Fostering Equitable Outcomes in Introductory Biology Courses through Use of a Dual Domain Pedagogy

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ABSTRACT

Recent studies demonstrate that significant learning gains can be achieved when instructors take intentional steps to address the affective components of learning. While such efforts enhance the outcomes of all students, they are particularly beneficial for students from underrepresented groups and can reduce performance gaps. In the present study, we examined whether intentional efforts to address the affective domain of learning (through growth mindset messaging) can synergize with best practices for addressing the cognitive domain (via active-learning strategies) to enhance academic outcomes in biology courses. We compared the impact of this two-pronged approach (known as dual domain pedagogy, or DDP) with that of two other pedagogies (lecture only or active learning only). Our results demonstrate that DDP is a powerful tool for narrowing performance gaps. DDP, but not active learning, eliminated the performance gap observed between Black and white students in response to lecture. While a significant gap between white and Latin@ students was observed in response to active learning (but not lecture), this gap was reduced by DDP. These findings demonstrate that DDP is an effective approach for promoting a more equitable classroom and can foster learning outcomes that supersede those conferred by active learning alone.

INTRODUCTION

Science, technology, engineering, and mathematics (STEM) educators have made noteworthy progress in identifying best practices for advancing students to higher levels of learning within the cognitive domain of Bloom's taxonomy (Bloom, 1956; Freeman *et al.*, 2014). An abundance of data now indicates that significant learning gains are achieved—particularly those that foster the mindset of a scientist—when instructor-centric pedagogies are replaced with student-centered learning strategies (Crouch and Mazur, 2001; Knight and Wood, 2005; Bauer-Dantoin, 2008; Blanchard *et al.*, 2010; Freeman *et al.*, 2014). Active-learning strategies can take on a variety of forms in STEM classrooms (e.g., problem-based learning, case studies, inquiry-based laboratories, writing), but all have the common characteristic of actively engaging students in the learning process, as students work—often in groups—to gather and organize data, critically analyze data, and draw conclusions. Active-learning pedagogies thus prompt students to understand and engage in science as a process, rather than as a collection of facts, and thereby help students to develop the higher-order thinking skills and behaviors of a scientist (empirical, systematic, collaborative). Given the powerful impact of active-learning strategies on student learning, the American Association for the Advancement of Science (AAAS) issued a national "call to action" in 2011 for science educators, challenging them to reform undergraduate biology courses and curricula through incorporation of "first-rate, student-centered learning" pedagogies. In so doing, educators will "ensure that the biology we teach reflects the biology we practice" (AAAS, 2011). Likewise, in 2012, the President's Council of

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Advisors on Science and Technology recommended the widespread adoption of these "empirically validated teaching practices" (PCAST, 2012).

While active-learning strategies enhance the learning outcomes of all students, they have a disproportionate benefit for students from underrepresented groups, who are economically disadvantaged, who are first generation, and/or who are considered high-risk students (Haak *et al.*, 2011; Freeman *et al.*, 2014). Many explanations have been offered for the positive impact of student-centered learning strategies on the academic outcomes of underrepresented students. The enhanced course structure associated with active-learning interventions has been cited as one potential explanation (Haak *et al.*, 2011). Active-learning interventions require greater preclass preparation and typically involve completion of more homework assignments (Freeman *et al.*, 2014), and thus students are receiving more structure and guidance from their instructors regarding the need for explicit practice to deepen their learning. Indeed, Eddy and Hogan (2014) found that active-learning interventions that have a "moderate structure" are more effective than "low structure" interventions for enhancing the academic outcomes of Black and first-generation students. In response to "moderate structure" interventions, students were more likely to engage in distributive practice, rather than cramming, as their primary learning strategy. They were also more likely to engage with the topics of interest not just during class, but before and after as well. Thus, active learning may close performance gaps by providing the necessary structure and explicit guidance needed to engage *all* students in practices that foster higher levels of learning within Bloom's cognitive domain (Bloom, 1956).

Active-learning strategies may also close achievement gaps because they are a powerful tool for addressing the affective components of learning. During active-learning interventions, underrepresented students—who often do not see themselves reflected in the curriculum or the faculty—have the opportunity to feel a stronger sense of community and belonging (Eddy and Hogan, 2014), as they engage in scientific thinking with a peer group (Graham *et al.*, 2013) and begin to identify as scientists. Consistent with this theory are the findings of Ballen *et al.* (2017), who observed that an increase in self-efficacy mediates the positive effects of active learning on underrepresented minority (URM) student performance in introductory biology courses. Thus, active learning may close performance gaps in STEM classrooms not only because it effectively addresses the cognitive domain of learning for all students, but also because it indirectly addresses another important domain of learning identified by Bloom, namely, the affective domain (Krathwohl *et al.*, 1956).

The affective domain of learning—originally described by Bloom and colleagues in 1956 along with the cognitive and psychomotor domains—refers to the actions, feelings, and thoughts students develop as a result of the instructional process. The affective domain is considered to be the gateway to learning, because students' feelings and attitudes about themselves, about particular subject matter, and/or about a particular context influence their motivation and willingness to engage in their course work (Dweck, 2006; Yeager and Dweck, 2012; Graham *et al.*, 2013; Albarracin and Shavitt, 2018). To positively influence students' behaviors in this regard, STEM educators have focused efforts on identifying effective classroom interventions that positively influence students' attitudes about their ability to be scientists (Lopatto, 2008; Ballen *et al.*, 2017) and their sense of belonging in STEM classrooms (Ballen *et al.*, 2017) and that inspire them about their subject matter (Lopatto, 2004; Seymour *et al.*, 2004).

