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# Closing Equity Gaps in Statics for BIPOC Students with a Free-Body Diagrams App

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# Closing Equity Gaps in Statics for BIPOC Students with a Free-Body Diagrams App

**Objectives:** This paper 1) examines the potential of an FBD App to close equity gaps in skills for drawing free-body diagrams between BIPOC students and their white peers in Statics; and 2) assesses hypotheses for explaining the app's impact.

**Significance.** While advancing the research on ed tech, the study contributes to a growing body of research that challenges deficit-based assumptions about BIPOC engineering students and explores best practices to improve BIPOC student retention in engineering. Deficit-based assumptions include beliefs about the shortcomings of BIPOC students that impede learning (eg, limited intelligence, motivation, training) in higher education. Engineering education studies are beginning to explore the prevalence and implications of these beliefs and to propose ways to frame engineering education research in less prejudiced ways to determine what best helps BIPOC students persist in engineering.

**Methods:** The study is quasi-experimental. Six statics courses (taught by three Mechanical Engineering faculty at two universities) offered students the use of the FBD app to complement the typical curriculum. The sample was 317 students - two thirds chose to use the app and one third did not. Fourteen percent of students were BIPOC, yielding a small, but sufficient sample for exploratory analyses. Independent t-tests were conducted to assess differences across BIPOC and white students. Four hypotheses for explaining differences were assessed using hierarchical multiple regression modeling. Significance was set at $p < .05$ for all tests.

**Findings:** BIPOC students significantly increased their ability to draw FBDs [$t(42) = -1.78$, $p<.05$], closing a gap between BIPOC students and white students who did not use the app [$t(113) = 1.84$, $p<.05$]. Among those who used the app, BIPOC students indicated that it had a significantly greater impact on their learning than their white peers [$t(192) = -2.72$, $p<.05$].

The first three hypotheses were all rejected (with evidence provided in the full paper):
Hypothesis 1: BIPOC students liked the app environment more than their white peers
Hypothesis 2: BIPOC students are more likely to be underprepared for college-level work and therefore found the extra assistance provided by the app more useful
Hypothesis 3: BIPOC students have different learning styles and the FBD app better suits how they learn

Hypothesis 4 that BIPOC students have less self-efficacy, which negatively effects their FBD skills, was supported by the evidence. The FBD App increased BIPOC students' self-efficacy, closing a gap between them and their white peers. In modeling growth in FBD drawing skills,

confidence in statics had a significant effect (ß = .13), similar in size to attending lecture (ß = .18). The model was significant, $F(15,370) = 20.37$, $p<.05$.

There may be other hypotheses that could contribute to explaining why the FBD App is particularly useful for BIPOC students and closing equity gaps and these findings are not generalizable. Our next phase will involve implementing the app with a larger sample across multiple institutional contexts.

# Closing Equity Gaps in Statics for BIPOC Students with a Free-Body Diagrams App

## 1 Introduction

Technology-based tools, such as games and apps, will play an increasingly important role in the education of the next generation of engineers. The adoption of such learning tools is already widespread in K-12 education [1], and higher education has begun to follow suit. Although many technology-related factors, including the rise of generative AI, will play a role in advancing this change, it is ultimately because these tools are effective [2,3] that they will continue to become more ubiquitous. Their effectiveness, in turn, should be unsurprising: technology-based tools provide motivating environments for active engagement, thereby aligning with well-known principles for learning [4].

As learning apps become more prominent in engineering education, it is important to study how their design and use can be optimized to promote learning for all students, particularly for those historically underserved by education systems. In this paper, we investigate how using an app that allows students to practice skills related to free-body diagrams (FBDs) impacts students identifying as Black, Indigenous, or People of Color (BIPOC). The app being used (the FBD app) [5] was previously demonstrated to help all students learn free-body diagram skills and to help close gaps in self-efficacy between men and women [6] when used as part of an introductory statics course. This suggests that learning apps can be tools for enhancing equity in addition to learning, spurring the current study to investigate differences in how BIPOC and majority students experience the FBD app. Specifically, we explore the potential of the app to close equity gaps in free-body diagram skills between BIPOC students and their white peers. Furthermore, we examine several explanatory hypotheses for the app's impact.

We use the term BIPOC in this study while acknowledging that it is not without flaws. Any umbrella term, including BIPOC, as well as underrepresented minority and marginalized, minimizes the distinct cultural experiences and histories of different racial and ethnic groups. In this exploratory study, we do group together students with different racial/ethnic identities to accumulate a sample size adequate for analysis. BIPOC has also been criticized for setting up hierarchies by naming some groups that have been targeted by racism and nativism, but not others. We acknowledge the limitations of our choice and commit to providing as much transparency about our decisions as possible throughout the paper. We contend that engaging in analyses of equity gaps, even with imperfect language, better positions us to act on our findings about interventions that work than waiting until we have noncontroversial language for asking critical questions. We choose to use imperfect language in parallel with continuing our own education about better possibilities for future work.

