiveness investigated for the introductory physics courses discussed here.

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