Increasing evidence suggests that classroom interventions designed to intentionally address Bloom's affective domain of learning are powerful tools for enhancing underrepresented student outcomes. Students from underrepresented groups can feel stigmatized and/or uncertain about their social belonging in science classrooms (Walton and Cohen, 2007, 2011). Given that URM students can sometimes be stereotyped and marginalized based on ethnic group, socioeconomic class, and/or gender, they may feel unsure about whether they will be fully included or that their contributions will be valued (Steele, 1997; Aronson *et al*., 2002). This uncertainty can undermine academic performance (Walton and Cohen, 2007), presumably because negative feelings influence attitude (Van Kleef *et al.*, 2014), which then undermines motivation and performance. Interventions that target students' feelings and beliefs about their academic abilities and social belonging can lead to significant academic gains (Yeager *et al.*, 2016). For example, when African-American freshmen receive messages that lessen psychological perceptions of threat on campus, they exhibit significantly higher grades than control groups by their senior year, and achievement gaps are halved (Yeager and Walton, 2011). Other strategies that show promise for bolstering the affective components of learning in URM students include opportunities to engage in self-affirmation writing exercises (Cohen *et al.*, 2006), peer mentoring and learning communities (both reviewed in Light, 2013), community outreach and service learning (Segarra *et al.*, 2015), and receiving growth mindset messages—namely, being taught that intelligence can grow and improve with effort and good strategies (Aronson *et al.*, 2002; Yeager *et al.*, 2013).

This last strategy—the use of growth mindset messaging—is now being studied in higher education classrooms and holds great potential for promoting a more inclusive academic environment. Extensive studies in the K–12 setting and preliminary studies in higher education indicate that, when students in math and science classrooms are exposed to instructional approaches that foster a growth mindset, they are more likely to respond resiliently to challenges and show greater learning and achievement in the face of difficulty compared with students who retain a fixed mindset (namely, who believe intelligence is finite and unchangeable; Dweck, 2006; Blackwell *et al.*, 2007; Yeager and Dweck, 2012; Yeager *et al.*, 2013). For example, when students enrolled in an undergraduate mathematics course receive frequent messages about the malleability of intelligence, they exhibit measurable increases in the number of problems attempted and in the rate of progression (an indicator of motivation) to mathematical proficiency (Williams *et al.*, 2013). Conversely, messages that convey a fixed mindset have the capacity to activate stereotype threat, and students' exam scores can decline by as much as 30% (Spencer *et al.*, 1999). Indeed, Canning *et al.* (2019) recently demonstrated that STEM faculty with fixed mindsets have achievement gaps among racial/ethnic groups in their courses that are twice as large as

TABLE 1. Pedagogy descriptions, year(s) employed, and number of students assessed under each condition

Pedagogy (experimental condition)	Description	Number of students	Years in which pedagogy was employed
Lecture	Course material in lecture sections was delivered through traditional didactic lecture. Laboratory sections were taught primarily with the use of "cookbook" exercises.	1908	2010–2014
Active learning	In lecture sections, at least 25% of course material was delivered through student-centered learning strategies. Laboratory sections were taught primarily with guided inquiry.	311	2016
DDP	In addition to employing the same best practices that were used in the active-learning condition to address the cognitive domain of learning, weekly growth mindset messaging was employed to address the affective domain of learning.	604	2015, 2017

those of STEM faculty with growth mindsets. When professors have fixed mindset beliefs, it is likely that they structure courses and communicate in a way that negatively influences students' motivation and achievement in their courses. Indeed, research has demonstrated that when stigmatized students expect to be stereotyped, they experience less belonging and trust and become less interested (Emerson and Murphy, 2015; Bian *et al.*, 2018).

Recent studies suggest that growth mindset interventions are particularly effective in enhancing academic performance when coupled with classroom strategies that teach students the skills and habits of mind necessary for success in their discipline/profession (Blackwell *et al.*, 2007; Yeager and Dweck, 2012). In other words, when classroom approaches that directly address the affective domain of learning are coupled with teaching strategies that most effectively address the cognitive domain of learning (namely, student-centered pedagogies), highly synergistic effects on student outcomes can be observed. A potential explanation for this was recently given by Cavanagh *et al.* (2018), who found a significant relationship between students' growth mindset and other important variables, such as trust in their instructors and their commitment to active learning. It may be the case that, when students view their intelligence as malleable—and when they have a high level of trust in their instructors, as result of intentional growth mindset messages from their instructors—they may exhibit deeper engagement with active learning and, consequently, may reap more of the benefits.

Given the potential for synergy between classroom approaches that most effectively address the cognitive domain of learning and those that intentionally address the affective domain, we conducted the present study, in which we examined the impact of a novel dual domain pedagogy (DDP) on student academic performance in two courses: an introductory biology course that serves as a gateway to the major and a general education biology course for nonmajors. In both courses, DDP instructors employed best practices for addressing the cognitive domain of learning (i.e., active-learning strategies) while also intentionally addressing the affective domain of learning through regular and frequent use of growth mindset messaging. Results from our study demonstrate a powerful effect of DDP on closing or narrowing performance gaps among certain racial/ethnic subpopulations in introductory biology courses. This pedagogy can confer advantages that supersede those of active learning only, providing further evidence for the importance of directly addressing the affective components of learning for student success.

METHODS

Our study was approved by the High Point University Institutional Review Board (IRB #201509-396). Refer to Table 1 for a summary description of the pedagogies investigated in our study, the number of students assessed under each condition, and the year(s) in which the impact of each pedagogical approach was assessed.

