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Active Learning in an Inequitable Learning Environment Can Increase the Gender Performance Gap: The Negative Impact of Stereotype Threat

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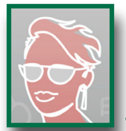

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In the past few decades, educators and physics education researchers have been developing and evaluating instructional approaches designed to improve students' conceptual understanding and problem-solving skills in physics for students with different prior preparation and backgrounds.[1-3] These instructional approaches often require students to be active participants in their learning,[4] and are often developed through research, which provides evidence for their effectiveness. Hence, we refer to them as "Evidence-Based Active Engagement" (EBAE) strategies.

While EBAE strategies have often been shown to improve learning outcomes on average for all students taken together (e.g., improved learning gains on conceptual assessments such as the Conceptual Survey of Electricity and Magnetism or CSEM[5]), relatively little research has been devoted to investigating the extent to which EBAE strategies benefit students from different demographics, e.g., women and men, equally. For example, much has been written in recent years about a gender gap, i.e., a performance difference often found between male and female students (with male students performing better) on conceptual assessments, and to a lesser extent, sometimes on exam scores and overall course performance.[6-10] Research has also revealed that these differences are at least in part due to stereotype threat, the anxiety associated with conforming to a negative stereotype (e.g., people expecting men to generally perform better in physics than women), resulting in reduced performance of members of the stereotyped group.[11-18] Prior research has also found that female students have lower self-efficacy than male students despite similar grades and exam performance,[19-22] while other research studies have reported on other aspects of how gender relates to performance and persistence in physics.[23-27] It is possible that while students on average benefit from EBAE instruction, not all student demographics benefit equally, and some groups may obtain a larger benefit from use of these strategies than others.

Here, we summarize two research studies on the gender gap since they have important implications for physics teaching. One study compared the gender gap on the CSEM survey in calculus-based college introductory courses that primarily make use of lecture-based (LB) instruction (i.e., instructor lectured 90% or more of the class) with courses that make significant use of EBAE strategies.[9] The EBAE courses included flipped courses in which students watched lecture videos at home and answered a pre-lecture assignment before coming to class, and class time was used for clicker questions involving peer discussions and lecture demonstrations preceded by questions and collaborative problem solving in which students worked in groups of two to three on quantitative problems. The second study focused on stereotype threat associated with gender stereotypes in physics and its impact on student performance on the CSEM.[14] In particular, we investigated the extent to which agreeing with a gender stereotype (i.e., I expect men to generally perform better in physics than women) correlates with performance on the CSEM. We focus on calculus-based introductory physics courses taken by engineering, physical science, and mathematics majors in which female students are severely underrepresented. The demographic information of students in these courses is: gender – 67% male and 33% female, race – 77% White, 11% Asian, 4% Latinx, 4% Multiracial, 3% Black, and 1% Other.

Gender gap remains constant in LB courses, but increases in EBAE courses

Table I shows that the gender gap on the CSEM remains relatively constant in LB courses (4% at the beginning and 6% at the end), and both male and female students exhibit similar normalized gains on the CSEM (18% and 22% for female and male students, respectively). For EBAE courses, the gender gap increases significantly from 4% to 10%, which is also reflected in the effect sizes comparing male and female student CSEM performance: 0.27 on the pretest and 0.54 on the posttest, i.e., the effect size doubles. Also, the data suggest that while both men and women benefit from EBAE instruction (larger normalized gains in EBAE courses compared to LB courses), male students benefit disproportionately more than female students: the normalized gain for male students in EBAE courses is 39% compared to only 28% for female students. Normalized gain[4] is defined as

$$\frac{<post> - <pre>}{100\% - <pre>},$$

where $<pre>$ and $<post>$ are the class averages on the pretest and posttest (in %), respectively, and provides information about how much students learned beyond what they knew at the beginning of the semester. We also calculated the effect size in the form of Cohen's d, defined as

$$\frac{\mu_2 - \mu_1}{\sigma_{\text{pooled}}},$$

where μ_1 and μ_2 are the averages of the two groups being compared and $\sigma_{\text{pooled}} = \sqrt{(\sigma_1^2 + \sigma_2^2)/2}$ (here σ_1 and σ_2 are the standard deviations of the two groups being compared). We considered $d < 0.5$ as small effect size, $0.5 \leq d < 0.8$ as medium effect size, and $d \geq 0.8$ as large effect size, as described in Ref.

