The Impacts of Instructor and Student Gender on Student Performance in Introductory Modeling Instruction Courses

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Abstract. This study considers the impact of instructor on the gender gap in students’ scores on the Force Concept Inventory (FCI) in Modeling Instruction (MI) courses at Florida International University (FIU). Earlier work has shown that MI had increased FCI scores overall when compared to traditional lecture courses; however, the gap between male and female students’ scores in the MI courses increased over the course of the semester. Student data were collected from 559 students at FIU, over 18 semesters, with 10 different instructors. General linear regression was used to determine the significance of the student gender and instructor factors in predicting a student’s FCI score post-instruction and the fraction of variance explained by these factors. Effect sizes were then calculated from the difference in female students’ gains from male students’ gains and compared between instructors. Analysis showed an instructor-independent, medium effect favoring male students’ scores on the FCI.

Keywords: Physics Education, Modeling, Gender, Instructor, FCI, Introductory

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INTRODUCTION

It has long been a standard in physics that male students outperform female students, be it on classroom tests, course grades, or standardized concept inventories \cite{1, 2}. This difference in scores is often referred to as the “gender gap”. Recently, the gender gap on physics concept inventories was shown to be present across multiple different inventories and institutions, including both lecture-style and reformed-style teaching methods \cite{2}.

In particular, Brewe et. al found “Modeling Instruction (MI) widens the understanding gap on FCI scores that exists between men and women prior to instruction” at Florida International University (FIU)--a large, Hispanic-serving institution \cite{3}. MI is a reformed curriculum and pedagogy where lecture, lab, and recitation are combined in a studio format, which encourages students’ participation and agency through group activities and guided classroom discussions \cite{4}. Students are responsible for developing, testing, evaluating, and revising models, which are defined as a coordinated set of representations that can be used to explain, predict and describe a particular class of phenomena \cite{5}. In this classroom format, students’ FCI scores, for both male and female students, were shown to be higher when compared to the equivalent lecture-based course. Despite the careful design and planning that went into the MI mechanics course, it is still plagued with the growth of the gender gap internal to the course, providing larger FCI gains for male students than for female students \cite{3}.

The purpose of this study is to explore the difference in FCI scores between male and female students in the introductory MI courses at FIU, using the existing FCI data archive at FIU, and to propose plausible explanations for the results found.

METHODS

FCI data were collected through 18 semesters of introductory mechanics MI courses, spanning from Fall 2004 to Fall 2013 \cite{6}. During this time, 10 different instructors taught the course, bringing a variety of backgrounds and experiences to the classroom. Pre- and post- FCI scores were matched for 559 students, 257 of which were female and 302 of which were male. The number of matched scores for each instructor varied from 17 to 153, depending on the number of semesters the instructor taught and the number students in each section.

Histograms of students pre- and post-FCI scores, shown in Figure 1, reveal notably different distributions in post-scores when disaggregated by student gender. The pre-score distributions for both male and female students are similar and skewed toward the low end of the range; however, the post-score distribution for male students shows both an overall shift toward higher scores and the distribution itself is now skewed toward higher scores, while the post-score distribution for female students only shows an overall shift toward higher scores, maintaining the right skewed distribution seen in the fe-
male pre-scores. Similar distributions and shifts are seen when the data are separated by instructor.

**General Linear Regression**

In order to further investigate the difference in scores seen in Figure 1, general linear regression was used on the raw FCI scores (out of 30 points) to determine how much of the variance in students’ post-FCI scores could be determined by the students’ pre-FCI scores, genders, and instructors. Note that all instructors in the model were compared to Instructor A because Instructor A had both the most experience teaching MI and the greatest number of students overall. This makes Instructor A the natural baseline for comparison. A threshold of \( \alpha = 0.05 \) was used to determine significant results.

**Effect Size**

To quantify the difference in scores, the raw percentage gain (\( \% \text{Gain} = (\text{Post}\% - \text{Pre}\%) \)) was calculated. (Raw gain is used over normalized gain because of the non-linear nature of normalized gains.) Cohen’s \( d \) was then calculated from the students’ gains using

\[
d = \frac{\mu_f - \mu_m}{\sigma_{pooled}} \tag{1}
\]

where \( \mu_f \) is the average gain for female students, \( \mu_m \) is the average gain for male students, and \( \sigma_{pooled} \) is the pooled standard deviation given by

\[
\sigma_{pooled} = \sqrt{\frac{(n_f - 1)s_f^2 + (n_m - 1)s_m^2}{n_f + n_m - 2}} \tag{2}
\]

