# Does Problem-Solving Before Instruction Reduce the Minoritized Student Achievement Gap?

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**Abstract:** Despite equal ability, racially-minoritized students disproportionately underperform and drop out of STEM courses. Active learning methods have been shown to help reduce this gap. We examined whether exploratory learning, a type of active learning, has similar benefits. Exploratory learning reverses traditional instruct-then-practice approaches by giving students a novel activity prior to instruction. Undergraduate students (*N*=354) were randomly assigned to learn concepts of statistical variance in explore-first (activity then instruction) or instruct-first (instruction then activity) conditions. Posttest scores improved overall in explore-first compared to instruct-first conditions. However, underrepresented students had lower scores than non-underrepresented students in both conditions. Although effective overall, exploratory learning did not decrease the underrepresented student achievement gap. Certain one-time active learning methods may not be sufficient to promote inclusivity and reduce barriers to underrepresented students' learning.

## Introduction

Racially-minoritized students are underrepresented (UR) in Science, Technology, Engineering, and Mathematics (STEM) disciplines (Curry & DeBoer, 2020; PCAST, 2012). Yet, these students are essential for the STEM workforce, and enter colleges and universities aspiring to major in STEM at the same rate as non-underrepresented students (non-UR) (Malcolm & Feder, 2016). UR students show disproportionate underperformance and dropout rates from STEM disciplines (Ballen et al., 2017; PCAST, 2012). Disproportionate retention of UR students in STEM is thought to be due to various factors, such as social isolation, "chilly" classrooms (i.e., instructor dominated lectures that involve little student participation in large introductory classes), low confidence, and stereotype threat (Ballen et al., 2017). Active learning may help to reduce this gap (Saunders & Kardia, 2011).

The current study more closely examined the role a specific type of active learning can play in decreasing the UR student achievement gap in STEM fields. *Exploratory learning* adds a problem solving (exploration) phase before lecture (DeCaro & Rittle-Johnson, 2012), often improving students' conceptual understanding and knowledge transfer to related concepts (Darabi et al., 2018; Loibl et al., 2017). No prior studies have examined whether exploratory learning also helps reduce the UR student achievement gap. Active learning includes multiple instructional methods targeting students' understanding (e.g., in-class activities, low-stakes quizzes) and classroom climate (e.g., collaborative learning; Bauer et al., 2020). Examining how one specific type of active learning impacts UR student learning may provide insight into what factors help to reduce achievement gaps.

## Active learning

Multiple studies have shown that UR students are interested, and as capable to excel, in STEM as much as non-UR students (Malcolm & Feder, 2016; Steele & Aronson, 1995). The U.S. Federal Government has called for action to increase representation in STEM (National Academies Press, 2011). One solution is to employ more inclusive instruction in STEM curricula. *Inclusive instruction* is a pedagogical approach that promotes the idea that all students in the classroom belong and possess the ability to be successful (Johnson, 2019). In an inclusive classroom, instructors and students all take responsibility for students' learning. Instructors create a space where students feel supported and encouraged (Saunders & Kardia, 2011).

One way to implement inclusive instruction is to use active learning (Saunders & Kardia, 2011). *Active learning* engages students through activities, collaborative learning, and/or in class discussion, as opposed to passively listening to lectures (Brame, 2016). Active learning encourages students to analyze and critically think about concepts, improving student outcomes such as grades (Ballen et al., 2017; Freeman et al., 2014). Ballen and colleagues (2017) showed that active learning, compared to traditional lectures, closed the UR student achievement gap in an introductory biology course. After adding active learning to the course curriculum, UR students' assessments and grades increased to the level of non-UR students. UR students' science self-efficacy—confidence in their capability to do science—also increased. Similar results have been found in other studies (e.g., Eddy & Hogan, 2014; Haak et al., 2011).

## Exploratory learning

More work is needed to determine which active learning methods lead to these benefits. The current study examined *exploratory learning*, a specific type of active learning in which students explore a novel concept prior to instruction on that topic. Exploratory learning encompasses several methods (DeCaro & Rittle-Johnson, 2012), including problem-solve-instruct methods (e.g., Loibl et al., 2017), productive failure (e.g., Kapur, 2012), and preparation for future learning (e.g., Schwartz & Martin, 2004). A growing number of studies have shown that exploratory learning generally improves students' understanding of concepts; rote problem-solving procedures are learned equally well in explore-first and instruct-first methods (Loibl et al., 2017).