Having tools that simultaneously promote learning and enhance self-efficacy is vital to meeting the need for diversification of the engineering workforce identified by bodies such as the National Academy of Engineering and the National Society of Professional Engineers as critical for maintaining the engineering capabilities of the United States. Self-efficacy is associated with better outcomes related to student retention and persistence [7] , and is particularly important for underrepresented minorities, who often feel they do not belong in engineering due to the many signals given in STEM spaces and by engineers and engineering educators [8,9]. While such signals may reflect implicit bias, they nonetheless have been widely documented to negatively influence the retention of BIPOC students in STEM pathways and careers. Identifying tools and interventions that can increase representation by improving BIPOC students' experiences of core engineering courses, such as statics, is one important step towards advancing these goals.

This study also contributes to a growing body of research that challenges deficit-based assumptions about BIPOC engineering students [10,11]. Deficit-based assumptions include beliefs about the shortcomings of BIPOC students that impede learning (eg, limited intelligence, motivation, training) in higher education [12,13]. Interventions that assume that BIPOC students need to improve their knowledge and skills to be able to be successful locates the problem within BIPOC students, rather than attributing it to inequitable systems of education. Doing so puts the onus for change on the very students who are victims of racism, prejudice, and inequitable systems. By assessing multiple hypotheses, including commonly-held, deficit-based beliefs, we are able to empirically ask whether deficit-based assumptions might not reflect the reality of BIPOC students.

## 2 App Development & Implementation

There are three games that are developed for the FBD app. These short mini games were designed with a wide audience in mind including women and causal gamers (Cunningham 2018). The games are scaffolded to improve learning as users work towards drawing full FBDs. The three games games focus on skills critical to the FBD drawing process. In "Connection Identification" users recall the force and moment reactions for standard connections, see Figure 1. In "System Identification" users isolate specific systems based on given prompts using their finger to trace the desired system, see Figure 2. In the final game "Free-Body Diagram" users practice generating full FBDs within the app using a drag and drop interface, see Figure 3. Immediate app based feedback including hints and solutions provides learners with real time information to correct misunderstandings. Hints for the "System Identification" and "Free-Body Diagram" games are shown in Figures 2 and 3 respectively.

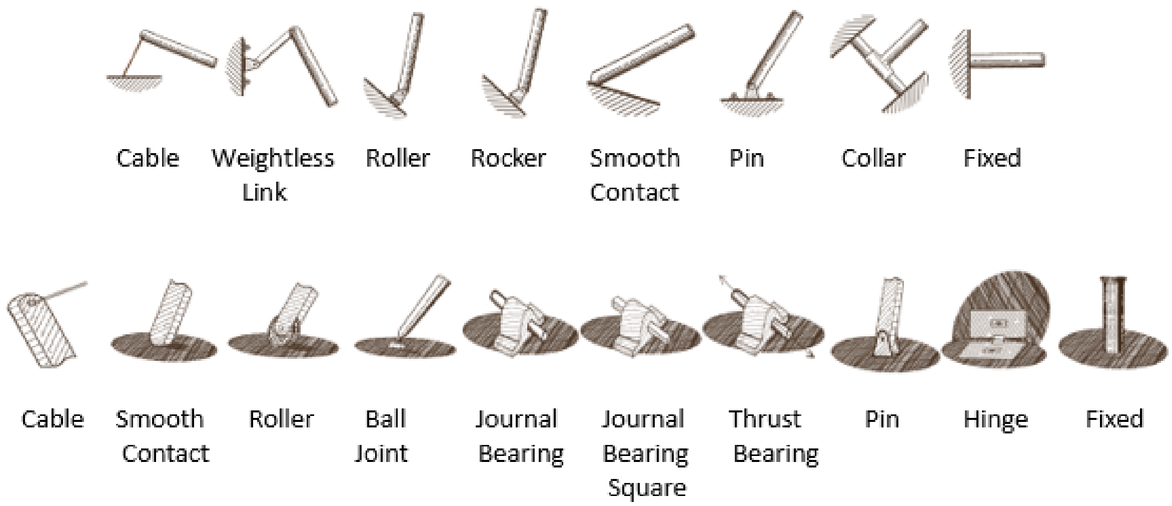


Figure 1 - 2D and 3D standard conditions from the Connection Identification mini-game [6].