Here, \( n_f \) & \( n_m \) are the number of female and male students, and \( s_f \) & \( s_m \) are the standard deviations of the female and male gains, respectively [7, 8]. Cohen’s \( d \) was calculated for the total data set as well as for each instructor. The 95% confidence interval (CI) was calculated from

\[
CI = d \pm 1.96 \times s_d \tag{3}
\]

where \( d \) is from equation (1) and \( s_d \) is given by

\[
s_d = \sqrt{\frac{n_f + n_m}{n_f \times n_m} + \frac{d^2}{2(n_f + n_m)}} \tag{4}
\]

where \( n_f \) and \( n_m \) are the same as from equation (2) and \( d \) is again from equation (1) [8]. Thus, Cohen’s \( d \) serves as a measure of the magnitude of the gender gap in students’ gains of FCI scores. As an effect size, Cohen’s \( d \) allows for the comparison of the gender gap across instructors with varying numbers of students.

**TABLE 1.** Summary of general linear regression for post-FCI score as predicted by pre-FCI score, student gender, and instructor. All instructors listed are compared to Instructor A. The bold face p-values are those that were considered significant at \( \alpha = 0.05 \).

<table>
<thead>
<tr>
<th>Factor</th>
<th>Estimate</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-FCI Score</td>
<td>0.728</td>
<td>( \approx 0 )</td>
</tr>
<tr>
<td>Male</td>
<td>2.504</td>
<td>( \approx 0 )</td>
</tr>
<tr>
<td>Instructor B</td>
<td>-1.760</td>
<td>( 0.001 )</td>
</tr>
<tr>
<td>Instructor C</td>
<td>-2.498</td>
<td>( 0.008 )</td>
</tr>
<tr>
<td>Instructor D</td>
<td>-1.940</td>
<td>0.067</td>
</tr>
<tr>
<td>Instructor E</td>
<td>-3.062</td>
<td>( \approx 0 )</td>
</tr>
<tr>
<td>Instructor F</td>
<td>-3.304</td>
<td>( 0.004 )</td>
</tr>
<tr>
<td>Instructor G</td>
<td>-1.565</td>
<td>( 0.030 )</td>
</tr>
<tr>
<td>Instructor H</td>
<td>0.649</td>
<td>0.315</td>
</tr>
<tr>
<td>Instructor I</td>
<td>-0.254</td>
<td>0.791</td>
</tr>
<tr>
<td>Instructor J</td>
<td>-5.400</td>
<td>( \approx 0 )</td>
</tr>
</tbody>
</table>

**ANALYSIS AND RESULTS**

**General Linear Regression**

The results of the general linear regression are shown in Table 1. The independent variables (left column) are the contributing factors considered in this analysis, the middle column is the estimated beta values for each contributing factor, and the p-values (right column) are a measure of the significance for the variables. A p-value of less than 0.05 was considered significant.

The adjusted \( R^2 \) value for the model is 0.517, which means that the students’ pre-FCI scores, genders, and instructors account for 51.7% of the variance in the students’ post-FCI scores. When broken down for each factor, pre-FCI score accounts for 43.4% of the variance, student gender accounts for 3.1% of the variance, and instructor accounts for 5.2% of the variance.

As Table 1 indicates, both the student’s gender and instructor are significant predictors for the student’s post-score on the FCI, which leads to two different conclusions. First, MI courses are affecting female students differently from their male counterparts, in such a way that male students have a better conceptual understanding of the material as measured by the FCI after the course. Second, students’ conceptual understanding, as measured by the FCI, is dependent on the instructor of the course, meaning student learning is influenced by more than just the curriculum. Since there were no significant interactions between student gender and instructor, this implies that the gender gap in post-scores, when controlled for pre-scores, is consistent across all instructors. There were no significant interactions between pre-scores and gender or pre-score and instructor, which means that all the students are starting the semester on fairly equal conceptual understanding, again as measured by the FCI.
Effect Size

The results of the effect size analysis are shown in Table 2. For each instructor and for the total data set, Cohen’s $d$ is calculated as a measure of the gender gap (second column from the right), the 95% CI on $d$ is given (second column from the left), and the number of students for each calculation is shown (left column). A negative $d$-value means that male students have larger conceptual gains than the female students (as measured by the FCI), a $d$-value equal to zero means that the gains for male and female students are equal, and a positive $d$-value means that female students have larger gains than the males. The bold face data sets in Table 2 indicate those that have CIs which do not cross zero.

As is displayed by the histograms in Figure 1, we see a medium, negative effect of -0.311 for the total data set, which means that the average male student is outscoring approximately 67% of the female students. This confirms and quantifies the gender gap present in the MI course FCI gains. When broken down by instructor, only two out of the 10 instructors have CIs which do not cross zero; however, this is largely due to small sample sizes.

