Large gender differences in physics self-efficacy at equal performance levels: A warning sign?

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Abstract. Self-efficacy, or the belief in one's capability to succeed in a particular task, course, or subject area, has been shown to influence students' learning outcomes and career decisions. Previous studies have shown that female students have lower self-efficacy than males in physics courses. However, few studies have focused on gender differences in self-efficacy at equal performance levels, which also vary by gender. We examined the self-efficacy by gender at matched achievement levels in introductory physics courses and found large self-efficacy differences. Implications of the self-efficacy differences for similarly performing males and females are discussed.

I. INTRODUCTION AND BACKGROUND

Advances in science and technology are often the result of diverse perspectives and collaborations that produce novel ideas. While some efforts have been made to enhance diversity in science, technology, engineering, and mathematics (STEM) fields in the last several decades, the number of women pursuing physical science and engineering careers has not changed significantly within the last decade [1]. For example, since 2000, women have earned approximately 20% of the bachelor's degrees awarded in physics and engineering, with a similar under-representation at the Masters and PhD levels [1]. Although there have been many studies about underrepresentation of women, the primary reasons for the low participation of females in physics and engineering fields have not been fully explained.

The introductory level physics sequence is one of the gateway courses for students who intend to pursue engineering or physical science majors. Therefore, female students' experiences and motivational characteristics in these physics courses can likely play a significant role in their early college experience, academic achievement, and their persistence in the STEM majors. Although the various efforts in physics education have enhanced learning, the enrollment rate of female students in the physics major or physics classes continues to be small [2].

Prior research posits that students' decision to pursue a STEM careers and continue to persist in STEM fields are affected by several factors, including their prior preparation and skills, quality of teaching and type of teaching approaches, sociocultural factors, and motivational factors [3]. In particular, research indicates that factors which impact different facets of motivation can at least partly explain the underrepresentation of women in physics and other STEM fields [3]. In this regard, students' motivational characteristics in physics classes are some of the factors that can account for the lack of diversity in physics. For example, students' self-efficacy, or their belief in their capability to succeed in a particular task, course, or subject area can impact students' persistence, engagement and course performance [4]. Self-efficacy, in particular, can have large long-term effects because it can thrust a student into a negative or positive feedback loop. As students complete their short-term goals (e.g., complete a physics course requirement for a physical science or engineering major), they obtain feedback about their performance that can further shape their self-efficacy. Research suggests that for a variety of reasons, self-efficacy beliefs can constrain performance in science courses even after controlling for students' prior knowledge and skills [5]. For example, students with a high self-efficacy are more likely to exhibit effective learning strategies such as self-monitoring or metacognition [4,6,7] and tend to make more efficient use of problem-solving strategies and time-management [6]. In addition, students with high self-efficacy are less likely to reject correct hypotheses prematurely and tend to be better at solving conceptual problems than students with low self-efficacy but equal performance [8]. As a result, the feedback loops can be very different for the high and low self-efficacy cases and higher initial self-efficacy can produce higher performance which can further strengthen self-efficacy. By contrast, lower initial self-efficacy can produce lower performance which can further weaken a student'sself-efficacy.

Prior research has shown that women, on average, have lower self-efficacy than men in physics and other STEM domains [6,7,9]. Several studies have found that self-efficacy can shape students' interest [6], influence level of engagement and affect performance even after controlling for prior knowledge and background differences [5]. Research has mostly focused on the gender differences in learning outcomes and/or gender gap in students' physics related self-efficacy [10,11].

Given the interactions between performance and self-efficacy, we aim to investigate whether differences exist at matched performance levels. In particular, we focus on an understudied form of the self-efficacy gender gap: self-efficacy differences within equal performance levels in introductory physics courses. Differences in self-efficacy even within similarly performing males and females can have many detrimental effects. A large underestimation of one's capability and/or performance can impact interest and goals. For example, female students inaccurately perceiving that they are not capable of succeeding in a STEM field can lead to decreased interest in STEM disciplines and underrepresentation of females in STEM fields [3,12,13]. Therefore, we examined similarly performing female and male students' self-efficacy differences in introductory-level physics courses, using final course grades as a performance marker. In particular, we focus on the following research question: Controlling for course performance (final grades), what are the relative self-efficacies of female and male students throughout a two-semester physics course sequence?

II. METHODOLOGY

To investigate the self-efficacy of students with similar performance outcomes in physics, we administered a self-efficacy survey in several sections of a two-course calculus-based introductory physics sequence. We collected data across two consecutive academic years. We obtained "gender" information from the university records which includes female, male and unidentified. Less than 1% of the students in our data did not identify their gender. Although our data are binary and potentially focused on biological sex, we acknowledge that gender is multi-dimensional and sociocultural in nature.