Exploratory learning is thought to benefit understanding through several learning mechanisms (Loibl et al., 2017). First, solving novel problems helps students activate relevant prior knowledge, integrating what they know with the new instruction (Newman & DeCaro, 2019). Second, students realize where they have gaps in their knowledge, calibrating their metacognition, and alerting them that the instruction can help fill those gaps (Loibl et al., 2017). Third, students begin to discern what features of the problem are key, and which are less important, deepening their understanding of the concepts (DeCaro & Rittle-Johnson, 2012; Schwartz & Martin, 2004).

## Current Study

We examined whether exploratory learning, as a type of active learning activity targeting conceptual understanding, would help to reduce the UR student achievement gap. We combined data collected for other studies in psychological statistics courses with lab studies using the same materials, and conducted a secondary analysis. Participants were randomly assigned to one of two conditions. Students in the *explore-first condition* explored a standard deviation problem and "invented" an equation to solve it. Then they read instruction on the concept and procedures of standard deviation. Students in the *instruct-first condition* viewed the materials in the opposite order (instruction, then problem). Either immediately after (lab sessions) or one week later (classroom sessions), students completed a posttest that assessed conceptual understanding of standard deviation.

We hypothesized that students in the explore-first condition would score higher on the posttest overall, compared to students in the instruct-first condition. We also hypothesized that any difference in posttest scores between UR and non-UR students in the instruct-first condition would be reduced in the explore-first condition. However, another possibility is that the cognitive benefits of exploratory learning are insufficient to increase inclusive instruction, especially in a one-time intervention in which students work individually. This experiment therefore tested whether exploring alone is a sufficient method to reduce the UR student achievement gap.

# Methods

## Participants

Participants (*N*=354) were undergraduate students enrolled in introductory psychology statistics courses (*n*=263) or who participated in a lab study at the same university (*n*=91). Students were categorized as UR (*n*=94; 26.4%) based on their reported race/ethnicity, including African-American/Black, Hispanic/Latinx, Native American, Hawaiian/Pacific Islander, or biracial/"mixed" (Curry & DeBoer, 2020). Non-UR (*n*=262; 73.6%) participants indicated that they were Caucasian/white. Participants from other racial/ethnic groups (e.g., Asian) were not included in analyses, as they are not typically considered to face the same academic challenges as other minoritized groups (Curry & DeBoer, 2020).

Participants were included in the dataset if they completed both the intervention and posttest. Participants were excluded if they had experience with the learning materials, or if they reported previously learning about standard deviation and scored above 97% on the posttest. Participants were also excluded if they reported that their primary language was not English, due to the large reading component of the study (this variable was not collected from 174 participants; all were included in the dataset).

## Materials

The **intervention packet** (adapted from Kapur, 2012; Wiedmann et al., 2012) consisted of three sections that varied in order depending on condition: instruction, activity, and survey (demographics). The **instruction section** included a written text passage giving direct instruction on the concepts and procedures for calculating standard deviation, with two short practice questions. The **activity section** included a problem asking students to determine the consistency of antioxidants in tea produced by three different tea growers over six years (Newman & DeCaro, 2019). Students viewed a table designed to facilitate contrasting cases, to help students ascertain the relevant problem features (e.g., the importance of sample size; Schwartz et al., 2012). Students in the *explore-first condition* were asked to "Come up with a formula for consistency to show which tea grower has the most consistent levels of antioxidants…" Students in the *instruct-first condition* were instead asked to use what they just learned about standard deviation to calculate consistency. The **posttest** included four essay questions that targeted conceptual and procedural aspects of standard deviation, drawn from Newman and DeCaro (2019) (interrater reliability: Cronbach's alphas > .80).