Context

The impact of pedagogy on student academic performance was examined in two courses: a one-semester foundation course within the biology major, taken by a mixed population of students (biology majors, exercise science majors, biochemistry majors, and psychology majors) during the Fall semester of their freshman year (BIO 1399: Introduction to Biological Principles and Literature I: Cellular and Molecular Processes); and a biology course for nonmajors that meets the natural sciences requirement within High Point University's general education curriculum (BIO 1100: Biology: A Human Perspective). Both courses have lecture and laboratory components. In BIO 1399 and 1100, lecture enrollments are capped at 36 and 50 students, respectively. In both courses, laboratory enrollments are capped at 18 students. Lecture sections for both courses meet for either three 50-minute periods per week or two 75-minute periods per week. Weekly laboratory sections are 3 hours in length for BIO 1399 and 2 hours in length for BIO 1100.

During Fall semesters, multiple sections (six to 12) of each course are taught by several different instructors. While additional sections of both courses are offered during Spring semester, these sections are often populated by students who are taking the course for a second time in order to improve their grades. Thus, only data from sections offered during Fall semesters were analyzed in the present study.

Instruction within BIO 1399 sections is tightly coordinated through weekly instructor meetings to ensure that learning outcomes pertaining to both scientific content (cell biology, molecular biology, and genetics) and inquiry are addressed uniformly among sections. Given that learning outcomes in the general education course for nonmajors (BIO 1100) focus on scientific inquiry (and not on a specific content area of biology), there is greater variability in the topics covered from section to section, depending on the instructor's area of expertise. The common thread among BIO 1100 sections is exposure to scientific inquiry within both lecture and laboratory sections.

Both BIO 1100 and BIO 1399 are open to students regardless of the number of years they have been enrolled at the university, but the majority of those enrolled are first-year college students (60 and 95%, respectively). Given that BIO 1100 is a nonmajors general education course, students enrolled represent a variety of majors from across campus that fall outside the sciences. The opposite is true for BIO 1399, which serves as a foundation course in biology and other science majors. The most common majors of students enrolled in BIO 1399 are biology, exercise science, biochemistry, and psychology. The combined student demographics for both courses stayed relatively fixed during the years of the study and were as follows: 77% white, 6.2% Black, 5.4% Latin@, 3.5% mixed descent, 1.8% Asian, 1.1% Native American, and 5% of either undeclared race/ethnicity or international origin. In our statistical analyses, we restricted our examination of the impact of pedagogy (lecture, active learning, or DDP) on academic performance to those racial/ethnic groups that had a sufficient sample size in each cohort. These racial/ethnic groups included students who identified as either white, Black, Latin@, Asian, or of mixed descent.

Fifty-nine percent of students participating in the study identified as female, 40% as male, and 1% as unspecified gender. Data were not available that allowed us to identify study participants who were first-generation college students.

The measure of academic performance used in the study was final course grades. Final grades were determined similarly in both BIO 1100 and BIO 1399 for the active-learning and DDP conditions, with four exams counting for ~60% of final grades, discussion participation counting for 10%, and laboratory performance (determined by pre- and postlab quizzes, lab practicals, and the quality of experiment completion) counting for 30%. During the prior years in which the course was taught via lecture, final grades were determined through performance on two to three exams (70% of final grades) and in lab through performance on worksheets and lab practicals (30% of final grade).

Population-Specific Student Learning in Response to DDP, Traditional Lecture, or Active Learning

From 2010 to 2014 (the lecture-only condition), BIO 1399 and BIO 1100 were taught with traditional lecture delivery, and laboratory sections for each course were predominantly "cookbook" in nature. Then, in 2015—the year in which DDP was first implemented—both courses were revised significantly. Active-learning strategies were incorporated into the curriculum of lecture sections to more effectively address the cognitive domain of learning. We defined active-learning strategies as those teaching approaches that directly involve students in the learning process. These strategies took a variety of forms (e.g., problem-based learning, case studies, discussions of the primary scientific literature, online problem sets that are later discussed in class), and instructors were free to employ the active-learning strategies that best fit their teaching styles. Instructors worked collaboratively to design student-centered approaches to learning that addressed course outcomes and enhanced course rigor, with the goal of devoting at least 25% of class time (an amount that all agreed was reasonably achieved) in lecture sections to active learning.

Laboratory curricula for both courses were also substantially revised in 2015 and moved from predominantly "cookbook" approaches to guided inquiry in order to provide students with greater exposure to the scientific method. For example, before 2015, students studied enzyme activity with a "cookbook lab" in which they were instructed to treat a starch solution with amylase or water. Students then used starch and glucose indicators to measure the level of starch hydrolysis for each treatment. All instructions were provided for setting up and completing the experiment. Starting in 2015, students studied enzyme activity with a guided-inquiry lab in which they measured the rate of catalase activity on hydrogen peroxide reduction. Students first established a rate of reaction for catalase from potato juice that is exposed to 3% hydrogen peroxide. They then designed experiments of their own that tested the effects of one of the following variables on enzyme activity: substrate (hydrogen peroxide) concentration, temperature, pH, or salt concentration. Students set up their experiments, measured reaction rates, and interpreted the effects of their variables on enzyme activity.

In addition to implementing best practices to address the cognitive domain of learning in BIO 1399 and BIO 1100, we also employed practices that intentionally addressed the affective domain of learning in 2015 and 2017. This took place through the infusion of classroom discussions and course materials with growth mindset messages. Messages that emphasize the malleability of intelligence and the importance of hard work combined with the strategic use of resources were included in course syllabi and other handouts. We also shared a common, weekly growth mindset message or finding at the start of class each week. These weekly messages consisted of PowerPoint slide(s) that summarized a recent finding in growth mindset research that emphasized the malleability of intelligence (see Figure 1 for an example). Faculty then referred back to the messages throughout the week as students encountered challenging problems during active-learning activities or during their laboratory research, reinforcing a growth mindset. This two-pronged approach—in which DDP was used to simultaneously address both the cognitive and affective domains of learning—was repeated again in Fall of 2017, and students' final grades from these 2 years were pooled for the DDP experimental condition.

