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Impacts of a Free-body Diagram Mobile App on Content Mastery and Women's Self-Efficacy

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Abstract

Objectives: Current techniques for learning to draw free-body diagrams (FBDs) are insufficient for some students. This study examines the potential for an app that gamifies learning how to visualize and construct FBDs. The value of this innovation for women, who tend to rate their spatial skills and STEM self-efficacy lower than their peers who are men, was examined to assess the app's potential as a tool for retaining women in engineering.

Methods: This study uses an experimental design to assess the efficacy of a new app. Participants included 245 first- and second-year students in three sections of statics at two universities (Worcester Polytechnic Institute and Bucknell University). Another 197 WPI students who took statics before the app was created serve as a comparison group. Of the participants, 37% are women and 14% BIPOC. Data were collected using the retrospective Student Assessment of their Learning Gains - an NSF-funded and validated survey that asks students how much they learned for each of a set of learning objectives and the extent to which they attribute their learning to specific learning activities. Items were combined to construct measures of growth in self-efficacy related to statics, content mastery, and willingness to seek help. Independent sample t-tests and hierarchical multiple linear regression were used to assess learning outcomes and differences across genders and app use.

Results: Students who had the app available and completed half or more of the game levels reported significantly greater gains in their ability to draw appropriate FBDs for given systems than those who did not have the app available to them. In a second set of analyses with the students who completed at least half the game levels in the app, using the FBD app was a significant predictor of content mastery after controlling for the influences of demographics, the professor, self-efficacy, attending lecture, listening to and participating in class discussion, and group project work. Other significant predictors included attending lecture and self-efficacy. Women who used the app reported greater gains in self-efficacy related tostatics and willingness to seek help than men; there were no gender differences in content mastery. Multiple linear regression models indicate that these gender effects remain after controlling for BIPOC status, the professor leading class, the influences of attending lecture, listening to and participating in class discussion, group project work, and using the FBD app; among those who did not use the app, women reported fewer gains in self-efficacy than men after these controls.

Implications: Each year, more than 600,000 students enter engineering programs in the United States. These students plan to master a challenging skill set that requires them to understand how to model and analyze real world problems. Frustrating core course experiences can dissuade students from continuing to pursue an engineering degree and subsequent career. These findings provide emerging evidence that gamifying learning can be useful for all students taking statics, but particularly for women.

Keywords: statics, women, self-efficacy, content mastery, curriculum development

1 Introduction

Being able to draw a free-body diagram (FBD) correctly is a foundational skill in many engineering disciplines. Instruction about how to draw a free-body diagram is typically provided in a physics and/or statics class early in an engineering program, with the skill then being employed throughout the curriculum and in engineering practice. Because a FBD serves as an effective tool for the first-order analysis of almost any scenario involving mechanics, it is ubiquitous in industry. Thus, efforts to improve the ability of students to draw complete and accurate FBDs represent a crucial way of increasing the effectiveness of the engineering workforce.

Current techniques for learning to draw free-body diagrams are insufficient for some students. This is because opportunities to practice drawing FBDs have traditionally been in the context of homework, using problems sourced from a textbook. This type of learning environment suffers from drawbacks because (1) the process of drawing FBDs is not scaffolded into discrete tasks (e.g. isolating the body), (2) the ability to practice only a particular task is not possible, and (3) feedback is not immediate. The lack of immediate feedback is a particularly important issue, as immediate feedback is necessary to prevent students from reinforcing bad practices and has been shown to be an important factor in learning [1,2].

Although learning to reliably draw accurate FBDs is difficult for most students, women may be at a disadvantage when developing this skill for two major reasons. First, one of the largest gender-related differences in cognitive skill is related to spatial visualization techniques. Women may initially have more difficulty visualizing FBD scenarios, but studies have shown these spatial skills are not fixed and can be improved [3]. Second, and perhaps more importantly, women consistently rate themselves as having lower confidence in their ability to formulate and solve engineering problems [4-6] and may feel like they do not belong in engineering [7,8]. Studies have shown that building up confidence, or self-efficacy, in women and BIPOC (Black, Indigenous, People of Color) engineering students is particularly important for them to be successful [9]. Therefore, new techniques for teaching FBDs that target women engineers, helping them to build both skills and self-efficacy, are particularly important to resolving perennial issues with recruiting and retaining women in many engineering disciplines [10].

This study examines the potential for an app that gamifies learning how to visualize and construct FBDs. The value of this innovation for women, who tend to rate their spatial skills and STEM self-efficacy lower than their peers who are men, was examined to assess the app's potential as a tool for retaining women in engineering.

2 App Development

The FBD app was developed for both Android and iOS platforms with a focus on short, problem-solving mini games because of their known appeal to broad audiences, including women and casual gamers [11]. The idea behind using mini games was to scaffold the FBD process into discrete tasks; careful scaffolding has been shown to improve learning in an app-based environment [12]. Additionally, immediate user feedback, in the form of hints and solutions, is provided for each mini game. Feedback is another way of driving student learning that is supported by research [1,2].

There are currently 3 mini games available for play. Each of the games focuses on a key skill or processes associated with developing and drawing FBDs. In the first game, "Connection Identification," users identify pictorial image representations of standard 2D and 3D boundary conditions, see Figure 1. These connections "fall" from the top of the screen and users sort them based on prompts given in each level. Upon completion of each level, users receive a summary report detailing the connections with which they struggled.

