The Impacts of Modeling Physics in Upper Level Courses: The Persistence of Men and Women

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Abstract: Active-learning approaches to teaching introductory physics have been found to improve student performance and learning gains. We report on longitudinal investigations of student performance in upper level physics courses after having previously taken Modeling Instruction introductory physics courses at Florida International University. Student performance data were analyzed for academic years 2005-2014 in upper level courses including Modern Physics, Mechanics, Electromagnetism, and Quantum Mechanics. We compare how male and female students who took traditional or reformed Modeling Instruction introductory courses perform in these subsequent courses. We look for differential effects between men and women who had these two types of introductory experiences. The implications of this work for our understanding of the impacts of active-learning experiences will be discussed.

Keywords: Modeling Instruction, gender, survival analysis, persistence
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INTRODUCTION

The persistence of women in physics has been widely studied by physics educators [1,2]. A gender shift has been identified between high school and university physics: gender parity exists in first high school physics classes but does not persist to university physics [1]. A recent report by the American Institute of Physics (2010) finds that only 21% of physics bachelor's degrees are awarded to women [3]. Research also finds that female students perform as well or better than male students at the high school level but do not persist at the same rate as males [1]. Physics educators have a great concern for what occurs to female students at the undergraduate level and how female students can be better served in university physics classrooms.

Interactive, reformed based curricula in university introductory physics increase student performance as compared to less interactive pedagogies in introductory physics [2]. At Florida International University (FIU) we have implemented Modeling Instruction (MI) for the past decade. We have also implemented the ISLE curriculum for the last five years. Both MI and ISLE are interactive studio-based classrooms with student-centered activities and minimal time spent on lecture. Students that take these reformed introductory physics courses outperform students taught in a lecture format on a physics conceptual survey by 14% [4]. Differences in performance between male and female students in MI persist, yet female students in reformed classes do better than female students in lecture-taught introductory classes [4,5].

Long-term questions remain, though; namely, what happens to students who experience reformed introductory courses throughout their undergraduate physics career beyond introductory physics? We look at the performance of students in upper-level physics courses for the past ten years and analyze their survival probability to persist in the physics major using survival analysis [6], including a breakdown by gender.

SURVIVAL ANALYSIS

Survival analysis is a collection of statistical procedures for data in which the outcome variable is the time it takes for an event to occur [7]. Survival analysis is often used in the study of clinical trails investigating, for example, the time to relapse under a medical treatment [7]. In higher education, survival analysis is effective in analyzing longitudinal data of student persistence [8].

In the current analysis, a dichotomous variable is assigned to students to identify if they have failed (1) or if they have passed (or have not yet failed) (0). The survival function: $S(t) = P(T>t)$ is defined as the probability that the survival time T is greater than a specific value t. A commonly used estimate of the

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survival data is the Kaplan-Meier product limit estimate [7] where the survival probability of a certain time is dependent on survival at a previous time. For example, a physics students' probability of surviving Physics II is dependent on having survived Physics I. Our analysis uses the Kaplan-Meier method to understand student persistence in upper level physics courses.

To evaluate whether the survivor curves of two groups are statistically equivalent, we use the log-rank test. The log-rank test is a large sample chi-square test that makes use of the observed versus the expected cell counts over the categories of outcomes [7].

DATA COLLECTION

The data for this study are taken from Florida International University transcript records of upper-level physics courses for the years 2005-2014. Data collection began in year 2005 and includes the first cohort of students that took Modeling Instruction or ISLE in their introductory physics course in 2004. Students that take a reformed introductory course are self-selected students that volunteer to take these reformed classes and are enrolled through a lottery system. The data are inclusive of students with physics as their currently declared major and those who graduated with a physics degree. This selection gives a total of 1131 course enrollments and 262 unique students in the sequence of eight upper level courses in the major for the past 9 years. We use the number of course enrollments as the total number of data entries. The data has a frequency of 22.1% female students and 77.8% male students. The data also has a frequency of 19.8% of the student that have taken a reformed introductory course and 80.1% that have taken a traditional introductory course.

We first calculate the survival probability of surviving the sequence of course in the physics program. A failure event (1) is defined by a course grade of C- or below, including drops and withdrawals and a passing grade in the course is given a failure event value (0). We included all 1131 enrollments for this variable analysis.

We also calculate the survival probability to survive the entire physics program up to graduation. Every student enrolled in any of the upper-level physics courses from 2005-2014 is assigned a pass or fail value of (1) for failure to graduate with a physics degree, and (0) if a student does graduate with a physics degree or is still enrolled as a major. Switching out of the major or dropping out of the university is considered a failure event (1). Any students who repeated course is considered a pass (0) if they still graduated with a physics degree, regardless of how many times they needed to repeat a course. Students that enrolled in the first and second upper level courses of the major sequence during the last three years of the study were excluded from the program graduate survival analysis, as they had not yet had enough time, in principle, to graduate. Such enrollments account for 16% of the total enrolled students in the data set.