The final pedagogy examined—active learning, without growth mindset messaging—was employed in Fall of 2016. A number of studies have demonstrated that implementation of active-learning strategies alone—without intentional efforts to simultaneously address the affective domain of learning—can produce academic gains among students and can be particularly effective in narrowing or closing achievement gaps between majority and URM students (Haak *et al.*, 2011; Eddy and Hogan, 2014; Freeman *et al.*, 2014). Thus, in the present study, it was important to determine whether any learning gains observed in response to DDP versus traditional lecture were simply the result of implementation of active-learning strategies, or whether the addition of growth mindset messaging was a key factor in eliciting the gains. Thus, a third experimental condition was implemented in 2016 ("active learning only"), in which the same active-learning strategies used in 2015 and 2017 were implemented in BIO 1399 and BIO 1100 *without* any additional efforts to address the affective domain of learning. In other words, growth mindset messaging was not implemented in 2016.

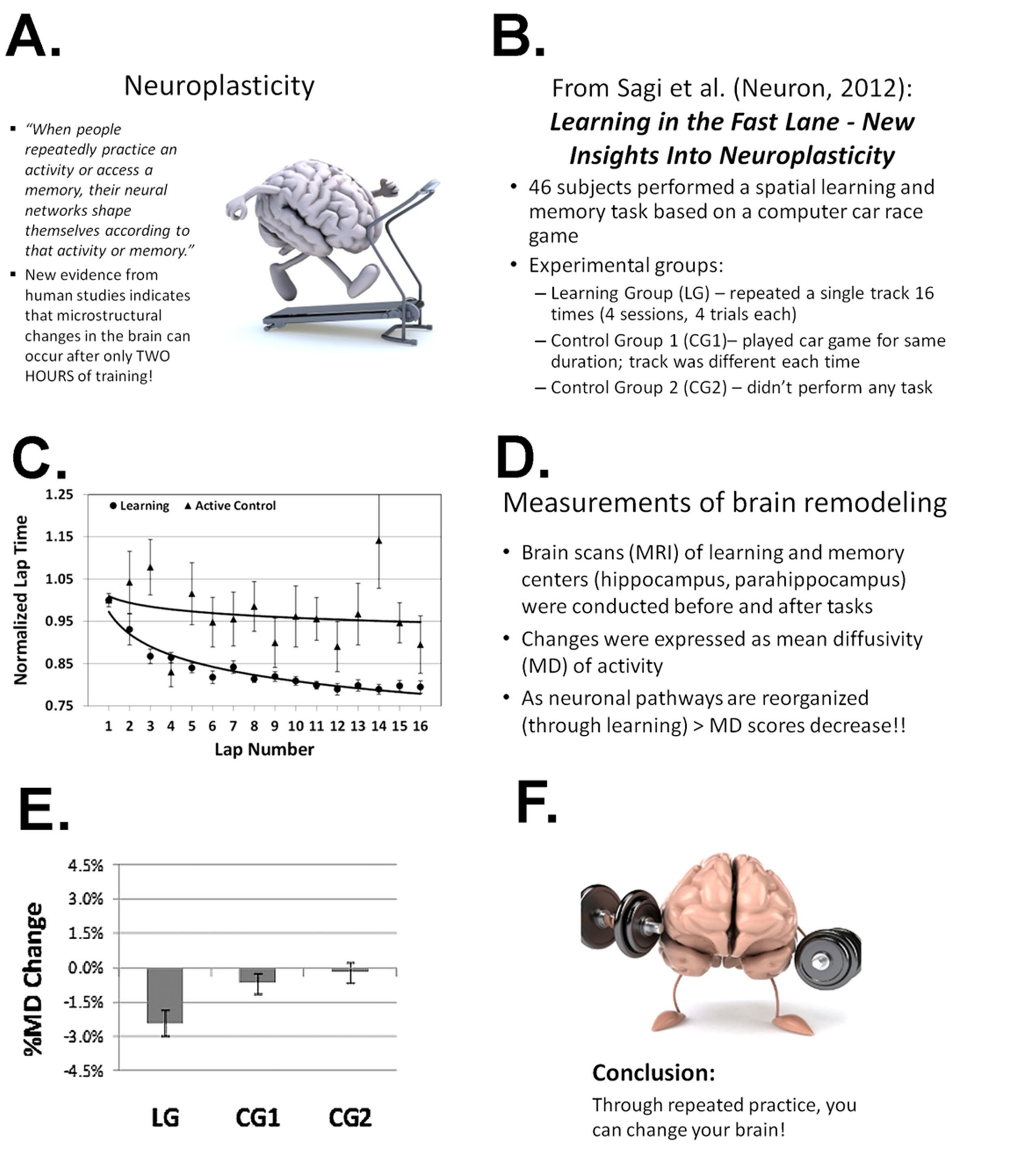

FIGURE 1. Example of a weekly growth mindset message shared with students in introductory biology courses taught with DDP. Changes in mean diffusivity (MD) in the right parahippocampus of the learning group (LG), control group 1 (CG1), and control group 2 (CG2) are shown in E (Sagi *et al.*, 2012).