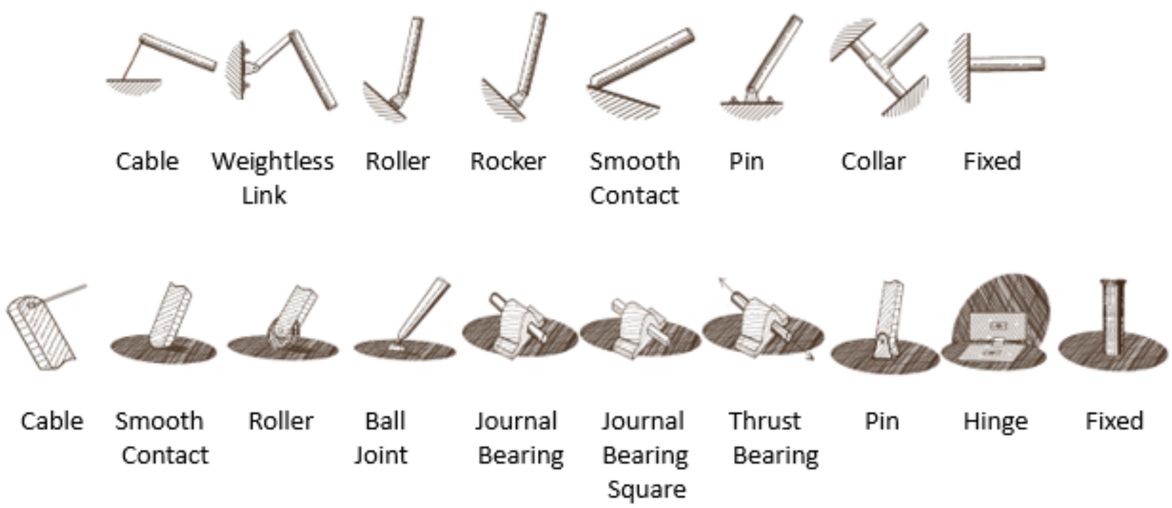
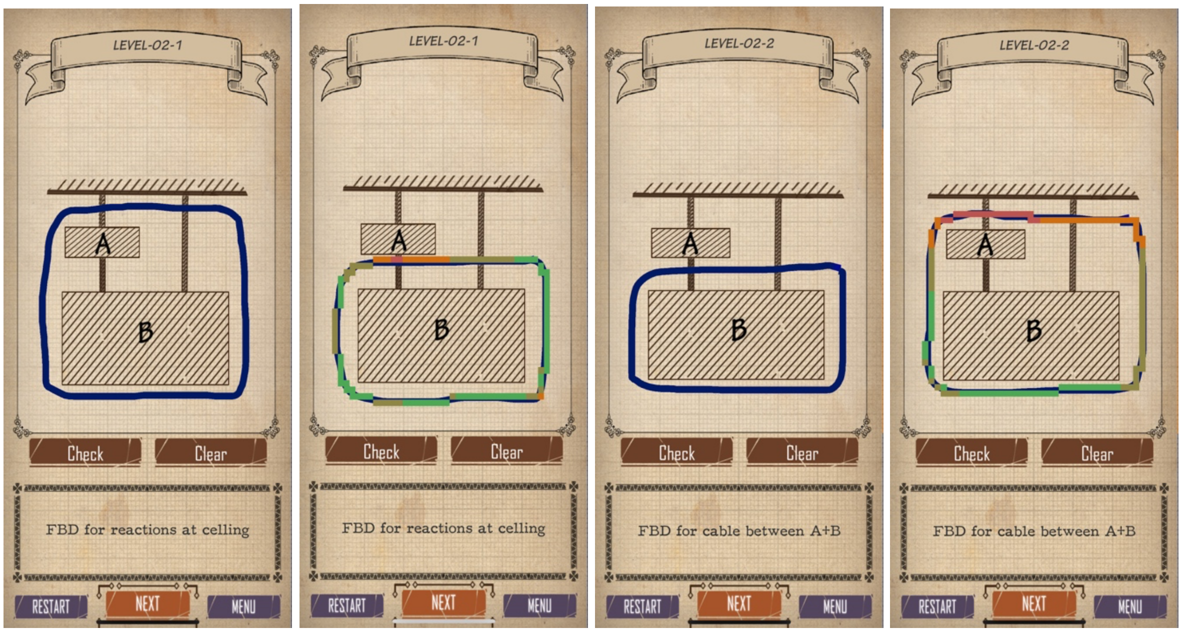


Figure 1: 2D and 3D boundary conditions from the "Connection Identification" mini game.

In the second game, "System Identification," users practice isolating a body of interest based on a prompt given within the level. Levels are given in sequences that allow users to isolate multiple systems from the same image based on changing prompts. This skill is particularly important when analyzing real world and multi-component systems. Users use their finger to trace their answer and are provided feedback based on a color-coded heat map. See Figure 2 for examples of the multi-component systems and the heat map hints system. Areas with green are correct and areas with orange and red show users when they are near, or within, areas that should not be included within the system. Users have unlimited attempts to determine the correct body to isolate for the given prompt.



