Successful Interventions to Eliminate Achievement Gaps in STEM Courses

Larrabee, Tracy
larrabee@ucsc.edu
UC Santa Cruz

Norouzi, Narges
nanorouz@ucsc.edu
UC Santa Cruz

Robinson, Carmen
crobins3@ucsc.edu
UC Santa Cruz

Quynn, Jenny
jquynn@ucsc.edu
UC Santa Cruz

***Abstract*—At our institution equity gaps persist between student subgroup populations in STEM courses, mirroring a nationally recognized trend in higher education. This research applies backward design to explore the size of those gaps and reasons for differences in achievement between 1) female versus male, 2) first generation versus non-first generation, 3) LatinX versus non-LatinX, and 4) EOP versus non-EOP student groups. During her career, the first author of this paper designed and applied a comprehensive teaching approach to her large, undergraduate, Computer Science theory course. Careful analysis reveals three main categories of pedagogical practice used during lecture: role modeling, demonstrating productive failure, and illuminating stereotype threat. Five quarters of experimentation, revision, and application of these practices produce promising results for reducing equity gaps. Course design and learning theories from the educational literature are explored and provide the framework the authors use to explore and explain findings.**

***Keywords*—Computer science education, Equity gap, Gateway courses, STEM majors, Intervention, Role modeling, Productive failure.**

I. Introduction

Disparity or differences in performance between student subgroup populations, such as differences between genders or differences between races [1], allows for predicting which students entering university are more likely to be successful in a certain course, successfully declare a STEM major [2], and graduate with a STEM degree. Disparity, or the gap between student performance by subgroup is evidence that crucial knowledge and critical thinking skills are not equitably distributed among students and are reserved for, or limited to, students whose backgrounds and experiences continue historical patterns [3]. Disparity allows for predicting which students will lead the nation when it comes to thinking technically and creatively, designing solutions that will save our species, and other species, and preserve life on our planet [4].

Believing that it is possible to know which students will make the greatest contributions to STEM fields limits what is possible for students at a time when the nation needs to expand possibilities and build inclusive environments where students can exercise problem solving skills and tackle the most historic and pressing challenges of their time [5]. Predicting who among us will be our future STEM leaders divides communities and society along technical lines and discourages Discipline-Based Education Research (DBER) to spread STEM content and higher-order problem solving skills [6].

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DBER offers a framework for considering disparity in STEM education by applying inquiry to create solutions that will close performance gaps, revealing solutions for inclusive and effective teaching practices that will ultimately impact the everyday decisions of people across the nation [7] and around the world [8]. Institutional data often replicates historical patterns confirming that STEM knowledge and skill are practiced by certain students. And institutional data can be used to redefine the nature of the work and program quality by the institutional data are evidence of the effectiveness of the invitation to study STEM, and that programs are creating louder, bolder, clearer messages of inclusion and student-centered teaching.

Along with many others, the authors of this paper desire to support learning, achievement, and equity within their courses and across degree programs, and to reduce indicators of disparity. To do this, they have consulted the educational literature, identified and tested our own DBER learning theories, participated in campus teaching community workshops, and consulted with others about their teaching methods and experiences. We try a variety of things, keeping our eyes on student performance by subgroup within our courses at our institution, the University of California, Santa Cruz. Our hope is to understand how students achieve by subgroup, particularly in our large, STEM gateway courses that have been identified as barriers to persistence for undergraduate students [9].

Recently, and with cautious optimism, we identified a course where student background could not be used to predict student performance by subgroup. This paper applies a backward design approach [10] to explore elements of the course that may explain reduction in achievement gaps. Guided by literature and grounded in theory on student-centered teaching practices [11] and growth mindset [12], the authors explain course design, teaching, and assessment practices. This paper is not intended to be prescriptive. The authors do not claim to have a recipe for all-inclusive teaching or that eliminating equity gaps is as easy as following a recipe. This paper is not a formula for success, but rather an opportunity for the authors to explore and explain a teaching practice in the context of equity gaps.

The term persistence, has been used in the educational literature to explain student success [13] and specifically in the study of STEM education [14]. However, the term persistence, which sounds like resilience, suggests a quality of the learner. In writing this paper, the authors consider the implications of using student qualities to describe outcomes in the face of disparity indicators and choose instead to unpack the learning experiences of students and instructors and use of data to improve student engagement [15], motivation, and learning, and to support all students to achieve. This paper intends to offer information to other instructors and degree programs that are working to develop a new analytical unit of study, student experience or satisfaction, as a more valid predictor of student success.

II. Course Outline

The focus course for this paper is "Applied Discrete Mathematics" that concentrates on mathematics for computer science. In addition to the mathematical core, there is substantial emphasis on application. For example, when discussing modular arithmetic, cryptology comes up, and the importance of proofs by induction in algorithms and asymptotics is emphasized. The course covers sets, logic, proofs, combinatorics, functions, and relations, but the emphasis throughout the course is on mathematical rigor and proof. This class is a traditional large-lecture class with ten weeks of homework and quizzes followed by a final exam.