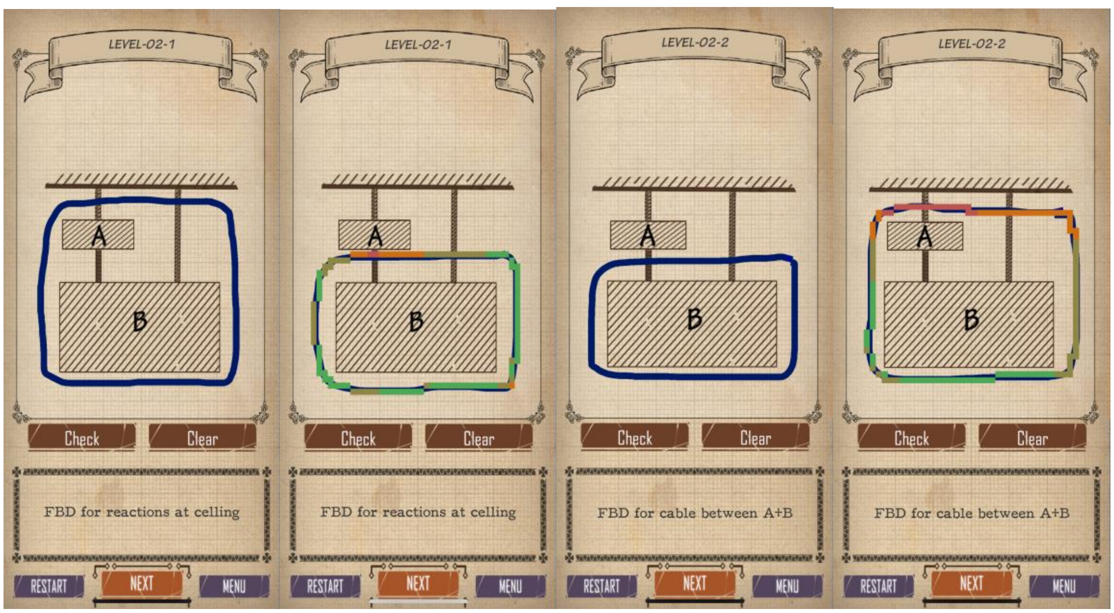


Figure 2: The two images on the left show level 02-1. The correct answer is on the far left shown with a traced blue outline. An incorrect attempt is shown in the center left. Areas highlighted in red and orange are activated through the use of the hints system and guide the user to the correct system. The two images on the right, from level 02-2, use the same image, but the prompt asks for a different system. As such, the correct solution is shown in the center right and an incorrect attempt with the hint system enabled is shown on the far right [14].

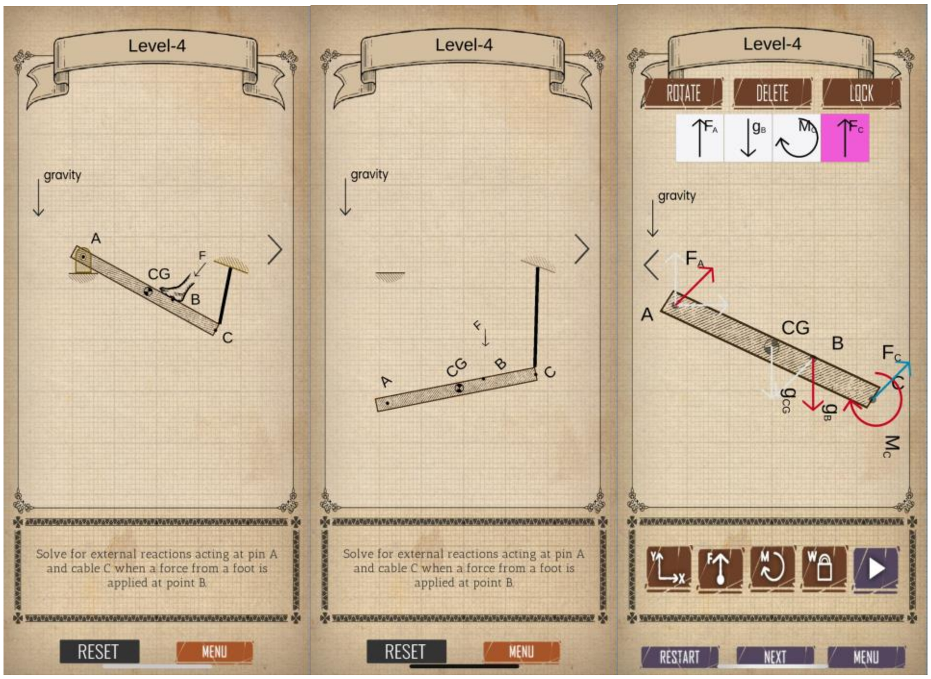

Figure 3: Level 4 from the FBD game shows a beam connected to a pin and a cable. The left image shows the initial state of the levels' first screen and the center image shows the physics of the cable. The right image shows an attempt at drawing the FBD with hint 2 activated. In this example, none of the applied loads (red) are correct and there are several missing (white) loads. The blue force, FC was drawn correctly by the user.

All of the mini-games were developed by a team of students, faculty and staff through an iterative prototyping process. Paper based models, focus groups, and beta testing provided development feedback throughout the design of the app. Discussions with potential faculty users also provided information in the development process that guided both the interface and the game play physics.

Students who utilize the app as a learning tool in their Introduction to Statics courses for this study were given access to the app at the start of their FBD drawing learning unit. The app was available to users through and beyond the end of their course offering, however, data about their usage was collected at the end of their course. Students were provided 20 minutes of in class to download the app and play with the provided mini-games during this class session. See Figure 4 for the progression of app integration and data collection for this study.