(a) (b) (c) (d)

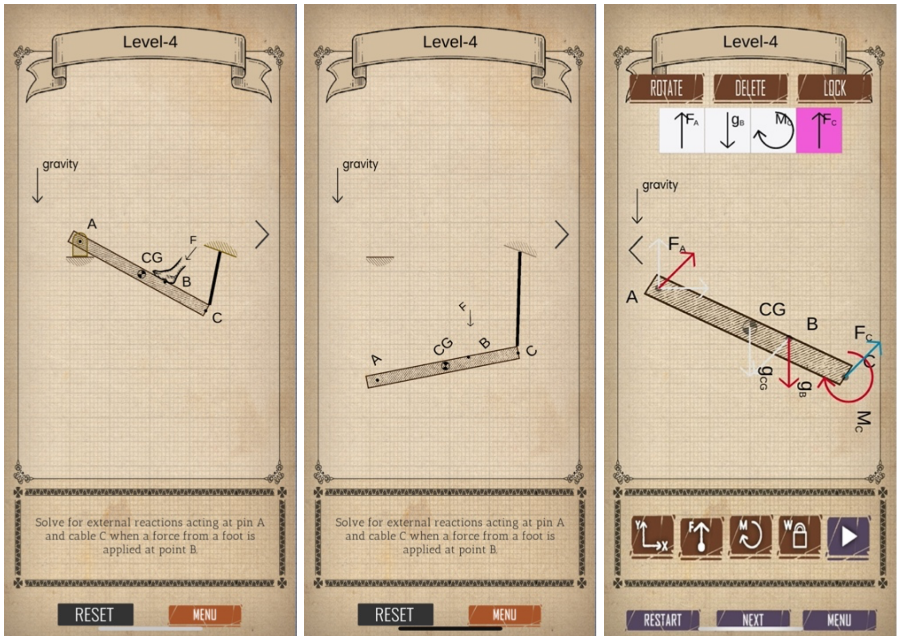
Figure 2: Images (a) and (b) show "System Identification" level 02-1. The correct answer is shown with a traced blue outline in (a). An incorrect attempt is shown in (b). Areas highlighted in red and orange in (b) are hint system indications of error used to guide the user to the correct response. Images (c) and (d), from level 02-2, use the same system but the prompt asks for a different FBD.

In the third mini game, "Free-Body Diagram," there are two interface screens. The first screen shows the system of interest connected to the outside world with standard boundary conditions. Users can interact with these boundaries to see their associated physics. On the second screen, users identify the system of interest based on the prompt before dragging and dropping elements (forces, moments, coordinate system, and weight) onto the body. A multi-level feedback system is incorporated into this mini game to provide guidance to the users as they play. See Figure 3 for an example of both screens within this game and the feedback from one of the hint types.

Each of these mini games was created and developed by a team of students, staff, and faculty using multiple prototypes, focus groups, and beta testing. Follow-up interviews from various stakeholder groups were also helpful in the development of feedback mechanisms and other mini-game refinement. Additional details about the process of developing the app and richer descriptions of the mini games are available in previous work by the authors [13].

3 Methods

The three studies described in this paper use a sequential quasi-experimental design to assess the efficacy of the new app and its potential benefits for women. The research question guiding the study asked, "To what extent does the FBD App benefit women's development of self-efficacy, content mastery, and willingness to seek help on academic problems?"



(a) (b) (c)

Figure 3: Level 4 from the FBD game shows a beam supported by a pin and a cable. Image (a) shows the initial state in the level's first screen, and image (b) shows the physics of the cable. Image (c) 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.

3.1 Sample

Participants included 245 first- and second-year students in three sections of statics at two universities (Bucknell University and Worcester Polytechnic Institute). Of the participants, 37% are women and 14% BIPOC. The design makes use of a comparison group that did not use the app to strengthen causal claims. Students were given the opportunity to use the FBD app during a class period and then to continue to use the app to support their learning outside of class; data was then collected on how many of the levels they played. Those who completed half or more of the levels were considered part of the experimental group, which comprised 136 students (56% of the sample). Those who did not use the app at all or who explored some levels but not half or more were considered part of the comparison group, which comprised 109 students (44% of the sample). Within the comparison group, 57% of students did not use the app at all. There were no significant differences in any classroom experiences or outcomes of interest in this study between those who did not engage the app at all and those who explored the app, but did not regularly use it, which justified combining the two into a single comparison group.

3.2 Data Collection and Measures

Data were collected using the retrospective Student Assessment of their Learning Gains - an NSF-funded and validated survey [14] that asks students how much they learned for each of a set of learning objectives and the extent to which they attribute their learning to specific learning activities. The SALG has been used to date by more than 22,000 instructors to assess approximately half a million students.

3.2.1 Student Outcomes

Items were averaged to construct measures of growth in content mastery, self-efficacy related to statics, and willingness to seek help. Each of the items included the same question stem: "As a result of your work in this statics class, what GAINS DID YOU MAKE in your UNDERSTANDING of each of the following?" Response options were on a five-point Likert scale from no gains (1) to great gains (5). Content mastery included four items: the main concepts explored in this class, the relationships between the main concepts, identifying what type of problem you are asked to solve (e.g., particle vs. rigid body, 2D vs. 3D), and drawing appropriate free body diagrams (FBDs) for given systems. Self-efficacy included three items: confidence that you understand the material, confidence that you can do Statics work, and your comfort level in working with complex ideas. Willingness to seek help was a single item: willingness to seek help from others (professor, classmates, friends) when working on academic problems.