Impact of DDP on Students' Growth Mindset and Science Self-Efficacy

To determine whether the intentional growth mindset messaging employed with DDP enhanced students' growth mindset and/or their confidence in their ability to "do science" (in other words, did DDP influence their attitudes about self, which in turn would influence motivation and academic performance?), we asked students to complete a survey instrument at the start and end of the semester in 2015. To assess their growth mindset, we included a 16-item growth mindset inventory, or GMI (addressing both general theories and self-theories of intelligence; Dweck, 1999; see the Supplemental Material), in the survey. The GMI asks participants to rate growth mindset statements based on their level of agreement (ranging from 1 = strongly disagree to 5 = strongly agree). The GMI also includes some fixed mindset statements, which are then reverse scored so that higher composite scores reflect a more growth-oriented mindset. For assessment of students' biology self-efficacy, 14 items from a biology self-efficacy instrument (Baldwin *et al.*, 1999; see the Supplemental Material) were also included in the survey. This instrument consists of questions that ask students to rate their confidence in their ability to perform certain aspects of science (e.g., "How confident are you that you could analyze a set of data—i.e., look at the relationships between/among variables?"). Participants then rate their level of confidence, with answers ranging from 1 ("not confident at all") to 5 ("totally confident"). Higher total scores indicate stronger self-efficacy.

The presemester online survey was administered in class during the first week of the semester, before the employment of any growth mindset messaging. The postsemester survey was also administered online in class, during the last week of the semester.

Statistical Analyses

We used a multilevel regression model to determine whether student performance in lower-level biology courses is correlated with pedagogy. Our data had two levels, with students (level 1) nested within class sections (level 2). We regressed grade on race/ethnicity (with Black, Latin@, Asian, and mixed descent categories as dummy variables and white as the reference category) and pedagogy (lecture, active learning, DDP) and their interaction. Our model included a random intercept for class section to account for the nesting. In so doing, class section was included in the model as a random effect (rather than as a main predictor), whereas ethnicity and pedagogy were fixed effects. We did not include course type (BIO 1100 or BIO 1399) as a predictor, given that a preliminary multilevel regression analysis indicated no differences between the courses.

Students' pre- and postsemester scores on the GMI and the biology self-efficacy survey were analyzed using two-way analysis of variance (ANOVA; time × race/ethnicity), followed by Tukey's honestly significant difference test for post hoc comparisons. For all analyses, results were considered significant if $p < 0.05$.

RESULTS

Impact of Pedagogy on Academic Performance Gaps in Introductory Biology Courses

We examined the academic performance of students from different racial/ethnic groups in response to three different pedagogies in introductory biology courses: 1) lecture only (in which the vast majority of course content was addressed through didactic lecture and laboratory sections were taught with cookbook protocols); 2) active learning (in which at least 25% of course content was addressed in the classroom via student-centered learning strategies and cookbook laboratories were replaced with guided inquiry); and DDP (in which the same best practices for addressing the cognitive domain of learning used in the active-learning condition were combined with intentional efforts to address the affective domain of learning via weekly growth mindset messaging).

Our multilevel regression analysis of our data revealed a statistically significant interaction between pedagogy and race/ethnicity in our introductory biology courses, with DDP being the pedagogical condition that completely eliminated the academic performance gap between Black and white students (see Tables 2 and 3 and Figure 2 for a summary of results). In the lecture condition (the traditional format in which both courses were taught from 2010 to 2014), white students had an average course grade of 2.72, which was the highest grade among the racial/ethnic groups examined in the study. The average course grade of Black students in response to lecture was 2.29, a grade that was significantly lower ($p < 0.001$) than that of

TABLE 2. Impact of pedagogy on average course grade introductory biology courses

	White	Black	Latin@	Asian	Mixed descent
Lecture					
Average grade	2.72	2.29	2.54	2.48	2.52
Confidence interval	2.718–2.721	2.27–2.31	2.51–2.57	2.42–2.54	2.47–2.56
SE	0.001	0.008	0.016	0.030	0.024
t value[a]	—	–0.40	–1.36	–1.08	–1.09
p value[a]	—	0.001	0.17	0.28	0.29
Regression coefficient	—	–0.42	–0.16	–0.18	–0.16
Active learning					
Average grade	2.47	2.16	1.68	2.33	2.20
Confidence interval	2.462–2.477	2.05–2.27	1.58–1.78	2.01–2.65	2.02–2.38
SE	0.004	0.056	0.052	0.161	0.094
t value[a]	—	–0.87	–3.09	0.17	–0.99
p value[a]	—	0.35	0.002	0.87	0.33
Regression coefficient	—	–0.22	–0.71	–0.06	–0.26
DDP					
Average grade	2.58	2.56	2.05	2.63	2.53
Confidence interval	2.50–2.66	2.31–2.81	1.76–2.34	2.16–3.10	1.79–2.80
SE	0.04	0.13	0.15	0.24	0.14
t value[a]	—	0.07	–3.23	0.63	0.20
p value[a]	—	0.94	0.001	0.53	0.84
Regression coefficient	—	0.01	–0.51	0.17	0.03

[a]Reference is grade point average of white students in response to the same pedagogy.

TABLE 3. Impact of pedagogy on the size of performance gaps in introductory biology courses

	Lecture vs. active learning		Lecture vs. DDP		Active learning vs. DDP	
Student group	*t* value	*p* value	*t* value	*p* value	*t* value	*p* value
Black	0.76	0.45	2.53	0.01*	0.79	0.43
Latin@	−2.13	0.03*	−1.77	0.08	0.71	0.48
Asian	0.60	0.552	1.12	0.26	0.23	0.81
Mixed descent	−0.32	0.749	0.88	0.38	0.95	0.33

*$p < 0.05$ when comparing the size of performance gaps between white students and students of this racial/ethnic group in response to the two pedagogies.

white students from 2010 to 2014. While the average course grades of Latin@ students, Asian students, and students of mixed descent (2.54, 2.48, and 2.52, respectively) were also lower than that of white students in response to lecture, the differences were not statistically significant.