The course moves quickly, with a semester's worth of topics packed into ten weeks, but the start of the course involves making sure that all the students, who have very different preparations, have the same basic foundation in sets and logic. In the first weeks, there are frequent allusions to deeper explorations of interesting material and equally frequent opportunities for students to gauge their mastery. For example, when the students are asked to provide the combinatorial argument for Pascal's identity (which can be found online), they are required to try it themselves before accessing the many wonderful online explanations. When the students hand in their solutions, the instructor and TAs cannot know which students looked up the solutions without attempting the problem first.

For every lecture there are one or two "Questions of the Day" (which the students call QotDs). For this students are not only given the problems, but they are told that if they can handle various parts of the problem without resorting to looking up the answer, they are showing mastery of the material. The instructor talks to students about the importance of private self-evaluation. The QotD answers are handed in with the weekly homework, but students do not hand in their self-evaluations. Sometimes a QotD will be used as a short pair-and-share activity in class, where students speak with each other in small groups, finishing the problems later, outside of class. The weekly quizzes often visit QotD, or other homework problems.

III. Methodology

We have examined different interventions to close the equity gap in CS gateway courses. The main author of this study, recently, after five quarters of steady improvement and constant experimentation with teaching methods, was able to close the gap between the grades of her underrepresented minority and first-generation college students and the rest of the class. In the latest approach, the author used a three-pronged approach described in the following sections.

A. Role Modeling

The first intervention identified is diversity within a teaching team approach. The teaching team is identified as the professor or instructor, four Teaching Assistants (TAs) and four Modified Supplemental Instructors (MSIs). During the past five quarters that this course was offered, half of the teaching team was female and the teaching team was diverse. From the literature, a unified, collaborative, and diversified teaching environment supports student engagement, sense of belonging, and achievement [16].

B. Productive Failure

Aligned with growth mindset [12], the instructor used lecture to incorporate the notion of failure as the appropriate path to learning, incorporating failure into problem solving as typical. The instructor normalized failing with statements like "Engineering majors are hard; it's good to fail the first time you attempt a problem." and "People who fail at a problem the first time tend to retain things better than those who luck into the right answer" [17].

In practice, TAs did not take points off on homework for arriving at the wrong answer. The homework policy is based on effort and students understand that they are expected to try and that parallel homework problems will show up on the weekly quiz that is graded. Students have the responsibility for learning the content through problem solving. To help students do this, students are supported by the teaching team, making help more accessible. A video of lecture is posted for students as well as links to Khan Academy and other sources for outside help on the course website. The instructor is also available during office hours and monitors online forums where students ask and answer questions. In addition to instructor's availability, TAs and tutors hold regular office hours and/or individual and group tutoring sessions.

C. Modeling Self-Compassion

Steele and Aaronson coined the term "stereotype threat" in 1995 to mean "being at risk of confirming, as self-characteristic, a negative stereotype about one's group" [18]. Stereotype threat is an issue for underrepresented students as it can cause grade sensitivity. The danger is that students may fail an exam and instead of considering becoming more engaged with the course such as putting in more study time, they believe the failure is confirmation that they don't belong and become at risk of withdrawing.

The final tactic was to explicitly discuss the stereotype threat. An African American MSI tutor in one Section of the course — who was an extremely high achieving students selected to provide supplemental tutoring to others — told the instructor that it was like having a light bulb go on for him. Until the instructor addressed the issue in class, he felt as if he did not belong in a STEM major, but after stereotype threat was discussed, he quickly realized it wasn't that he was unsuited for engineering, but that the material is hard for everyone. In addition to the instructor's in-class efforts to raise awareness about the concept of stereotype threat, the School of Engineering at our institution has had other successes in bringing disadvantaged populations closer to parity. The Multicultural Engineering Program (MEP), which serves approximately 291 of the school's 4,234 declared undergraduate majors, has also closed the gap significantly.

IV. Data and Results

Institutional data identifies STEM gateway courses that demonstrate at least one of four equity gaps meaning that when students in a STEM course are divided into two cohorts, the average grade of one cohort is statistically significantly lower than the other cohort. The four equity gaps are represented by cohorts 1) female vs. male, 2) first-generation vs. non-first-generation, 3) LatinX vs. non-LatinX, and 4) EOP vs. non-EOP (At our institution, an EOP student is one who has been identified as having educational disadvantages via family income, first-generation status, attended historically underperforming schools, are currently in the military, were raised in a foster family, or are undocumented students). Many students are represented in all four Equity measures (such as a female, Latina, first generation, former foster-child). At our institution, large STEM lecture courses tend to demonstrate all four of these equity gaps. Tables below show historical course demographics by quarter for all cohorts under study. The data represented here have been collected from the "Applied Discrete Mathematics" course from Fall 2014 to Summer 2018.