3.2.2 Learning Activities

Five types of learning activities and their impact on student learning were assessed in the survey. Each item used the same question stem: "HOW MUCH did each of the following aspects of this Statics class HELP YOUR LEARNING?" Response options were on a five-point Likert scale from no help (1) to great help (5). The items were: attending lectures, participating in discussions during class, listening to discussions during class, participating in group work during class, and the FBD Mobile App.

3.3 Analysis

Independent sample t-tests and hierarchical multiple linear regression were used to assess learning outcomes and differences across genders and app use. The overarching procedure for determining decisions across the three studies is outlined in Figure 4. Study 1 focused on examining whether the FBD App demonstrated efficacy for its intended design, addressing two questions: 1) Did those who used the FBD App experience greater gains in learning than those who did not?, and 2) Does evidence of this efficacy remain after controlling for other potential influences on learning? This first study is necessary for establishing whether there are any indications that the FBD App's influence on learning to further explore or whether it requires additional development to meet its intended benefits for students.

Study 2 was designed to extend this foundation only if the results of Study 1 suggest that the FBD App has achieved basic efficacy. Study 2 examines whether there were any gender effects within the efficacy of the FBD App by addressing two additional questions: 1) Are there any differences in learning gains across genders?, and 2) Does evidence of this gender effect remain after controlling for other potential explanatory factors? This second study provides additional examination of whether there are different experiences among women compared to their peers who are men, but does not allow us to attribute any differences to the FBD App.

Study 3 was designed to deepen our understanding of which of any gender effects identified remain among those using and not using the app.

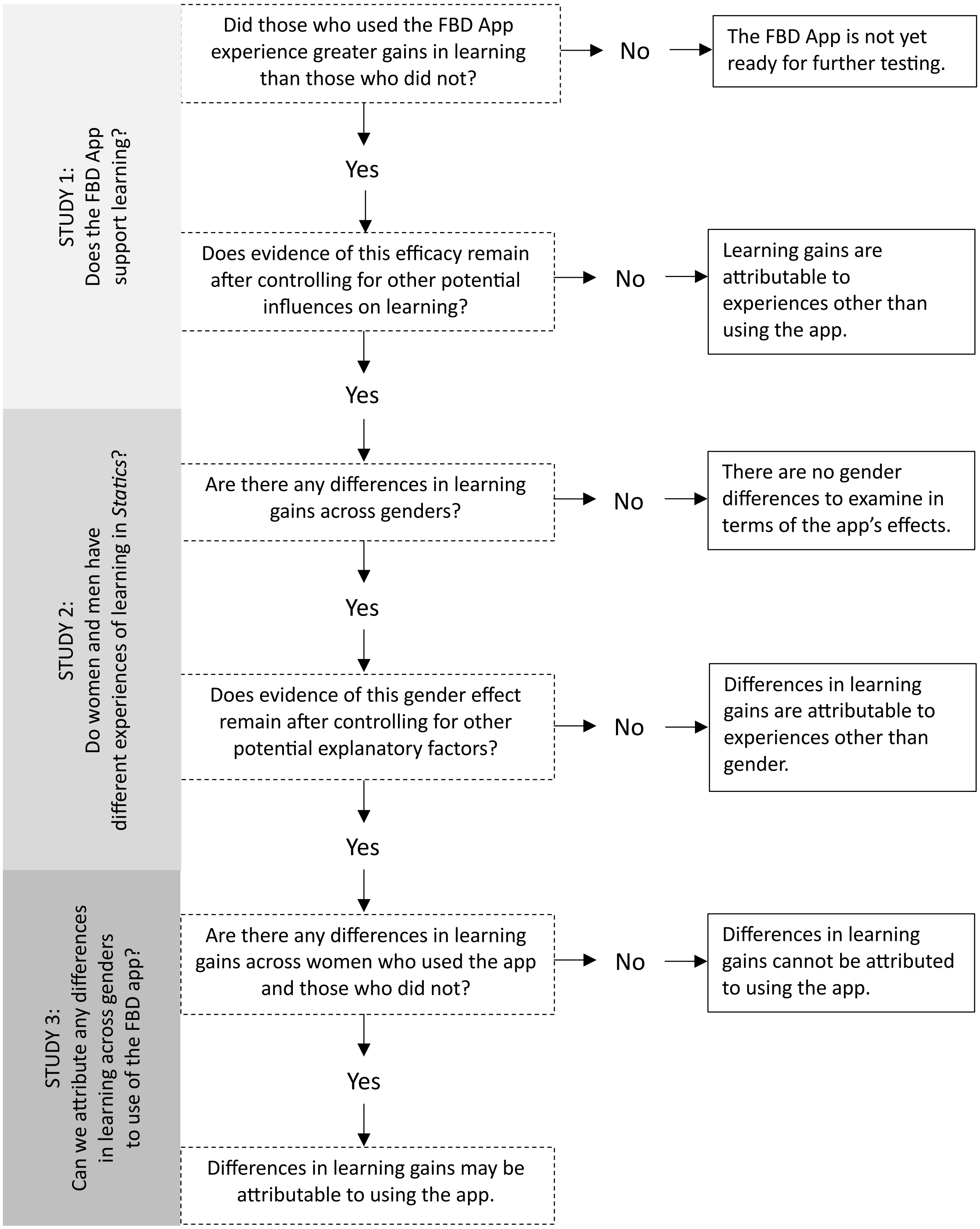


Figure 4: Methodological decisions guiding sequential design.