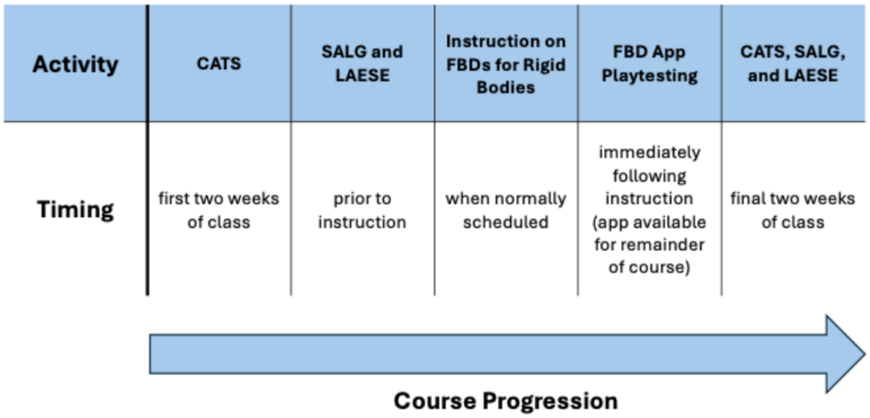


Figure 4 Timeline of Research Activities Related to Intervention and Data Collection

## 3 Methods

### *3.1 Positionality Statement*

Our research team includes two women and one man, two of whom are mechanical engineering faculty members and one of whom is an education researcher in a Center of Teaching and Learning. All three team members have doctorates of philosophy, representing traditional training for academic appointments. One member was a first generation college student. For their bachelor's degrees, one of the authors attended small private liberal arts colleges and one attended a large public university. One faculty member is pre-tenure and one is tenured.

All team members identify as white. While the purpose of this paper is to identify learning gains for BIPOC students, our ability to recognize markers of learning, including self-efficacy and technical understanding, for this group is limited based on our experiences, which differ from those within the BIPOC community. The authors of this paper endeavor to minimize the impacts of our white privilege by listening to the experiences of individuals from the BIPOC community and educating ourselves about the histories of different groups of people. However, these strategies will never fully ameliorate the fact that our personal experiences that we bring to research are irrevocably shaped by the privileges of being white. Furthermore, we acknowledge that there are a variety of perspectives within BIPOC groups and that our personal work is not all encompassing.

### *3.2 Research Design*

The analyses presented in this paper build upon earlier studies that describe in more detail the design of the app and establish proof of concept of its ability to improve student learning. This study extends those analyses by further examining the app's ability to address gaps in self-efficacy across BIPOC and white students and the role of closing that gap in making opportunities to learn statics more inclusive and equitable. We use quantitative data from a Student Assessment of their Learning Gains survey (SALG). The course and app specific questions added to the survey tool and our decision to explore student self-efficacy as a metric for learning is informed by our marginalized identities and experiences. Self-efficacy has been associated with positive outcomes for persons with marginalized identities within non-traditional fields. Being acutely aware of this effect, because of our individual identities, led to this being a central focus of this work.

The study uses a sequential quasi-experimental design to examine whether any gaps between BIPOC students and their white peers closed when students used the FBD app. In the first phase, independent t-tests were conducted to assess differences across BIPOC and white students. If significant gaps were to be identified in the first phase, the second phase would then assess a series of hypotheses that might explain why using the FBD app might close equity gaps. Four hypotheses for explaining differences in educational experiences were assessed using hierarchical multiple regression modeling. These hypotheses were:

Hypothesis 1: BIPOC students liked the app environment more than their white peers
Hypothesis 2: BIPOC students are more likely to be underprepared for college-level work and therefore found the extra assistance provided by the app more useful
Hypothesis 3: BIPOC students have different learning styles and the FBD App better suits how they learn
Hypothesis 4: BIPOC students have less self-efficacy, which negatively effects their FBD skills

### *3.3 Sample*

Participants included 317 students in six statics courses taught by three Mechanical Engineering faculty at two universities. All students in these six courses were offered the use of the FBD app to complement the typical curriculum; two thirds chose to use the app and one third did not. Fourteen percent of students were BIPOC, yielding a small, but sufficient sample for exploratory analyses.

It is also worth noting that the experimental group (those who completed half or more of the FBD App) and the comparison group (those who did not) were similar to each other in several ways that might otherwise have confounded the findings. Both groups have similar proportions of women (32% in the experimental group, 33% in the comparison group); any differences found between the experimental and control groups are not masking gender effects.

Those who used the FBD App had slightly more students who found it very easy to get the grades they wanted in high school and slightly fewer students who had to work hard to get the grades they wanted in high school (see Table 1); however, this difference was not statistically significant, with $\chi^2(3, n=169)=2.30$, $p=.51$. Furthermore, there were no significant differences in the proportions of students who indicated that they have to work less, the same, or harder than they did in high school to get the grades they want in college (see Table 2), with $\chi^2(2, n=169)=.24$, $p=.89$. Together, these two analyses suggest that the experimental group and the comparison group do not differ in terms of student engagement and motivation.

Table 1. Results of Chi-square Test and Descriptive Statistics for High School Effort by Comparison/Experimental Group

| **Level of High School Effort** | **Participant Assignment** | | | |
|---|---|---|---|---|
| | **Comparison Group** | | **Experimental Group** | |
| | ***n*** | ***%*** | ***n*** | ***%*** |
| Very easy to get the grades I wanted | 14 | 22% | 30 | 29% |
| With some exceptions, easy to get the grades I wanted | 22 | 34% | 36 | 35% |
| Had to work some to get the grades I wanted | 16 | 25% | 25 | 24% |
| Had to work hard to get the grades I wanted | 13 | 20% | 13 | 13% |