Participants were students enrolled in 9 sections of two large introductory physics courses in a two-semester sequence. This calculus-based physics sequence is typically taken by engineering and physical science majors as required courses. The topics in Physics 1 consist of kinematics and force concepts, work and energy, and oscillation and waves whereas Physics 2 focuses on topics such as electricity and magnetism, electromagnetic waves, and optics. Both courses have four hours of lecture and one hour of recitation per week. In regard to teaching methodology, we administered the self-efficacy survey in courses varying in their instructional formats: either traditional lecture-based or more active engagement methods. The research participants are composed of engineering students and physical science majors and consist of approximately 32% female students.

We administered self-efficacy survey during the recitations. Instructors were encouraged to give a small amount of course credit to students for completing the surveys to ensure that the students took the survey seriously. The number of participants in the self-efficacy survey is given in Table I. In Physics 1, students responded to the post self-efficacy survey after they received their course (letter) grade. In Physics 2, students responded to the self-efficacy survey before they receive their course grade, although they had already received substantial course performance data (e.g., earlier mid-terms and assignments) such that their rough grade was likely known at the time of the survey. The number of students is different at each time point since some students were not present in the recitation when the survey was given or some students did not take Physics 2 in the following term. When the analysis is performed using only matched students, the results are qualitatively similar.

Our self-efficacy survey is adapted from other validated instruments and has been used in our prior work [11]. The survey was iteratively improved and validated via exploratory factor analysis and individual interviews with introductory level and graduate students. The final version of the self-efficacy survey items is shown in Table II.

Table I. The number of students completing the self-efficacy survey as posttest for Physics 1 and Physics 2.

Course	Posttest
Physics 1	N=914
Physics 2	N=630

Table II. The physics self-efficacy survey. One item is reverse coded and indicated with an (R).

<table>
<tr><th>Survey Item</th><th>Response options</th></tr>
<tr><td>I can complete the physics activities I get in a lab class</td><td>Rarely
Half of the time
Most of the time
All of the time</td></tr>
<tr><td>If I went to a museum, I could figure out what is being shown about physics in:</td><td>None of it
A few areas
Most areas
All areas</td></tr>
<tr><td>I am often able to help my classmates with physics in the laboratory or in recitation.</td><td rowspan="4">No!
no
yes
Yes!</td></tr>
<tr><td>I get a sinking feeling when I think of trying to tackle difficult physics problems. (R)</td></tr>
<tr><td>If I wanted to, I could be good at doing physics research.</td></tr>
<tr><td>If I study, I will do well on a physics test.</td></tr>
</table>

Table III. The number of students (N) who responded to the self-efficacy survey, binned by letter grade along with the percentage of female (F) students in that bin. Students who had below a C are not included in this table.

Course	C, C+	B-, B, B+	A-, A
Physics 1	N=220 40% F	N=253 32% F	N=136 30% F
Physics 2	N=203 34% F	N=245 36% F	N=108 25% F

We obtained students' course grades in Physics 1 and 2 in order to determine performance groups. We grouped students into bins by their grades as follows: 1) C- and below is considered insufficient to move on to the next course so we did not include this group in our analysis presented here, 2) C and C+, 3) B-, B, B+, and 4) A-, A, A+. The number of students in each grade bin is shown in Table III.

To determine whether there are differences in the self-efficacy of female and male students, controlling for performance on physics conceptual surveys, we performed a 2 (gender: male vs female) by 3 (grade: A, B, C) between subjects ANOVA in which the dependent variable was students' average post self-efficacy score in either Physics 1 or Physics 2 and the independent variables were gender and the grade bin. Within each grade bin, we also calculated the effect size (Cohen's d [$d = (\mu_1-\mu_2)/\sigma_{pooled}$]) [14] between male and female students' average self-efficacy scores to compare the differences in two groups' means.

III. RESULTS

We found substantial gender gaps in self-efficacy scores within all three grade bins (C, B, A). In Physics 1, female students' self-efficacy was significantly lower than that of male students collapsed across all performance groups ($F(1,608) = 66.31$, $p<.0001$)) [15]. In addition to the gender effect, there was also the expected main effect of course grade bin ($F(2,607) = 43.06$, $p<.0001$)) [15] but no significant interaction between the gender and grade ($F(2,607) = 1.65$, $p = 0.19$)) [15]. In other words, students who earned higher grade reported higher self-efficacy. As shown in Figure 1, the effect sizes for self-efficacy differences in Physics 1 are above 0.60, which indicate a medium to large gender gap in self-efficacy regardless of course grade bin. Figure 1 also shows the relative sizes of grade and gender on self-efficacy: female students receiving an A grade had similar self-efficacy as males receiving a B grade.