4 Results

For a brief description of the meaning of the statistical symbols used below, please see the list provided in section 8.

4.1 Study 1: Efficacy of the FBD App

In the first study, we assess whether the app does what it intends and supports student learning about the main concepts of Statics and how to draw FBDs. Students who had the app available and completed half or more of the games (n=136, M=4.15, SD=.64) reported significantly greater gains in content mastery than those who did not (n=127, M=3.94, SD=.65), with t(243)=-2.53, p=.01. More specifically, students who used the app (n=136, M=4.27, SD=.84) reported significantly greater gains in their ability to draw appropriate FBDs for given systems than those who did not (n=127, M=4.07, SD=.99), with t(261)=-1.78, p=.04. This establishes a foundation for the app's efficacy in teaching students how to draw FBDs.

We then conducted a second set of analyses with the students who used the app to model the influences on gains in content mastery. We constructed a series of hierarchical linear regression models to control for the influences of demographics, the professor leading class, students' sense of self-efficacy, and the influences of other course activities (attending lecture, listening to and participating in class discussion, and group project work). This allowed us to assess whether the relationship between using the app and content mastery was significant for students regardless of various factors, such as who was leading the class and the extent to which students felt confidence about their skills; it also allowed us to assess the relative influence of using the app against other learning activities used in the course.

The first model includes demographics, the instructor, and students' self-efficacy as a set of controls. Together, these account for 52% of the variance in content mastery gained during the course, which is substantial (see Table 1). The next model adds four predictors describing the influence of various learning activities - lecture, participating in class discussion, listening to class discussion, and group projects. Adding these parameters to the model explains an additional 8% of the variance, which is significant with a change in F(4,122)=7.11, p<.001. The third and final model includes one additional parameter describing the influence of completing half or more of the games in the app. This explains an additional 2% of the variance in content mastery, which - while seemingly small - is significant with a change in F(1,121)=6.16, p=.01. Using the FBD app was a significant predictor of content mastery (see Table 1).

After establishing that using the FBD app had a distinct influence on content mastery, we can assess the relative influence of the parameters by examining the standardized beta coefficients (see Table 1). Three parameters were significant predictors of content mastery: self-efficacy, attending lectures, and using the FBD app. Self-efficacy has the largest influence, at twice that of attending lectures and three times that of using the FBD app. While the content mastery gained through lectures is reported to be larger than that of using the app, they are similar in size.

Table 1. Effects of the FBD App after Controlling for Demographics, Instructor, and Learning Activities in Modeling Content Mastery

	Model 1: Control Variables					**Model 2: Learning Activities**					**Model 3: Gender**				
Effect	***B***	***SE B***	**β**	***t***	***p***	***B***	***SE B***	**β**	***t***	***p***	***B***	***SE B***	**β**	***t***	***p***
Intercept	2.03	.20	-	9.95	<.001	1.59	.22	-	7.17	<.001	1.49	.22	-	6.73	<.001
Woman	-.04	.08	-.03	-.45	.65	-.08	.08	-.06	-1.04	.30	-.07	.07	-.05	-.97	.33
BIPOC	.25	.11	.14	2.22	.03	.13	.11	.07	1.20	.23	.08	.11	.04	.71	.48
Professor	.11	.09	.08	1.24	.22	.04	.08	.03	.43	.67	.05	.08	.04	.65	.52
Self-efficacy	.52	.05	.70	11.41	<.001	.38	.05	.51	7.42	<.001	.38	.05	.51	7.51	<.001
Lecture						.19	.05	.27	3.56	<.001	.18	.05	.27	3.60	<.001
ParticipateDiscussion						-.01	.05	-.01	-.18	.86	-.03	.05	-.05	-.57	.57
ListenDiscussion						.10	.06	.16	1.80	.07	.09	.06	.14	1.58	.12
GroupProject						-.02	.05	-.02	-.29	.78	-.03	.05	-.05	-.64	.53
FBDApp											.10	.04	.16	2.48	.01
R^2	.52					.60					.61				
ΔR^2	.52					.08					.02				
F for ΔR^2	35.68					7.11					6.16				
p	<.001					<.001					.01				

Note. Dependent variable is content mastery, a composite of four items asking "As a result of your work in this statics class, what GAINS DID YOU MAKE in your UNDERSTANDING of the main concepts explored in this class; the relationships between the main concepts; identifying what type of problem you are asked to solve; drawing appropriate free body diagrams (FBDs) for given systems" with a five-point Likert scale from 1 (no gains) to 5 (great gain)
n = 131

To further understand the extent to which the app could make a meaningful difference for students, we used two cases to compare the effect of using the app to varying extents. Consider a student who was in Author 2's class, is a White woman with moderate self-efficacy who (like the average woman in the class) gained a good deal from lecture, if not the most possible gains. She did not participate much in class discussion, though found it somewhat useful to listen to it. She reports learning a moderate amount from group projects. If she were to use the app and find them only a little useful, she would be predicted to make "good gains" in content mastery during the course (see Figure 5).