TABLE I
TABLE 1. PERCENTAGE OF DIFFERENT GENDERS BY QUARTER

Gender	*Fall*	*Spring*	*Summer*	*Winter*
F	19.6%	21.12%	20.66%	20.64%
M	80.4%	77.68%	79.34%	77.74%
U		21.12%		20.64%

TABLE II
TABLE 2. PERCENTAGE OF FIRST GENERATION STATUS STUDENTS BY QUARTER

First Gen	*Fall*	*Spring*	*Summer*	*Winter*
N	66.58%	70.13%	70.40%	72.93%
Y	33.42%	29.87%	29.60%	27.07%

TABLE III
TABLE 3. REPORTED STUDENT ETHNICITY BY QUARTER

Ethnicity	*Fall*	*Spring*	*Summer*	*Winter*
Asian	2.45%	1.21%	0.0%	1.13%
LatinX	19.66%	16.12%	23.21%	14.61%
International	7.79%	10.09%	14.29%	8.79%
Two or more	6.16%	5.54%	0.0%	7.52%
Unknown/Unspecified	1.63%	1.85%	0.0%	2.70%
Caucasian	28.8%	27.13%	32.14%	26.88%

TABLE IV
TABLE 4. PERCENTAGE OF EOP-STATUS STUDENTS BY QUARTER

EOP	*Fall*	*Spring*	*Summer*	*Winter*
N	68.74%	74.86%	70.40%	73.22%
Y	31.26%	25.14%	29.60%	26.78%

In order to compare the effect of the methodology described earlier, we have compared the GPA of each cohort under study in the "Applied Discrete Mathematics" course with two other STEM courses (a mathematics class and a computer science class). In the graphs below, we illustrated the Hispanic/LatinX versus Caucasian Equity gap. A similar pattern has been observed when comparing female versus male, first-generation versus non-first-generation, and EOP versus non-EOP equity gaps.

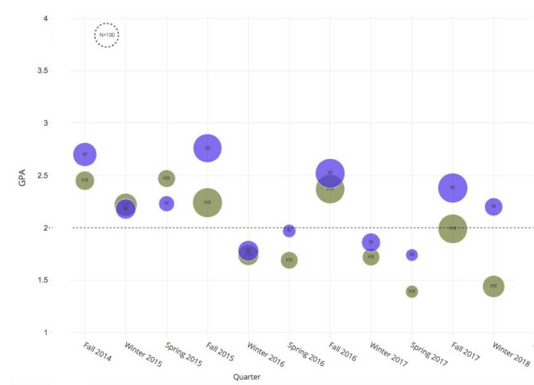

Fig. 1. GPA by Ethnicity: Latinx vs. Caucasian in a Mathematics class

Fig. 2. GPA by Ethnicity: Latinx vs. Caucasian in a Computer Science class

As illustrated in Figure 3, after incorporating the set of interventions in the Applied Discrete Mathematics course, the course presents none of the four Equity gaps. One of the previously marked Equity gaps is shown in Figure 3.

V. Discussion

Addressing disparity or differences in student achievement between student subgroups requires the appropriate data, apply institutional support, and a willingness to acknowledge

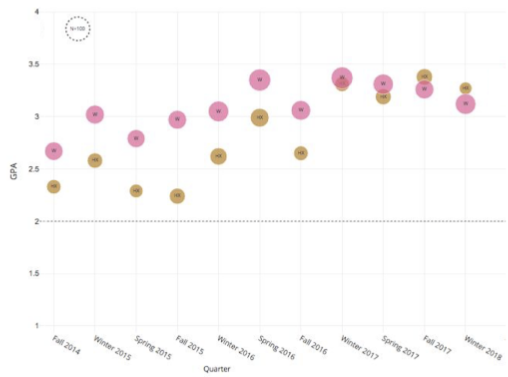

Fig. 3. GPA by Ethnicity: Latinx vs. Caucasian in a Mathematics class

gaps exist. Having looked at disparity indicators for different gateway courses over several quarters, it was only recently there was the opportunity to apply backward design to explain success.

Looking for disparity indicators within a course or gaps in achievement by subgroup should be a process that takes place over time, using data from several quarters and from the same course and instructor. The authors of this study intend to continue to follow disparity patterns for this course and explore the design of a disparity index. This index would capture more general levels of student achievement using mean average and standard deviation of student scores, and allow for instructors to share indicators along with their pedagogical theories and practices as a way to explain student achievement. This will work for STEM instructors and programs interested in examining gaps, eyes wide open. The data in this paper, and accompanying analysis, represent a beginning point for meaningful, course, program, and institutional discussions related to teaching practices and course design, and not only how to account for disparity, but how to talk about gaps based on evidence. One trend is notable – the higher the overall average score in the course, the smaller the achievement gaps between subgroups of students. This finding is consistent with student achievement data from other engineering courses. The authors of this study intend to expand on this project and investigate additional data trends that relate to teaching for inclusion and designing equitable assessment practices.

VI. Acknowledgments

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