In 2016, our biology courses were taught with active learning only (and no growth mindset messaging). In other words, the same active-learning strategies used in the DDP pedagogical condition were implemented *without* any additional efforts to address the affective domain of learning. While the course grades of Black students did not differ significantly from that of white students in response to active learning only (2.16 vs. 2.47, respectively), a gap still persisted that did not differ significantly in size from the gap observed in response to lecture only. Similar to what was observed in response to lecture only, no significant difference was observed between the average course grade of Asian students (2.33) and students of mixed descent (2.20) when compared with the average grade of white students in the active-learning condition. However, the introduction of active learning into our introductory biology courses caused a significant gap to appear between the average course grades of Latin@ students compared with white students—a gap that was not present in response to lecture only. Latin@ students exhibited an average course grade of 1.68 in response to active learning, a grade that was significantly lower than the average grade of white students in response to the same pedagogy ($p < 0.002$).

When DDP was implemented in our introductory biology courses in 2015 and 2017—in other words, when faculty made intentional efforts to effectively address both the cognitive and affective domains of learning throughout the semester—the academic performance gap between white and Black students that was previously observed in response to lecture was eradicated, with white students having an average course grade of 2.58 and Black students an average grade of 2.56 in response to DDP. Likewise, the course grades of Asian students and students of mixed descent (2.63 and 2.53, respectively) did not differ significantly from that of white students in response to DDP. Only Latin@ students showed significantly lower course grades (2.05) than white students in response to DDP ($p < 0.001$). Nonetheless, it is important note that the size of this gap was smaller than that observed between Latin@ and white students in response to active learning only. In fact, while the size of the gap between Latin@ and white students in response to active learning versus lecture reached statistical significance ($p < 0.03$), the size of the gap between Latin@ and white students in response to lecture versus DDP did not (see Table 3).

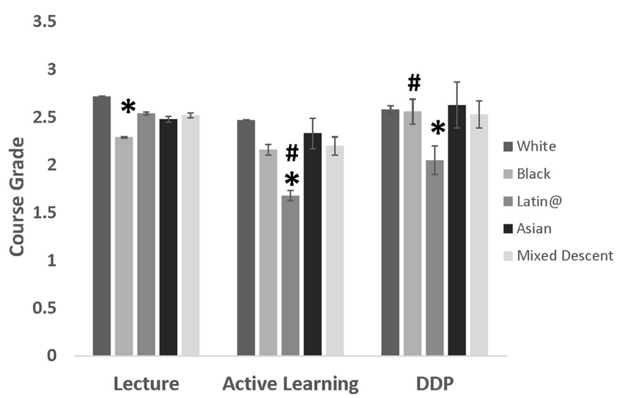

FIGURE 2. Impact of pedagogy on the academic performance of different racial/ethnic groups in introductory biology courses. *, $p < 0.002$ compared with white students' average course grade in response to the same pedagogy. #, $p < 0.05$ compared with the size of the gap observed between the same ethnic group and white students in the lecture condition.

Impact of DDP on Students' Growth Mindedness and Biology Self-Efficacy

To determine whether students' growth mindset changed in response to weekly growth mindset messaging, we administered a 16-item GMI at the start and end of the semester in 2015 (the semester in which DDP was employed in introductory biology courses; Dweck, 1999). Two-way ANOVA revealed no significant difference between pre- and postsemester scores in any racial/ethnic group in response to DDP. The only statistically significant difference noted in the analysis was that, overall, Black students' growth mindset score was significantly greater than those of white and Latin@ students ($p < 0.05$; see Table 4).

To determine whether students' confidence in their ability to "do science" changed in response to DDP, we administered a biology self-efficacy instrument (Baldwin *et al.*, 1999) in introductory biology courses at the start and end of the Fall 2015 semester. Two-way ANOVA revealed that the self-efficacy score of all students combined was higher at the end of the semester than at the beginning of the semester in response to DDP ($p < 0.05$; Table 5). No significant difference between pre- and postsemester scores was evident in any subpopulation of students when the data were analyzed by racial/ethnic group.

DISCUSSION

In this study, we introduce DDP, a novel pedagogy developed in response to the preponderance of literature emphasizing the benefits of classroom approaches that address the affective components of learning for reducing or closing performance gaps in STEM fields. We hypothesized that, if we coupled efforts to address the affective domain of learning (through weekly

TABLE 4. Growth mindset scores in response to DDP

Score	White	Black	Latin@	All students
Presemester	3.81 ± 0.04	4.20 ± 0.11	3.81 ± 0.29	3.85 ± 0.04
Postsemester	3.85 ± 0.00	3.99 ± 0.17	3.30 ± 0.21	3.85 ± 0.05
Overall	3.83 ± 0.03	4.07 ± 0.11*	3.63 ± 0.21	3.85 ± 0.03

*$p < 0.05$ compared with overall score for white and Latin@ students.

growth mindset messaging) with best practices for addressing the cognitive domain of learning (namely, active-learning strategies), we would see benefits for student learning that supersede those observed with active learning only or with lecture. Indeed, results from our study demonstrate that DDP is a powerful tool for eliminating performance gaps among different racial/ethnic populations in introductory biology courses. While statistically significant gaps in academic performance existed between white and Black students in our lecture condition and between white and Latin@ students in our active-learning condition, these gaps were eliminated or reduced during the years in which DDP was implemented. These results demonstrate the power of DDP for promoting a more equitable classroom and suggest that this pedagogy may confer learning benefits that pre-empt those associated with active learning alone when teaching a classroom of diverse learners.