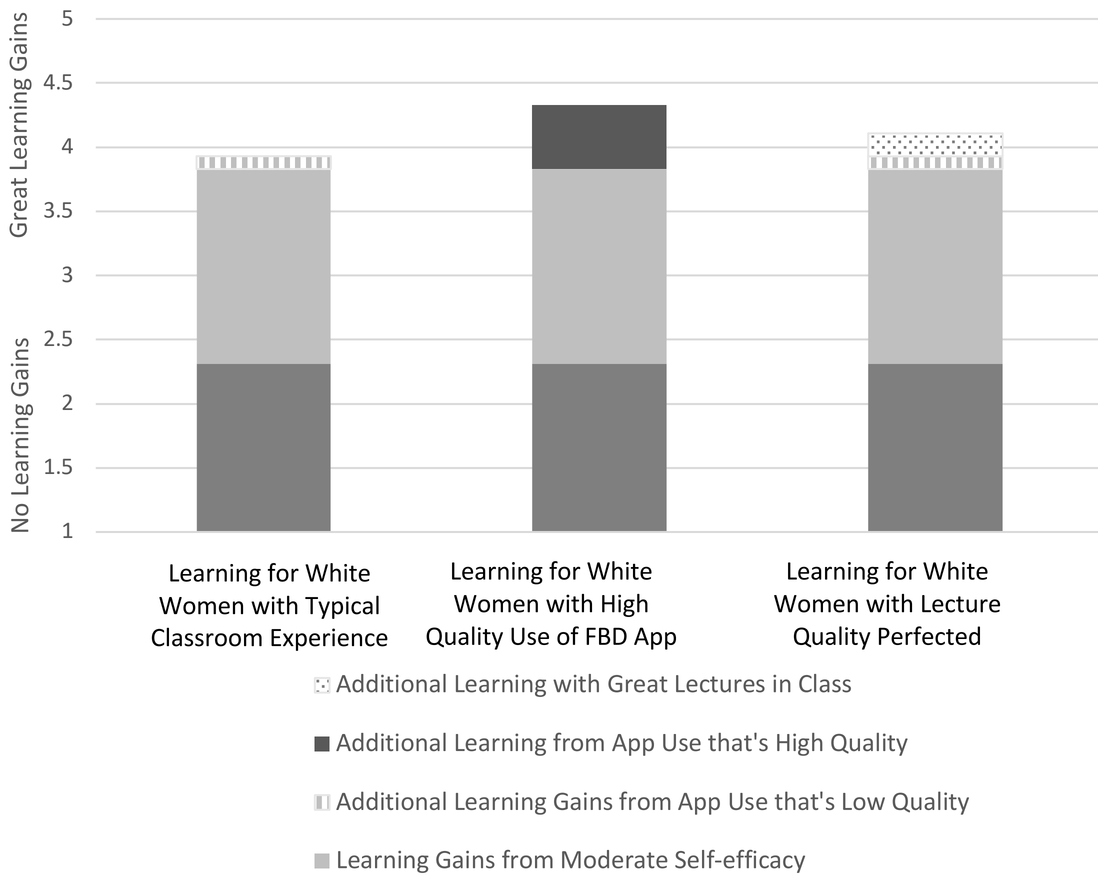


Figure 5: Benefits of the FBD app for gains in content mastery among white women.

However, if she were to have the same classroom experience plus find the app highly useful, the predicted gains in content mastery would increase from "good" to midway between "good" and "great" - a greater increase than what would be predicted if the quality of the lecture were perfected from having a good influence to a great one. The level of effort on the part of faculty to polish already strong lectures is significant, while the level of effort required to have students use the FBD app is insignificant. Thus, the app provides a robust, additional avenue to foster learning that is highly cost-effective to faculty. Overall, the potential for a highly useful app to provide additional meaningful benefits to students above and beyond those provided by lecture, class discussion, and projects is established with the predictive modeling fit to the data for this study.

We conclude that the body of evidence in Study 1 establishes the efficacy of the FBD app. Given this determination, we proceeded to conduct a second study to examine whether the FBD app has demonstrated benefits specifically for women.

4.2 Study 2: Gender Effects

4.2.1 Gender Differences in Self-efficacy Gains

We began the second study by examining gender differences for the full sample to establish justification for more sophisticated analyses. Overall, men reported greater gains in self-efficacy ($n=163$, $M=3.80$, $SD=.79$) than women did ($n=82$, $M=3.51$, $SD=.95$), which was significant with $t(243)=2.37$, $p=.01$. This trend is in line with research that suggests that men are more confident in their STEM knowledge and skills than women are [4-6]. Women reported greater gains in their willingness to seek help on academic matters ($n=82$, $M=3.94$, $SD=1.05$) than men did ($n=163$, $M=3.62$, $SD=1.10$), which was also significant with $t(243)=-2.19$, $p=.02$. Although this test does not attribute this growth to any particular experience, it establishes grounds for further exploring whether using the FBD app played a role in this experience. There were no significant differences between women ($n=82$, $M=3.99$, $SD=.64$) and men ($n=163$, $M=4.09$, $SD=.65$) for gains in content mastery when examining the full sample, with $t(243)=1.14$, $p=.25$.