## Procedure

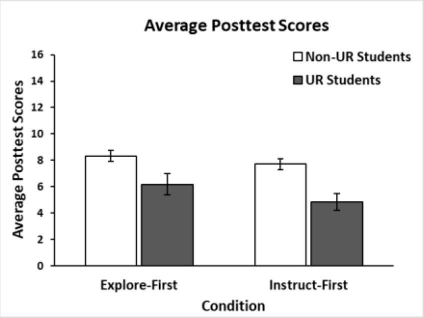
Students were randomly assigned to condition based on the intervention packet given. Students in the *explore-first condition* (*n*=174) completed the activity, then the instruction. Students in the *instruct-first condition* (*n*=180) completed the instruction then activity. Students were given 15 minutes for each section of the packet and 35 minutes for the posttest. Students in the psychology statistics lab classes completed the posttest one week after the intervention. Students in the lab (non-classroom) study completed both packets in one session. Students in classroom studies were debriefed via email and given the option to remove their data from the study. Students in the lab study completed a consent form at the beginning and were given psychology research credit for participation. All procedures were approved by the university Institutional Review Board.

## Results

A preliminary analysis showed that the difference between conditions (explore-first, instruct-first) was statistically significant without including representation status as a factor, $F(1,356)=4.25$, $p=.040$, $\eta_p^2=.012$. Posttest scores were higher in the explore-first (*M*=7.88 out of 16, *SE*=0.37) than the instruct-first condition (*M*=6.80, *SE*=0.37).

Posttest scores were then analyzed using a 2 (condition: *explore-first*, *instruct-first*) × 2 (representation status: *UR*, *non-UR*) between-subjects factorial ANOVA. No main effect of condition was found, $F(1,356)=2.67$, $p=.103$, $\eta_p^2=.008$. A main effect of representation status was found, $F(1,356)=17.83$, $p<.001$, $\eta_p^2=.048$. There was no condition × representation status interaction, $F<1$, $p=.566$, $\eta_p^2=.001$. As shown in *Figure 1*, UR students scored lower on the posttest than non-UR students in both the explore-first condition (UR: *M*=6.17, *SE*=0.80, *CI*[4.59–7.74]; non-UR: *M*=8.32, *SE*=0.41, *CI*[7.52–9.13] ) and instruct-first condition (UR: *M*=4.86, *SE*=0.64, *CI*[3.61–6.11]; non-UR: *M*=7.71, *SE*=0.43, *CI*[6.85–8.55]). Exploratory learning did not reduce the achievement gap.

**Figure 1** *Average Posttest Scores as a Function of Condition and Underrepresentation (UR) Status (Error Bars=SEs)*



## Discussion

This study examined whether exploratory learning would reduce the UR student achievement gap when learning about a statistics concept and procedure across undergraduate classroom and lab settings. Compared to an instruct-first condition, students in the explore-first condition scored higher on a posttest, although the effect was weak. UR students performed at a lower level than non-UR students across both instruct-first and explore-first conditions, demonstrating that exploratory learning did not significantly reduce the UR student achievement gap.

This finding contrasts prior studies showing that using active learning techniques can reduce the achievement gap between UR and non-UR students in STEM courses (e.g., Ballen et al., 2017; Haak et al., 2011). However, these studies included multiple active learning methods used over an entire semester. Thus, it is unclear which specific methods drove these benefits or whether a single lesson using active learning may be sufficient to demonstrate additional learning benefits for UR students. The current results demonstrate that a single exploratory learning lesson—at least as used in this study—is insufficient to reduce the achievement gap.

Several factors may have limited our ability to differentially improve UR students' learning. Our results may be limited by weak implementation of exploratory learning. In addition, students only experienced this learning method once. Perhaps repeated exposure to learning methods known to improve students' conceptual understanding is necessary to have more widespread benefits. Given the challenges of exploratory learning, instructions aimed at a growth mindset may need to be included (e.g., Bauer et al., 2020). Finally, students worked individually in our study, but collaborative learning may be key to an inclusive learning environment. Collaboration encourages relationships between students and instructors, and may be necessary to reduce a "chilly" climate.

Our findings underscore the importance of continuing to discern the key ingredients of active learning that do increase inclusivity and academic performance for UR students. For example, Bauer et al. (2020) argue that instructional methods should target both cognitive and affective aspects of learning. Others (e.g., Lorenzo et al., 2006) focus primarily on the social aspects of an inclusive teaching environment. Exploratory learning may be useful, but insufficient, without being combined with other aspects of inclusive teaching, to help promote equitable learning for all students.

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