Note. $\chi^2 = 2.30$, df = 3.
$p = .51$

Table 2. Results of Chi-square Test and Descriptive Statistics for College Effort by Comparison/Experimental Group

| **Level of College Effort** | **Participant Assignment** | | | |
|---|---|---|---|---|
| | **Comparison Group** | | **Experimental Group** | |
| | ***n*** | ***%*** | ***n*** | ***%*** |
| Less than high school to get the grades I want | 2 | 3% | 2 | 2% |
| Same amount as high school to get the grades I want | 9 | 14% | 15 | 14% |
| Harder than high school to get the grades I want | 54 | 83% | 87 | 84% |

Note. $\chi^2 = .24$, df = 2.
$p = .89$

### *3.4 Data Collection and Measures*

The primary source of data was the Student Assessment of their Learning Gains (SALG) survey, which offers a post-only measure of students' learning and the extent to which they learned from each learning activity or resource. The questions on the SALG ask respondents to report their growth during a specified time frame (which is the statics course in this study), not the current state of their knowledge and skills. The survey was created with NSF funding and has been validated to provide similar information as pre-/post-surveys and student grades, including specifically with students taking statics. In other words, we have demonstrated in peer-reviewed work published prior to this study that students' self-reported growth in learning as captured by the SALG sufficiently represents the information that would have been collected with more direct measures of student learning, including improvement on exam scores and accuracy of analyzing and drawing free-body diagrams. We do not re-articulate the evidence from our analyses in this paper, though it is available in a peer-reviewed publication. For those interested in more information on why the SALG tool, specifically in this project, can adequately stand in for more direct measures, please see LeChasseur, et al., 2024.

We chose to use the SALG after establishing its validity because of the very real impact of survey fatigue on campus. After establishing that the self-report measures give us statistically similar information as more laborious measures of self-efficacy that require more time and cognitive load, we chose to use the SALG as a more efficient means of data collection. This allowed for a more ethical demand of fewer resources from our student participants.

All students in each course were invited to complete the survey, which also included a question specific to this study that asked students how much of the FBD app they completed. We have previously assessed the correlation between this self-report item and actual completion of game rounds in the app with a subset of identified students. We found it to be an accurate proxy, allowing us to use it with a broader sample of students who participated in more parsimonious data collection.

#### *3.4.1 Student Outcomes*

The primary outcome examined in the first phase of this study is students' skills drawing FBDs. We assessed this using an item on the SALG that asks students, "As a result of your work in this Statics class, what gains did you make in the following skills?" with one of the skills listed, "Drawing appropriate free body diagrams (FBDs) for given systems." Students could respond with "no gains," "a little gain," "moderate gain," "good gain," or "great gain." This is part of a measure that has been determined in prior research to significantly predict students' ability to correctly draw FBDs in hands-on activities in class.

#### *3.4.2 Learning Activities*

The study makes use of the SALG to isolate the effects of various learning activities from each other. Students were asked, "How much did each of the following aspects of this Statics class help your learning?" with several activities assessed, including "Attending lecture," "Participating in group work during class," and "FBD Mobile App." Students could indicate that each learning activity provided "No Help," "A Little Help," "Moderate Help," "Good Help," or "Great Help."

Qualitative data regarding the FBD App as a learning activity was also collected with an open-response item on the survey. This item asked students, "Please comment on how the FBD App did, or did not, help your learning. Specific examples would be particularly useful."

*3.4.3 Student Characteristics*

Our construction of the BIPOC binary indicator variable is particularly salient for reporting this study. The survey gave students the prompt, “I identify as” and gave six possible responses: Black/African American/African, Native American/Alaskan Native, Asian, Native Hawaiian or Pacific Islander, Latinx/Hispanic, White, and Other race/ethnicity. Respondents could select multiple options to describe how they identify and could provide a description if they selected “Other race/ethnicity” if they so chose.

For these analyses, we adopted an approach based on the logic of minoritization within undergraduate engineering education. While the term BIPOC is imperfect, all terms for non-white collectives that indicate a false binary are equally blunt instruments. We used student responses to this item to construct a binary indicator for BIPOC in which any student who indicated they were Black/African American/African, Native American/Alaskan Native, or Latinx/Hispanic were considered BIPOC. We also included in the BIPOC category anyone who self-identified as “Other race/ethnicity” and listed an ethnicity that is minoritized in engineering education.

### *3.5 Analysis*

Significance was set at $p < .05$ for all tests. Due to large differences in standard deviations across the two groups for multiple variables, we use Glass’s delta to report effect sizes rather than Cohen’s d.

## 4 Findings

### *4.1 Examining Equity Gaps Across BIPOC and White Students*

The first set of findings establish whether there is any evidence to suggest that those who use the FBD App close an equity gap in skills related to drawing FBDs. Among students who did not use the FBD app, there was a significant gap in learning across BIPOC and white students. BIPOC students indicated significantly less gains in their skills for drawing appropriate FBDs for given systems (M=3.67, SD=1.11) than white students (M=4.12, SD=.86), with $t(113)=1.84$, $p=.04$. This aligns with findings from prior studies that suggest that marginalized students report lower skills requiring visual comprehension and manipulation. The effect size was moderate in size, with Glass’s delta of .41; according to Hattie’s meta-analysis, this is equivalent to the effect size of having a positive self-concept and of professional development programs.