The other instructors all show negative effects, but the CIs are too large to draw supported conclusions. Since the CIs for all the data sets overlap, we see no instructor dependence in these gains, which follows the results found in the linear regression analysis (note that this could be due in part to small sample sizes for some

TABLE 2. Summary of effect size analysis as described by equations (1)-(4). The bold face data sets are those whose confidence intervals do not cross zero.

<table>
<thead>
<tr>
<th>Data Set</th>
<th>$d$</th>
<th>CI (95%)</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>Instructor A</td>
<td>-0.399</td>
<td>± 0.320</td>
<td>153</td>
</tr>
<tr>
<td>Instructor B</td>
<td>-0.450</td>
<td>± 0.362</td>
<td>122</td>
</tr>
<tr>
<td>Instructor C</td>
<td>-0.023</td>
<td>± 0.804</td>
<td>26</td>
</tr>
<tr>
<td>Instructor D</td>
<td>-0.634</td>
<td>± 0.911</td>
<td>20</td>
</tr>
<tr>
<td>Instructor E</td>
<td>-0.044</td>
<td>± 0.530</td>
<td>59</td>
</tr>
<tr>
<td>Instructor F</td>
<td>-0.566</td>
<td>± 0.979</td>
<td>17</td>
</tr>
<tr>
<td>Instructor G</td>
<td>-0.320</td>
<td>± 0.555</td>
<td>51</td>
</tr>
<tr>
<td>Instructor H</td>
<td>-0.152</td>
<td>± 0.476</td>
<td>68</td>
</tr>
<tr>
<td>Instructor I</td>
<td>-0.208</td>
<td>± 0.783</td>
<td>25</td>
</tr>
<tr>
<td>Instructor J</td>
<td>-0.110</td>
<td>± 0.944</td>
<td>18</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>-0.311</strong></td>
<td><strong>± 0.167</strong></td>
<td><strong>559</strong></td>
</tr>
</tbody>
</table>

FIGURE 1. Histograms showing pre- and post-FCI scores for MI students, disaggregated by student gender.
lone found that high-achieving female students resisted materials and structure of the course itself. In addition, Car-
could have led to an implicit gender bias within the ma-
devolved and primarily male-taught [4, 10, 11], which
analysis). Third, the MI curriculum was primarily male-
dents' background factors were not available for this
post-scores, we hypothesize that students' backgrounds
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found that background factors such as math achievement
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male students to perform worse on tests than their male
growth in the gap between male and female students'
susceptible to the gender bias of the FCI, leading to a
working within the physics community for a semester (as
in a strongly male-biased field), female students are more
principals? We propose four possible contributing factors to the gender gap in MI me-
chancles courses. First, McCullough found evidence of a gender bias within the FCI test itself [9]. Perhaps, after
working within the physics community for a semester (as
a strongly male-biased field), female students are more
susceptible to the gender bias of the FCI, leading to a
growth in the gap between male and female students’
scores. Furthermore, stereotype threat often causes fe-
male students to perform worse on tests than their male
counterparts [1]. Second, Kost, Pollack and Finkelstein
found that background factors such as math achievement
and high school physics preparation were able to ex-
plain the persistence of the gender gap [1]. Since stu-
dents’ pre-scores account for 43.4% of the variance in post-scores, we hypothesize that students’ backgrounds could largely contribute to the gender gap at FIU (stu-
dents’ background factors were not available for this analysis). Third, the MI curriculum was primarily male-
developed and primarily male-taught [4, 10, 11], which
could have led to an implicit gender bias within the ma-
erials and structure of the course itself. In addition, Car-
lone found that high-achieving female students resisted

CONCLUSIONS AND DISCUSSION

From this analysis, we draw two main conclusions. First, MI courses affect male students differently than their fe-
ne female counterparts, in such a way that male students have
larger gains on the FCI when compared to female stu-
dents. This is evidenced by the distinct distributions in pre-
and post-FCI scores (Figure 1), the significance of
gender as a predictor of post-FCI score in the linear re-
gression (Table 1), and the medium-size, negative effect
calculated from FCI gains (Table 2). Second, while the raw post-FCI scores are instructor dependent, we see that the gender gap in FCI scores is not. This is demonstrated by the significance of instructor as a predictor of post-
FCI scores, combined with the lack of significant inter-
action predictors between instructors and student gender in the linear model. In addition, the CIs of Cohen’s $d$
for all instructors overlap (Table 2), which means that in terms of the gender gap on FCI gains, the instructors
cannot be distinguished from one another. Through these
results, we have highlighted the issue of a growing gen-
der gap on FCI scores in MI courses and quantified the
effect seen in existing data.

These results lead to the question, “why do we see a growing gender gap in MI courses?” We propose four possible contributing factors to the gender gap in MI me-
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