An especially important aspect of our study was the disaggregation of student data by racial/ethnic group, which revealed for us the power of DDP for reaching a classroom of diverse learners. The vast majority of studies investigating the impact of particular pedagogies on student learning either provide broad-scale measures of overall student performance or, at best, divide students into two groups: white and URM students. Had we taken either of these approaches in the current study, several important findings about the relative efficacy of each pedagogy for teaching a diverse population of learners would have been obscured. For example, it was not surprising that the introduction of active learning into our introductory biology courses reduced the long-standing performance gap between Black and white students that we had seen for several years prior in response to traditional lecture. Indeed, this finding is consistent with other studies on active learning (Haak *et al.*, 2011; Ballen *et al.*, 2017) in which students were disaggregated into only two groups (white and URM or disadvantaged students). However, had we not disaggregated our data, we would not have made the very important observation that the population of Latin@ students at our institution actually fare better in response to lecture than to active learning. When we introduced active learning (without growth mindset messaging) into the curriculum of our introductory biology courses, a significant gap in academic performance appeared between Latin@ students and white students. This was true in both our majors' course and in our general education course for nonmajors. However, when we combined intentional efforts to address the affective domain of learning along with active learning (in other words, when we implemented DDP), we were able to eradicate or significantly narrow performance gaps among the racial/ethnic groups examined.

Our observation regarding the difference in learning outcomes of Black and Latin@ students in response to active learning is an important one. Two other studies have noted differences in the impact of active learning on these two subpopulations of students in STEM classrooms. The first of these studies, conducted by Beichner *et al.* (2007), investigated the impact of the Student-Centered Activities for Large Enrollment Undergraduate Programs (SCALE-UP) Pedagogy on failure rates in calculus-based physics classes. The authors found that SCALE-UP significantly reduced failure rates (vs. lecture) for white and Black students, but had no impact on the failure rates of Hispanic students. Likewise, Eddy and Hogan (2014) observed that Black students benefit more than Latin@ students from moderate-structure active-learning interventions in an introductory biology course. To our knowledge, the present study is the first to note a significantly *larger* gap in the academic achievement of Latin@ students in response to active learning versus lecture. A potential explanation for this unique observation may be the institutional context in which the impact of active learning was investigated. The majority of studies published on active learning in STEM classrooms have taken place within the context of large lecture sections, often at public institutions, where the student body tends to be more diverse. The present study was conducted at a private institution with smaller class sizes (lecture sections capped at 36), where Latin@ students represent only 5.4% of the students enrolled in the courses of interest (vs. Black students, who represent a slightly higher percentage). This means that, in any given section of our introductory biology courses, we may have only one to two Latin@ students enrolled. Being faced with the expectation of participating in small-group work during active-learning activities while being very much in the minority may present social challenges for our Latin@ students that do not exist when they are sitting passively through lecture. Such a classroom context may necessitate intentional efforts on the part of the instructor to address the affective components of learning while implementing active learning (in other words, implementation of DDP), in order to create a more inclusive environment and reduce performance gaps for Latin@ students. Further studies will be necessary to better understand

TABLE 5. Biology self-efficacy scores in response to DDP

Score	White	Black	Latin@	All students
Presemester	3.14 ± 0.05	2.99 ± 0.18	2.90 ± 0.26	3.11 ± 0.05
Postsemester	3.53 ± 0.05	3.57 ± 0.15	3.11 ± 0.65	3.52 ± 0.05*
Overall	3.34 ± 0.04	3.34 ± 0.12	2.98 ± 0.27	3.32 ± 0.04

*$p < 0.05$ vs. the presemester score of all students.

the differential effect of active learning on the academic performance of Latin@ and Black students.

Prior studies have demonstrated the positive impact of messaging for helping students transition from a fixed to a growth mindset about their learning (Blackwell *et al.*, 2007; Burnette *et al.*, 2019). Yet in the present study, we did not observe a measurable change in students' growth mindset in response to DDP, even though this pedagogy helped us to eradicate or narrow performance gaps in our introductory biology courses. This finding prompted us to consider the possibility that DDP is positively impacting our students' classroom performance in ways unrelated to a mindset change. It may be that students are not experiencing any change in their *own* mindsets in response to their professors' weekly growth mindset messages, but may be benefiting from what they perceive to be the professor's mindset about their ability to do well in the course. Hearing the professor regularly affirm a growth mindset may enhance students' trust in the professor's commitment to their learning, minimize stereotype threat, and motivate them to engage in active learning. Indeed, Cavanagh *et al.* (2018) recently demonstrated that trust in the instructor (defined as students' perceptions of their instructors' understanding, acceptance, and care) results in a stronger commitment to and engagement in active learning, thereby enhancing final grades in an active-learning classroom. Likewise, Canning *et al.* (2019) recently demonstrated that, when courses are taught by faculty who have fixed mindset beliefs, racial achievement gaps are twice as large as those observed in courses taught by growth mindset faculty. Thus, we believe that a likely explanation for the positive impact of DDP observed in the present study is the affirmation that students receive regarding their instructor's confidence in their ability to do well, which minimizes stereotype threat, enhances trust, prompts a higher level of engagement in active learning, and thereby eradicates achievement gaps.