That gap disappears when we examine those who completed half or more of the FBD App. Within this group, BIPOC students reported nearly identical gains in their skills for drawing

FBDs (M=4.21, SD=.86) as white students (M=4.19, SD=.86), with t(193)=-.12, p=.45. Furthermore, BIPOC students significantly increased their ability to draw FBDs, with t(42) = -1.78, p=.04. This suggests that those using the FBD App effectively closed the equity gap among those who did not use it (see Figure X).

A second set of analyses confirm this initial finding. Students were asked, “How much did each of the following aspects of this Statics class help your learning?” Among those who used the app, BIPOC students indicated that it had a significantly greater impact on their learning (M=3.52, SD=1.15) than their white peers (M=2.92, SD=1.08), with t(192)=-2.72, p=.01. The effect size here is slightly larger, though still moderate in size with Glass’s delta of .52, which is roughly the same size effect as socioeconomic status and peer tutoring.

### *4.2 Assessing Potential Explanations*

#### *4.2.1 Hypothesis 1: BIPOC students liked the app environment more than their white peers*

The survey asked students “What did the FBD App environment feel like?” with four possible response options ranging from “It felt like a gamified environment” and “It felt somewhat like a gamified environment” to “It felt closer to a homework environment” and “It felt like a homework environment.” There were no significant differences across BIPOC and white students in the proportions who reported each type of experience of the app environment in either all students or among only those who completed half or more of the app (see Tables 3,4), with $\chi^2(3, n=231)=1.53$, p=.68 and $\chi^2(3, n=133)=.46$, p=.93, respectively. BIPOC students did not report engaging better through the app because they found it to be more like a game or take it more seriously because it felt more like “real” homework.

Based on these findings, we reject the first hypothesis as a potential explanation for the closing of racialized gaps in FBD drawing skills.

Table 3. Results of Chi-square Test for High School Effort by Race/Ethnicity for All Participants

| | **Student Race/Ethnicity** | | | |
|---|---|---|---|---|
| **FBD App Felt Like…** | **BIPOC Students** | | **White Students** | |
| | ***n*** | ***%*** | ***n*** | ***%*** |
| A gamified environment | 7 | 23% | 40 | 20% |
| Somewhat like a gamified environment | 15 | 50% | 112 | 56% |
| Closer to a homework environment | 8 | 27% | 43 | 21% |
| A homework environment | 0 | 0% | 6 | 3% |

Note. $\chi^2 = 1.53$, df = 3.
*p* = .68

Table 4. Results of Chi-square Test and Descriptive Statistics for College Effort for App Users

| FBD App Felt Like… | Student Race/Ethnicity | | | |
|---|---|---|---|---|
| | BIPOC Students | | White Students | |
| | *n* | *%* | *n* | *%* |
| A gamified environment | 4 | 29% | 21 | 27% |
| Somewhat like a gamified environment | 7 | 50% | 41 | 53% |
| Closer to a homework environment | 3 | 21% | 15 | 19% |
| A homework environment | 0 | 0% | 1 | 1% |

Note. $\chi^2$ = .24, df = 3.
*p* = .97

*4.2.2 Hypothesis 2: BIPOC students are more likely to be underprepared for college-level work and therefore found the extra assistance provided by the app more useful*

Students were asked two questions about how hard they have to work to meet whatever their version of successful grades looks like for them. The first asked, "My experience of the work required in high school classes was…" with four response options ranging from "It was very easy for me to get the grade I wanted in all my classes" to "I had to work hard to get the grade I wanted in my classes." There were no significant differences in self-reported effort required to succeed in high school in either all students or among only those who completed half or more of the app (see Tables 5,6), with $\chi^2$(3, n=168)=2.65, p=.45 and $\chi^2$(3, n=102)=1.53, p=.68, respectively.

Table 5. Results of Chi-square Test for High School Effort by Race/Ethnicity for All Participants

| Level of High School Effort | Student Race/Ethnicity | | | |
|---|---|---|---|---|
| | BIPOC Students | | White Students | |
| | *n* | *%* | *n* | *%* |
| Very easy to get the grades I wanted | 5 | 29% | 37 | 27% |
| With some exceptions, easy to get the grades I wanted | 11 | 50% | 46 | 53% |
| Had to work some to get the grades I wanted | 7 | 21% | 34 | 19% |
| Had to work hard to get the grades I wanted | 2 | 0% | 26 | 1% |

Note. $\chi^2$ = 2.65, df = 3.
*p* = .45

Table 6. Results of Chi-square Test for High School Effort by Race/Ethnicity for App Users

| Level of High School Effort | Student Race/Ethnicity | | | |
|---|---|---|---|---|
| | BIPOC Students | | White Students | |
| | *n* | *%* | *n* | *%* |
| Very easy to get the grades I wanted | 4 | 29% | 21 | 21% |
| With some exceptions, easy to get the grades I wanted | 7 | 50% | 41 | 41% |
| Had to work some to get the grades I wanted | 3 | 21% | 15 | 15% |
| Had to work hard to get the grades I wanted | 0 | 0% | 1 | 1% |

Note. $\chi^2$ = 2.47, df = 3.
*p* = .48

Though not significant with such a small sample size, there is a slight skew towards BIPOC students having to work less in high school to succeed than their white classmates. This may raise the question of whether BIPOC students had lower expectations to meet to deem themselves relatively successful in their high schools.