The next stage of this study was to model gains in self-efficacy to determine whether these gender effects remain after controlling for BIPOC status, the professor leading class, and the influences of a set of learning activities (lecture, class discussion, group projects, and using the FBD app). We constructed a series of hierarchical linear regression models with the first model including two controls - BIPOC status and instructor. This model did not explain a significant portion of the variance in self-efficacy gains (see Table 2).

The second model added five parameters describing the influences of learning activities. This model accounted for 29% of the variance in self-efficacy gains, which was a significant change in $F(5, 228)=19.76$, $p<.001$. The additional significant explanatory power of this model suggests that the learning activities provide a moderate influence on students' self-efficacy. A third model then adds a binary indicator of gender, explaining a further 3% of the variance. This is a significant change in $F(1, 227)=8.62$, $p<.01$, indicating that there are meaningful differences in self-efficacy gains regardless of BIPOC status, which instructor led the class, or experience of learning activities. In the full model, the only other significant effects are the influences of lecture and participating in class discussion, which both have a positive effect on self-efficacy (see Table 2).

In terms of the size of the gender effect, being a woman had the same size effect as participating in class discussion, though in opposite directions (see Table 2). In other words, women who gained a lot from participating in class gained half the self-efficacy from this activity as men. Both gender and participating in class discussion had approximately half the influence of lecture.

Table 2. Gender Effects in Modeling Self-efficacy Gains

	Model 1: Control Variables					Model 2: Learning Activities					Model 3: Gender				
Effect	***B***	***SE B***	**β**	***t***	***p***	***B***	***SE B***	**β**	***t***	***p***	***B***	***SE B***	**β**	***t***	***p***
Intercept	3.62	.18	-	20.43	<.001	1.86	.24	-	7.78	<.001	1.96	.24	-	8.25	<.001
BIPOC	.06	.14	.03	.47	.64	-.20	.14	-.08	-1.36	.17	-.19	.14	-.08	-1.35	.18
Professor	-.02	.16	-.01	-.13	.90	-.11	.12	-.05	-.91	.37	-.12	.12	-.06	-1.05	.30
Lecture						.27	.07	.32	3.99	<.001	.27	.07	.32	3.98	<.001
ParticipateDiscussion						.16	.07	.20	2.38	.02	.14	.07	.18	2.09	.04
ListenDiscussion						-.03	.07	-.03	-.37	.71	.01	.07	.01	.09	.93
GroupProject						.09	.06	.12	1.47	.14	.09	.06	.11	1.46	.15
FBDApp						.03	.05	.04	.60	.55	.03	.05	.04	.57	.57
Woman											-.29	.10	-.16	-2.94	<.01
R^2	-.01					.28					.31				
ΔR^2	-.01					.29					.03				
F for ΔR^2	.12					19.76					8.62				
p	.88					<.001					<.01				

Note. Dependent variable is self-efficacy, a composite of three items asking "As a result of your work in this Statics class, what GAINS DID YOU MAKE in confidence that you understand the material; confidence that you can do statics work; your comfort level in working with complex ideas" with a five-point Likert scale from 1 (no gains) to 5 (great gain)

n = 131

4.2.2 Gender Differences in Willingness to Seek Help

The third stage of this study was to conduct a parallel examination of gender effects on willingness to seek help while controlling for the same set of experiences. Model construction was the same as in the second stage other than the change in dependent variable. The first control model does not account for a significant portion of the variance in willingness to seek help (see Table 3). After adding parameters describing the influence of learning activities, the second model accounts for 29% of the variance in willingness to seek help. This is a significant change in $F(5, 228)=19.04$, $p<.001$.

As with modeling gains in self-efficacy, adding a gender parameter to the model accounts for an additional small, though significant, 1% of the variance, with a change in $F(1, 227)=4.75$, $p=.03$. Three parameters have significant positive effects on gains in willingness to seek help in the final model: participating in class discussion, listening to class discussion, and being a woman (see Table 3). Given the additional significant explanatory power of gender after accounting for the effects of class discussion, we conclude from this third stage of analysis that further examination of the gender effects regarding willingness to seek help are warranted.

4.3 Study 3: FBD App Effects Among Women

After establishing the efficacy of the FBD app and that there are gender effects in some areas of learning, the final study examined whether these differences can be reasonably attributed to using the FBD app. There were no significant differences in self-efficacy gains between women who used the app ($n=47$, $M=3.68$, $SD=.93$) and men who used the app ($n=88$, $M=3.81$, $SD=.82$). However, men who did not use the app reported gaining greater self-efficacy ($n=73$, $M=3.79$, $SD=.78$) than women who did not use the app ($n=34$, $M=3.31$, $SD=.95$), which was significant with $t(105)=2.73$, $p=.01$. This suggests that using the app closed the self-efficacy gap for women. This is important because past studies have shown women tend to lose self-confidence during their first year of engineering education and tend to judge themselves more harshly than male peers [9].