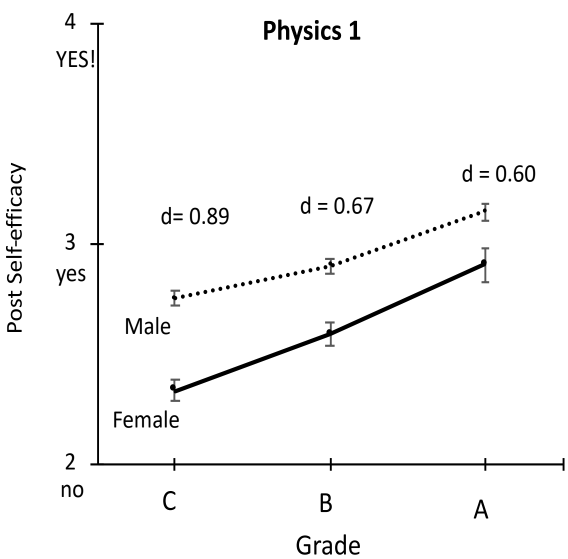

Figure 1. Post self-efficacy scores of female and male students binned by course grade (A, B, C) in Physics 1 courses (Error bars represent standard error of the mean).

For Physics 2, we observed similar patterns as with Physics 1. Male students had a higher self-efficacy than female students within each grade bin and the effect sizes for the self-efficacy gender gap are roughly similar within all three performance groups (C, B, A). The ANOVA revealed that female students' self-efficacy was significantly lower than male students' ($F(1,555) = 52.44$, $p < .0001$))[15] in addition to the significant effect of course grade ($F(2,554) = 21.32$, $p < .0001$)) [15]. There was no significant interaction of grade by gender in that the effect of gender on self-efficacy does not change based on the course grade ($F(2,554) = 1.14$, $p = 0.32$) [15]. However, in Physics 2, Figure 2 shows a greater gender effect relative to performance bin effect: women who received A grades had similar self-efficacy scores as men receiving C grades.

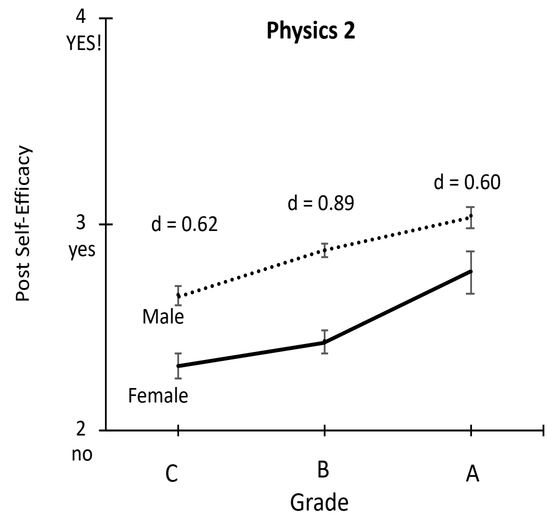

Figure 2. Post self-efficacy scores of female and male students binned by course grade (A, B, C) in Physics 2 courses (Error bars represent standard error of the mean).

IV. DISCUSSION AND SUMMARY

Our findings show that female students have significantly lower self-efficacy than male students. The gender gap in self-efficacy for every matched performance group in Physics 1 continues to persist in Physics 2. Thus, the findings suggest that the gender gap is not reduced from Physics 1 to Physics 2.

There are both short and long-term implications of our findings that similarly performing women in physical sciences and engineering have lower self-efficacy than men because it has the potential to thrust women into a negative feedback loop. For example, the lower self-efficacy can act as an internal stereotype threat [16] in these STEM disciplines in which women are underrepresented and can negatively impact their current and future performance. In fact, it is possible that women in this study would have performed even better in physics than they actually did if their self-efficacy was higher because self-efficacy gaps may produce higher levels of anxiety during exams, negatively impacting their performance (i.e., we may have underestimated the true self-efficacy bias by gender). Moreover, since students often consider course exams as a high-stakes assessment and attribute the letter grade obtained to their academic success, lower self-efficacy may increase the anxiety more in higher stakes tests, so women may perform even worse in high stakes situations.