A second question asked students, "In college, I expect…" with three comparisons available: "I will have to work less than I did in high school to get the grades I want," "I will have to work the same amount as I did in high school to get the grades I want," and "I will have to work harder than I did in high school to get the grades I want." Once again, there were no significant differences in self-reported effort required to succeed in either all students or among only those who completed half or more of the app (see Tables 7,8), with $\chi^2(3, n=168)=1.08$, p=.58 and $\chi^2(3, n=102)=.48$, p=.79, respectively. Based on these findings, we reject the hypothesis that BIPOC students needed the assistance the FBD App provides more than their white classmates did.

Table 7. Results of Chi-square Test for College Effort by Race/Ethnicity for All Participants

| | **Student Race/Ethnicity** | | | |
|---|---|---|---|---|
| **Level of College Effort** | **BIPOC Students** | | **White Students** | |
| | ***n*** | ***%*** | ***n*** | ***%*** |
| Less than high school to get the grades I want | 0 | 0% | 5 | 4% |
| Same amount as high school to get the grades I want | 3 | 12% | 21 | 15% |
| Harder than high school to get the grades I want | 22 | 88% | 117 | 82% |

Note. $\chi^2$ = 1.08, df = 2.
*p* = .58

Table 8. Results of Chi-square Test for College Effort by Race/Ethnicity for App Users

| | **Student Race/Ethnicity** | | | |
|---|---|---|---|---|
| **Level of College Effort** | **BIPOC Students** | | **White Students** | |
| | ***n*** | ***%*** | ***n*** | ***%*** |
| Less than high school to get the grades I want | 0 | 0% | 1 | 3% |
| Same amount as high school to get the grades I want | 2 | 25% | 3 | 9% |
| Harder than high school to get the grades I want | 6 | 75% | 30 | 88% |

Note. $\chi^2$ = 1.79, df = 2.
*p* = .41

*4.2.3 Hypothesis 3: BIPOC students have different learning styles and the FBD App better suits how they learn*

Although the concept of learning styles, once popularized by Gardner and other educational psychologists [14,15], has been definitely debunked [16,17], many in higher education less familiar with the current research in this area still believe they play a meaningful role in student learning [18,19]. We anticipate that a number of engineering faculty might wonder whether the FBD App caters better to some students' learning styles than to others and, consequently, whether this might play into the closing gaps found in the first part of this study.

There were no significant differences in how much BIPOC and white students reported any of the various types of learning activities to be for their learning (see Table 9).

On the basis of these findings, in addition to prior research that demonstrates learning styles do not exist as such, we reject this potential explanation for why the FBD App was able to close racialized gaps in FBD drawing skills.

Table 9. Differences in the Impact of Learning Activities by Student Race/Ethnicity

| **Learning Activities** | **BIPOC Students** | | **White Students** | | | |
|---|---|---|---|---|---|---|
| | **M** | **SD** | **M** | **SD** | ***t*** | ***p*** |
| Attending Lecture | 4.29 | .97 | 4.10 | 1.02 | -1.28 | .20 |
| Participating in Class Discussion | 3.45 | 1.08 | 3.52 | 1.11 | .44 | .66 |
| Listening to Class Discussion | 3.96 | 1.14 | 3.74 | 1.07 | -1.43 | .15 |
| Group Work | 3.77 | 1.22 | 3.78 | 1.12 | .09 | .93 |
| Graded Projects | 2.94 | 1.16 | 2.91 | 1.16 | -.16 | .87 |
| FBD App | 3.44 | 1.19 | 2.62 | 1.12 | -3.33 | <.001 |

*4.2.4 Hypothesis 4: BIPOC students have less self-efficacy, which negatively effects their FBD skills*

BIPOC students indicated significantly less gains in their development of confidence that they can do statics work (M=3.59, SD=1.14) than their white peers (M=3.82, SD=.96), with $t(367)=1.62$, p=.05. The effect size is relatively small, with a Glass's delta of .24; however, this is similar in size to the effects of other popular interventions, such as personalized instruction and problem-based learning.

Based on this gap, we further explored the relationship between growth in FBD drawing skills, confidence in statics, and other learning experiences in the class. The model was significant, $F(9,299) = 19.04$, $p<.001$ (see Table 10) and explained 35% of the variance in FBD drawing skills, suggesting it is a modestly robust model.

Confidence in statics had a significant effect (ß = .13) similar in size to attending lecture (ß = .24). This means that the difference between having moderate confidence and good confidence in statics can offset the loss in learning between good quality lectures and moderate quality lectures. A regression model allows us to estimate the relative effects of different types of experiences on the predicted outcome by plugging in the values representing those experiences into the regression equation. In this case, the regression models students' gains in FBD drawing skills during the course; because the SALG item used as an outcome variable was highly correlated with gains in these skills as measured with problem sets, we can trust that the proxy provided by the SALG is sufficiently accurate for these purposes. The resulting unstandardized beta coefficients represent the change in outcome variable for each unit of that variable.