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Table I. CSEM pre/posttest averages (Mean) and standard deviations (SD) for second-semester male and female students in introductory calculus-based LB and EBAE Physics 2 courses. The total number of students in each group, *N*, is shown. For both pretest and posttest, *p* values indicate that male students significantly outperform female students both in LB and EBAE courses. In LB courses, the normalized gains of male and female students are comparable (female students 18%, male students 22%), but in EBAE courses, the normalized gain of male students is larger than that of the female students (female students 28%, male students 39%).

Type of Class	CSEM	Female	Gender Comparison	Male
LB	Pretest	*N*: 84 Mean: 34% SD: 13%	*p*-value: 0.007 ← **gender gap: 4%** → Eff. Size: 0.35	*N*: 234 Mean: 38% SD: 13%
	Posttest	*N*: 78 Mean: 45% SD: 16%	*p*-value: 0.003 ← **gender gap: 6%** → Eff. Size: 0.38	*N*: 248 Mean: 51% SD: 17%
EBAE	Pretest	*N*: 112 Mean: 35% SD: 14%	*p*-value: 0.017 ← **gender gap: 4%** → Eff. Size: 0.27	*N*: 220 Mean: 39% SD: 16%
	Posttest	*N*: 98 Mean: 53% SD: 18%	*p*-value: <0.001 ← **gender gap: 10%** → Eff. Size: 0.54	*N*: 193 Mean: 63% SD: 19%

28. The data shown in Table I are based on two LB courses and two EBAE courses at a typical large research university in the United States.

One potential reason for this increase in gender gap in EBAE courses compared to LB courses is that in EBAE courses collaborative learning played an important part of the student learning environment. Although collaborative learning in diverse groups can greatly improve the outcome, this is likely to happen only if the environment is equitable and promotes and supports participation from all students regardless of their gender and ethnicity. In particular, in a collaborative environment, the possibility of stereotype threat becoming even more salient and the underrepresented groups not contributing optimally is high if equity and inclusion are not kept at the center of the design of collaborative environments. Therefore, in a subsequent study, we investigated whether women in physics courses are more likely to experience stereotype threat, and the extent to which this may be correlated with their deteriorated performance.

Female students who agreed with the gender stereotype performed significantly worse on the CSEM, but *only* on the posttest

Students in separate LB courses from those in Table I (also calculus-based introductory Physics 2 courses) were asked to indicate the extent to which they agree with a gender stereotype: "According to my own personal beliefs, I expect men to generally perform better in physics than women" with five options from strongly disagree to strongly agree. This question was used and validated in an earlier study,[29] and we also conducted our own validation with student interviews, which indicated that there were no confusions about what the question was asking. This question was asked after students completed the CSEM so that this task did not interfere with their performance on the CSEM, because asking students to consider the stereotype may activate or exacerbate the existing stereotype threat for women. The results for calculus-based Physics 2 are shown in Table II. Table II shows that there is no statistically significant performance difference for male students who agree vs. those who disagree with the stereotype both in the pretest and in the posttest. However, while at the beginning of the semester there is no performance gap between female students who agree with the stereotype compared to those who do not, at the end of the semester female students who agree with the stereotype performed significantly worse than female students who disagree with it (note that agreeing or disagreeing with the stereotype was the only difference between women in the two groups).

Discussion and summary

We find that the gender gap on the CSEM increases significantly in college calculus-based introductory physics courses taught using EBAE methods although students in EBAE courses, on average, perform better compared to LB courses. We also find that when asked about a gender stereotype, while there is no statistically significant difference on the pretest between female students who agree or disagree with the stereotype, on the posttest, female students who agree with the stereotype perform significantly worse than female students who disagree with the stereotype.

Much has been written about stereotype threat,[11-18] namely, the anxiety associated with conforming to a stereotype can make the performance in a particular task more likely to conform to the stereotype. Cognitive scientists[30-33] have argued

Table II. Numbers of introductory calculus-based Physics 2 students (*N*), averages (Mean), and standard deviations (SD) for the performance on the CSEM in pre/posttests of female and male students who agree/disagree with the gender stereotype. The *p* values (*p*) and effect sizes (Eff. Size) shown underneath the performance of female/male students for each class type were obtained when comparing the average performance of female/male students who agree with that of female/male students who disagree with the stereotype. These students answered the stereotype question after taking the CSEM.