Women who used the app reported greater gains in willingness to seek help ($M=4.26$, $SD=.85$) than those who did not use the app ($M=3.53$, $SD=1.16$), which is significant with $t(57.18)=-3.10$, $p<.01$. There were no other significant differences between women who did and did not use the app in other learning outcomes.

5 Conclusions

Students who used the FBD App reported greater gains in content mastery than those who did not, suggesting that the app is an efficacious tool for supporting learning about how to identify, analyze, and draw FBDs. Men gained more self-efficacy in the classes included in the study than women did; however, using the FBD App closed the gap in self-efficacy for women. In addition, women gained greater willingness to seek help on academic problems than men, which may be attributable to using the FBD App.

Table 3. Gender Effects in Modeling Gains in Willingness to Seek Help

	Model 1: Control Variables					Model 2: Learning Activities					Model 3: Gender				
Effect	***B***	***SE B***	**β**	***t***	***p***	***B***	***SE B***	**β**	***t***	***p***	***B***	***SE B***	**β**	***t***	***p***
Intercept	3.58	.22	-	16.12	<.001	1.48	.30	-	4.90	<.001	1.38	.30	-	4.57	<.001
BIPOC	.47	.21	.15	2.30	.02	.22	.18	.07	1.21	.23	.21	.18	.07	1.19	.23
Professor	.06	.17	.02	.37	.72	-.11	.15	-.04	-.73	.47	-.10	.15	-.04	-.65	.52
Lecture						.06	.09	.06	.68	.50	.06	.09	.06	.74	.46
ParticipateDiscussion						.20	.08	.20	2.39	.02	.22	.08	.22	2.63	.01
ListenDiscussion						.22	.09	.22	2.52	.01	.19	.09	.19	2.17	.03
GroupProject						.10	.08	.10	1.24	.22	.10	.08	.10	1.28	.20
FBDApp						.08	.06	.09	1.31	.19	.08	.06	.09	1.35	.18
Woman											.28	.13	.12	2.18	.03
R^2	.01					.29					.30				
ΔR^2	.01					.28					.01				
F for ΔR^2	2.67					19.04					4.75				
p	.07					<.001					.03				

Note. Dependent variable is gains in willingness to seek help with academic problems with a five-point Likert scale from 1 (no gains) to 5 (great gain)
n = 131

6 Implications

Each year, more than 600,000 students enter engineering programs in the United States [10]. These students plan to master a challenging skill set that requires them to understand how to model and analyze real world problems. Frustrating core course experiences can dissuade students from continuing to pursue an engineering degree and subsequent career [15]. These findings provide emerging evidence that gamifying learning can be useful for all students taking statics, but particularly for women.

The learning environment of the FBD app offers several advantages over conventional, homework-based practice because it (1) scaffolds the process of drawing FBDs into discrete tasks, (2) allows students to practice only a particular task in a way that is asynchronous and location independent, and (3) provides immediate feedback in the form of both hints and solutions. Taken together, these features mean that students can practice tasks with which they have difficulty until they are confident in their abilities, with mistakes caught and corrected as they happen. This makes it an effective environment for developing mastery, which is associated with building self-efficacy [16]. Our study demonstrates this self-efficacy building effect in women while also proving the app is effective in helping all students learn to construct FBDs.

Past efforts to harness computer-based environments to teach FBDs, such as a FBD Assistant developed at Vanderbilt University [17], the physics tutoring program *Andes* [18], and the freehand FBD software *Mechanix* [19] have demonstrated FBD-related learning gains. However, none of these interventions included study of student self-efficacy. Here we demonstrate that ascertaining how a learning environment impacts student self-efficacy is also an important consideration, to ensure underrepresented populations, such as women, are being included and equipped by a given intervention. We urge developers of computer-based learning tools to include assessment of self-efficacy as part of their data collection process.

While these initial outcomes are promising, there are three areas for future research that are necessary to strengthen conclusions regarding the app's efficacy. First, a broader sample is warranted to assess the extent to which these findings are transferable across contexts. The student population involved in the study was relatively small and both institutions involved were private not-for-profits. Future research will need to include a larger group of students, ranging across institutions from community colleges to R1 universities, to assess the app's efficacy over a wider population and set of circumstances.

Second, although the effects of which faculty member taught the class were controlled in the regression models, it is unclear if the app would be as effective for *any* instructor. More data would need to be collected from more faculty using the app to assess whether this is the case. Additionally, we hypothesize that how the app is implemented in the context of a course is likely important to its effectiveness. By this we mean how the app is deployed and how faculty use the app to complement other learning activities may affect outcomes. As our regression analysis demonstrates, other learning activities–like lectures–are very important; the app is not a replacement for these activities but an additional avenue to reach students, help them practice, and drive learning gains.

Finally, additional research is needed to determine whether the boost in self-efficacy and willingness to seek help experienced by women who used the app is sufficient to alter their subsequent experiences. Does being willing to seek help influence grades in future courses? Does the increase in self-efficacy last and does it influence retention in engineering? These questions will remain unanswered without further research.

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8 Statistical Symbols

B: unstandardized regression coefficient
β: standardized regression coefficient
F: F-value
M: mean
n: number of samples
p: p-value ($p < 0.05$ considered statistically significant)
R^2: coefficient of determination
SD: standard deviation
SE B: standard error of B
t: t-value

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