Table 10. Hierarchical Multiple Linear Regression of Willingness to Seek Academic Help among Full Sample of Students

| | Model 1: Demographic Controls | | | | | Model 2: Course-based Controls | | | | | Model 3: FBD App Mechanisms | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 95% CI | | | | | 95% CI | | | | | 95% CI | | |
| **Effect** | **b** | **SE** | **LL** | **UL** | ***p*** | **b** | **SE** | **LL** | **UL** | ***p*** | **b** | **SE** | **LL** | **UL** | ***p*** |
| Instructor | .06 | .12 | -.10 | .38 | .26 | .05 | .11 | -.10 | .32 | .30 | .02 | .11 | -.14 | .28 | .51 |
| BIPOC | -.03 | .14 | -.35 | .19 | .57 | -.09 | ,12 | -.44 | .02 | .08 | -.07 | .11 | -.39 | .05 | .14 |
| Woman | .03 | .11 | -.15 | .28 | .56 | <.01 | .09 | -.18 | .18 | .96 | .03 | .09 | -.11 | .24 | .48 |
| Attending Lecture | | | | | | .30 | .06 | .15 | .37 | <.01 | .24 | .06 | .10 | .32 | <.01 |
| Participating in Discussion | | | | | | .01 | .06 | -.11 | .12 | .92 | -.05 | .06 | -.15 | .07 | .49 |
| Listening to Discussion | | | | | | .25 | .06 | .09 | .32 | <.01 | .23 | .06 | .07 | .30 | <.01 |
| Group Work | | | | | | -.03 | .05 | -.13 | .09 | .72 | -.03 | .05 | -.12 | .08 | .70 |
| Group Projects | | | | | | .14 | .04 | .02 | .19 | .02 | .11 | .04 | <.01 | .17 | .04 |
| Confidence in Statics | | | | | | | | | | | .26 | .05 | .13 | .33 | <.01 |
| $R^2$ | .01 | | | | | .30 | | | | | .35 | | | | |
| $\Delta R^2$ | .01 | | | | | .29 | | | | | .05 | | | | |
| $F$ for $\Delta R^2$ | .71 | | | | | 27.31 | | | | | 22.31 | | | | |
| $p$ | .55 | | | | | <.001 | | | | | <.001 | | | | |

Note. Independent variable = Gains in FBD Drawing Skill; n = 309

This allows us to compare situations by entering in values for each part of students' experience. When we calculate the predicted gains in FBD drawing skills for students who experienced a moderate quality lecture by multiplying the value for that response on that predictor variable (3) and multiplying by the beta coefficient (.24), which translates into a .72 increase in predicted gains in FBD drawing skills (on a scale of 1 = no gains to 5 = great gains). Increasing the quality from moderate to good would require increasing the value for the predictor variable to 4, which adds an additional .24 in the increase gains. That additional learning is therefore lost when attending lecture moves from a good experience to a merely moderate one.

With the beta coefficient for confidence in statics being nearly identical in strength (.26), increasing students' confidence on unit, from moderate to good, can make up for learning gains that do not happen in moderate quality lecture experience. Quantifying the effects to allow this comparison provides a pragmatic means of assessing the relative value of each influence on learning how to draw FBDs. In this dataset, the quality of lecture and students' confidence have a similar degree of influence. This suggests an incredibly important role for closing any equity gaps in students' confidence for translating into more equitable learning outcomes.

## 5 Discussion

### *5.1 Significance*

The analyses in this study provide proof of concept that the FBD App can act as an equity lever in teaching statics within at least these two contexts. Although not generalizable, the effects were of large enough size to be detectable even with modest statistical power. Finding these effects suggests that there is sufficient promise to invest in expanding the study to collect larger samples of data to further explore the relationships between using the FBD App, learning outcomes, and student identities marginalized in STEM.

As we established this proof of concept, this study provides an example of why assessing the impact of educational interventions on a variety of historically marginalized students is important - and not only after accumulating large sample sizes. Not only is this often impractical in STEM where BIPOC students are severely underrepresented, it is apparently also not always necessary for detecting meaningful patterns. Part of the significance of this study is the encouragement it can provide other academics to conduct similar analyses during the development phase of new tools and interventions.

### *5.2 Limitations*

The small sample size and limited institutions participating in the study mean that the results of the statistical tests in this study are not generalizable and have limited transferability. The study demonstrates initial findings to establish whether additional study is likely to yield valuable findings.

There may also be other hypotheses that could contribute to explaining why the FBD App is particularly useful for BIPOC students. The analyses in this study explored four possibilities to reduce the alternative explanations and isolate the FBD App as the mechanism at play. They do not provide an exhaustive assessment. Further, while hypothesis testing points to self-efficacy and the app's ability to increase it as a particularly salient experience for BIPOC students, the data do not explore why or how this happens.

### *5.3 Future Research*

Our next phase will involve implementing the app with a larger sample across multiple institutional contexts. We have plans to collaborate with faculty across a range of institutional types beginning in the 2025-26 academic year, including Minority Serving Institutions and community colleges, which should increase the sample of BIPOC students available to replicate these analyses. The larger sample and additional types of institutions will improve the very limited generalizability of the current study.

The larger sample of BIPOC students will also hopefully allow for more nuanced analyses that acknowledge and respect that there are distinct racial/ethnic experiences and not all non-white people can be collapsed into singular narratives. With larger samples of each group of marginalized identity, we might find that there are different mechanisms that threaten equity in learning and support.

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