	PRETEST		POSTTEST	
	Female	Male	Female	Male
Disagree	*N*: 191 Mean: 35% SD: 14%	*N*: 388 Mean: 40% SD: 14%	*N*: 140 Mean: 50% SD: 18%	*N*: 288 Mean: 58% SD: 19%
Comparison	↑ *p*: 0.233 Eff. Size: 0.24 ↓	↑ *p*: 0.954 Eff. Size: 0.01 ↓	↑ *p*: 0.020 Eff. Size: 0.5 ↓	↑ *p*: 0.185 Eff. Size: 0.28 ↓
Agree	*N*: 20 Mean: 33% SD: 10%	*N*: 37 Mean: 40% SD: 18%	*N*: 23 Mean: 42% SD: 14%	*N*: 29 Mean: 64% SD: 23%

that the anxiety associated with conforming to a stereotype is essentially a threat, and it can take up part of the working memory, thus robbing an individual of cognitive resources that could be used for problem solving and learning. Moreover, the anxiety can also lead to procrastination or less time spent on learning as well as reduced engagement and use of effective study strategies (and asking for help). Prior research has suggested that a certain level of stereotype threat may be implicitly present for female students in an introductory physics course.[18] Our findings suggest that female students endorsing a gender stereotype may be undergoing additional stereotype threat (over and above what might already be present for many women). Over the course of the semester, this can have a significant negative impact, especially in a calculus-based course in which women are underrepresented.

Thus, in order to help all students learn physics, it is not sufficient for physics instructors to use EBAE instruction. Instructors must also attend to students' motivational constructs, such as self-efficacy, social belonging, growth mindset, and anxiety, and create an equitable and and inclusive learning environment.[34-37] It is important to recognize that all these factors are interrelated[38] and one cannot address any one in isolation of the others, but fortunately many interventions have been described in the literature that can help physics instructors in designing an equitable and inclusive instructional environment.[39-48] Below, we list several approaches described in the literature.

• ***Help promote a growth mindset:*** Promoting a growth mindset[41] can have a long-lasting impact on students' persistence and motivation. Students can read short articles that emphasize that learning is making new neural connections; in other words, the brain is like a muscle that grows stronger from practicing effective learning strategies. Yeager and Dweck[45] describe an intervention in which students read such an article that promoted "a formula for growing your brain: Effort + Good strategies + Help from others." Students in the intervention exhibited higher achievement and completion rates in challenging math courses. Paunesku et al.[42] found similar results with a similar intervention. Articles such as the ones used in these interventions can easily be found online; here is one example.[46] Note that promoting a growth mindset also helps with students' self-efficacy, because it helps students recognize that anybody could be good at physics, it just takes engaging in effective practice, working with others, and getting immediate feedback, which EBAE courses encourage.

• ***Provide narratives to scaffold students' experiences with adversity:*** Research has found that students' sense of belonging can be improved by providing narratives that help them recognize that the path to success is a journey with a beginning, middle, and an end.[40] Along that path, some struggles will be encountered but they will be overcome with effort and using struggle as a learning opportunity. One successful intervention[44] asks students at the beginning of the course to write about their worries about being in the physics class and then asked to discuss in small groups with peers what they are worried about, and later each group can share these with the entire class. The exercise helps students recognize that they are not alone in what they worry about, as many of the worries discussed by the groups will be common. They are also shown quotes from students who have excelled in the course that describe their own struggles and how they used them as stepping stones to excelling in the course and took advantage of their peers, TA, and instructor and focused on deliberate learning.

• ***Reduce stress and anxiety by promoting participation from all students:*** Students from underrepresented backgrounds in physics can often become isolated, or even shunned by their peers.[36] Creating groups in the context of using collaborative learning in a course can help significantly.[36] Others have suggested that incorporating a self-affirmation activity[29,47] can help reduce stress. Self-affirmation theory suggests that if people are reminded of positive aspects of themselves, it can help them see negative events as less threatening and reduce stress. A physics classroom can be a threatening environment for students who have low self-efficacy. Cohen and colleagues[47] designed an intervention in which White and Black students wrote about values that were important to them as well as why those values were important. This short writing exercise had striking results: by the end of the first semester, Black students earned significantly higher grades than their peers in the control condition (who wrote about values important to someone else), reducing the gap between White and Black students by 40%.

In summary, since stereotypes rely on an assumption that people have immutable characteristics, e.g., intelligence, doing interventions that emphasize growth mindset (e.g., mindset that intelligence is malleable and brain is a muscle that can grow with effort) and the importance of effort and productive struggle, while at the same time providing students with ample opportunity to practice appropriate skills and engage in good learning strategies, have the potential to improve the learning and performance of all students. Thus, instructors can empower all their students and create an ecological learning environment in which students are not fearful of being judged by the instructor and peers when they make mistakes. Instead they are proud to make mistakes and they view their mistakes as a learning opportunity. Indeed, these types of positive classroom transformations hinge strongly on the instructor having a growth mindset about their students' potential,[48] having high expectations from all students and assuring them that they can meet those high goals by working hard and working smart and embracing their failure as a stepping stone to learning physics.

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