While our students did not exhibit a significant change in growth mindset in response to DDP in the present study, they exhibited a statistically significant increase in biology self-efficacy in response to this pedagogy. Enhanced biology self-efficacy was observed uniformly among students, with no differences among any of the racial/ethnic groups examined. Whether the overall change in self-efficacy in response to DDP was elicited by growth mindset messaging, active learning, or a combination of the two remains to be determined and will be investigated in future studies. An explanation for enhanced self-efficacy in response to DDP will be important to ferret out, given the link between higher self-efficacy and motivation, which are ultimately linked with professional identification and academic success (Graham *et al.*, 2013). Determining the aspects of DDP that enhance biology self-efficacy and capitalizing on those characteristics in subsequent iterations of the pedagogy throughout the natural sciences curriculum could positively impact persistence in STEM.

LIMITATIONS

This study provides compelling evidence that DDP promotes a more equitable classroom environment (relative to active learning alone or traditional lecture) in the context of a private institution with smaller class sizes, in that it was the most successful pedagogy in the present study for eliminating or narrowing academic performance gaps among the different racial/ethnic groups examined. While institutional context is an important aspect of this study that makes our findings noteworthy, it is also limiting, given the small sample sizes that exist for some ethnic groups within our classrooms. As a result, we were unable to determine whether gender—when factored in with race/ethnicity—influences student outcomes in response to these three pedagogies, because our small sample sizes do not allow for a meaningful analysis at the intersection of gender and race/ethnicity. Thus, additional work—perhaps within the context of a multi-institutional study involving several private colleges—will be necessary in order to generate larger sample sizes. In so doing, we will be able to characterize how gender, within the context of race/ethnicity, influences responsiveness to DDP.

Additionally, our findings do not provide an explanation for the positive impact of DDP in closing performance gaps. We conducted two measurements to assess a change in affect in response to DDP: a pre- and postsemester growth mindset survey and a pre- and postsemester biology self-efficacy measure. While students' self-efficacy increased significantly overall, we did not observe population-specific improvements that help to explain the impact of DDP in closing performance gaps. Also, our growth mindset measurement did not reveal any significant changes in mindset in response to DDP among any of the racial/ethnic groups enrolled in our courses. Thus, we can only infer a positive impact of DDP on the affective components of learning, given the fact that it had a significant positive impact in the cognitive domain of learning (namely, by closing academic performance gaps in both courses). Further studies will be necessary to directly assess changes in the affective domain of learning in response to DDP, in order to gain further insight into the why this pedagogical approach is a powerful tool for causing change within the cognitive domain and creating a more equitable classroom.

CONCLUSIONS AND FUTURE DIRECTIONS

Our examination of the academic outcomes of different racial/ethnic groups in response to three different pedagogies has revealed the following:

1. Teaching with traditional lecture results in a significant performance gap between Black and white students (but not Latin@ and white students) in introductory biology courses at our institution.
2. Teaching at least 25% of course content with active learning (a best practice for addressing the cognitive domain of learning) narrows the performance gap between Black and white students in introductory biology courses, but introduces a statistically significant gap between Latin@ and white students at our institution.
3. Teaching introductory biology courses with DDP, a pedagogy that combines best practices for addressing the cognitive domain of learning (i.e., active learning) with intentional efforts to address the affective domain of learning (through growth mindset messaging), eradicated the performance gap between Black and white students and narrowed the performance gap between Latin@ and white students that was introduced by active learning in introductory biology courses at our institution.
4. No measurable change in students' growth mindset occurred in response to DDP in our study, suggesting that our messaging positively influenced student academic

outcomes via another mechanism (e.g., by enhancing trust in the instructor).

Taken together, these findings demonstrate the superiority of DDP (relative to traditional lecture or active learning only) for closing performance gaps among different racial/ethnic groups in introductory biology courses taught at a private institution with small class sizes. Further studies are necessary to characterize exactly how DDP is positively influencing student outcomes, as it appears that students' growth mindedness is not changing significantly in response to our messaging. Additionally, larger multi-institutional studies will be necessary to generate large enough sample sizes to explore the impact of DDP at the intersection of gender and race/ethnicity.

Another question worth exploring is whether DDP is effective at other types of institutions (e.g., R1 institutions). Given the relative ease of implementation of DDP, it is entirely feasible for this pedagogy to be scaled for higher-enrollment classes, combining growth mindset messaging with active-learning strategies designed for a larger audience (e.g., clicker questions). Results from such a study will illuminate whether the impact of DDP is generalizable, or whether it is specific to our institutional context. Finally, more research will be needed to determine whether the results obtained with DDP in the present study are specific to growth mindset interventions, or whether other efforts to address the affective domain of learning (e.g., self-affirmation writing exercises or peer mentoring) can be coupled with active-learning strategies to achieve the same effect.

The powerful impact of DDP on closing performance gaps highlights the need for additional research on the affective facets of learning in STEM classrooms. Until recently, STEM faculty have been reticent to engage in research on the affective domain of learning. It is easy to speculate why this gap in our understanding of this aspect of learning in STEM classrooms exists. Cognitively oriented classrooms are more predictable and controllable, and we have at our fingertips a significant body of material that allows us to evaluate performance in the cognitive domain of learning. Emotionally expressive classrooms are less predictable, and outcomes that emphasize feelings, tones, degrees of acceptance, and so on are more difficult to teach and measure (Pierre and Oughton, 2007). Thus, few STEM instructors have the time or inclination to investigate this domain of learning. Nonetheless, results from this study as well as the work of others (Aronson *et al.*, 2002; Yeager and Walton, 2011; Yeager *et al.*, 2013, 2016) emphasize the need to commit significant effort and resources to understanding this domain of learning. Not only will this allow us to discover new ways to foster a more equitable classroom environment (and ultimately educate a more diverse array of scientists and healthcare professionals), but it will also better prepare *all* graduates—regardless of their race/ethnicity—with the soft skills necessary for success (self-awareness, appreciation for diversity, listening skills, change readiness) once they graduate from our institutions.

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