In addition, self-efficacy issues have been shown to impact interest [6], and high achieving females may begin to lose interest in engineering and physical science due to their inaccurate assessment of their capability in physics. This decreased interest and the lower self-efficacy may even trigger female students to devote less time to their homework or studying in general, or even to drop out of physics courses or decide to exit the STEM major track altogether.

The self-efficacy gap may further influence even the students who choose to continue in physical science and engineering beyond the first year. For example, female students may not take advantage of opportunities that can help them reach their long-term goals at the same rate as equally qualified male students. These competent women may not apply for selective fellowships, grants, and/or internships at the same rate as equally qualified males, even though these experiences can greatly enhance their resumes and the probability of being selected for these [17]. Even in interview situations at various stages, highly qualified female students in the physical sciences and engineering may also have difficulties in promoting their strengths if they undervalue their skills, performance, and capabilities. Female students with excellent credentials who undervalue their ability and performance may feel that they are "lucky" to land an interview, especially in highly competitive fields. During the interview, these females may feel that they are "faking it" because they feel like they are not qualified for the job [17]. These difficulties may arise especially in male-dominated fields such as the physical sciences. In addition, highly qualified females may shy away from competitive situations due to their low self-efficacy. In laboratory settings, there are large gender differences in the propensity to compete when controlling for prior performance—females are much less likely to compete than males [18]. Thus, even high achieving women in physics may discredit their capabilities and undervalue their performance, possibly resulting in their exit from the physical science or engineering track altogether after graduation to non-STEM careers.

The findings also have implications in the very long-term when searching for and landing a physical science or engineering career. Women may shy away from applying for top-level positions in these STEM fields since they will have to compete with men [18]. Bargaining situations may also prove to be difficult, even for highly qualified females. Research suggests that females' insecurity about their abilities, skills, and credentials may prevent them from negotiating their salary and other benefits at the time of hire, and females do not as readily ask for salary raises, promotions, and other perks as males [17]. The gender differences in salary and other benefits at the initial time of hire, even if small, can result in large gaps in salary and other perks and productivity over the course of one's career.

The results suggest that it is imperative to reflect on ways to improve the situation, including implementing strategies to improve the environments of introductory physics courses to help female students improve their self-efficacy so that it better reflects their actual skills, knowledge and performance. Our future work will focus on developing and implementing activities aimed at improving students' self-efficacy and sense of belonging in introductory physics courses.

ACKNOWLEDGMENTS

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[1] https://www.nsf.gov/statistics/2017/nsf17310/data.cfm; https://www.aip.org/statistics/data-graphics/percent-physics-bachelors-and-phds-earned-women-classes-1975-through-2016

[2] E. Brewe, V. Sawtelle, L. Kramer, G. O'Brien, I. Rodriquez and P. Pamela, Phys. Rev. ST PER **6**, 010106 (2010).

[3] E. Seymour and N.M. Hewitt, Westview Press (1997).

[4] P. Pintrich, Journal of Educational Psychology **95**, 667 (2003).

[5] S. Britner, and F. Pajares, J. Res. Sci. Teach. **43,** 485 (2006).

[6] B. Zimmerman, Contemporary Educational Psychology **25**, 82 (2000).

[7] A. Bandura, Organizational Behavior and Human Decision Processes **50**, 248 (1991).

[8] T. Bouffard-Bouchard, S. Parent, and S. Larivee, Int. J. of Behavioral Development **14**, 153 (1991).

[9] P. Huang and S. Brainard, Journal of Women and Minorities in Science and Engineering **7**, 314 (2001).

[10] A. Cavallo and W. Potter, M. Rozman, School Sci. and Math. **104**, 288 (2004).

[11] E. Marshman, Z. Y. Kalender, T. J. Nokes-Malach, C. Schunn and C. Singh, Can. J. Phys. **96**, 391 (2017).

[12] A. Zeldin, and F. Pajares, American Educational Research Journal **37**, 215 (2000).

[13] J. S. Eccles et al, Psychology of Women Quarterly **18**, 585 (1994).

[14] J. Cohen, L. Erlbaum Associates (1998).

[15] R.G. Lomax, Lawrence Erlbaum Associates, (2007).

[16] C. M. Steele, and J. Aronson, J. of Personality and Social Psychology **69**, 797 (1995).

[17] L. Babcock and S. Laschever, Bantom Books, NY (2007).

[18] L. Vesterlund and M. Niederle, Quarterly J. of Economics **122**, 1067 (2007).