For both survival outcomes, time is the ordered course sequence for the physics major. The course sequence is Modern I, Modern II, Mechanics I, Mechanics II, Electromagnetism (EM) I, EM II, Quantum Mechanics (QM) I, QM II. The order of the eight courses is based on the common trajectory of courses taken by physics majors at FIU[1]. This eight-course sequence is labeled 1-8 in all following figures and charts.

RESULTS

Male and Female Survival of Courses

The time to first fail any upper-level course, takes into account all failed enrollments in each course and estimates the survival probability in the sequence of courses. Figure 1 shows the overall survival of females and males.

The survival analysis shows that female students have a higher likelihood of surviving through the course sequence (e.g. never having failed a course) than male students. The difference between the two survival curves is significant by

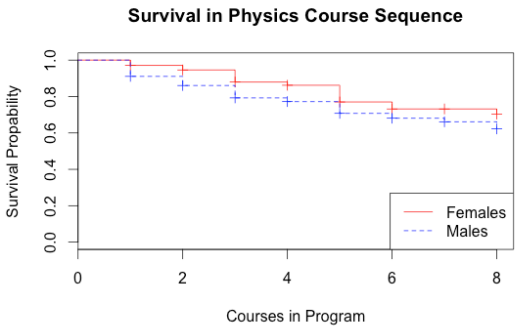


FIGURE 1. Survival curve estimates for the physics course sequence. The solid curve for females shows to have a better survival probability than males in the dashed curve.

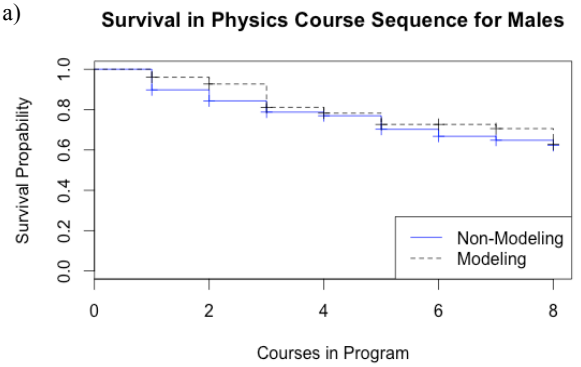
[1] Student may take different order of sequence even courses in parallel, although we ran the statics with different order sequence and the results remain the same.

the log-rank test with a $\chi^2 = 7.3$ ($p<0.01$). Figure 1 also shows a steady loss of male students in courses 1-3 (Modern I&II, and Mechanics) while females are most likely to fail in courses 3 (Mechanics I) and 5 (EM I). Mechanics and Electromagnetism are often taken in the same semester.

Impact of Reformed Intro Physics on Upper-Level Courses

We further disaggregated our sample by student's introductory class type, either MI (which includes ISLE) or a non-Modeling class. Figure 2a shows the survival curves for males in Modeling Instruction introductory class to not be statistically different from males that had a non-modeling introductory physics class. Females who take the reformed introductory courses are more likely to fail a subsequent course than females trained in more traditional settings. The difference in their survival probability is significant with a $\chi^2 = 8.9$ ($p<0.01$). These results are not to conclude against reform courses as the students that survive the MI courses are not the same population of students that survive the traditionally taught introductory courses. Our reformed courses have a higher retention [4,5] and the following section of graduation survival rates further confounds these results.

a)



b)

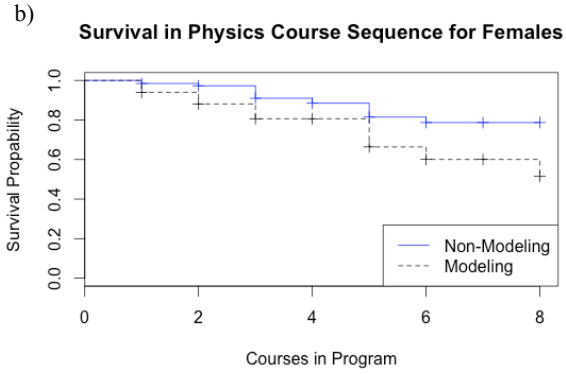


FIGURE 2. a) Males that had MI survive statistically the same as male students that did not. b)Female students that had MI have lower survival probabilities than female students that had non-modeling introductory physics.

Survival Probability to Graduate

Using the Kaplan-Meier method, the survival analysis indicates that all male students have a 0.95 (CI 0.92-0.97) likelihood of surviving and reaching graduation by the time they are in the seventh course in the sequence as shown in Figure 3. The largest chance of failure occurs at the beginning of the sequence in Modern I. For female students, the survivor curve is constant, which indicates that no females have yet failed to graduate with a physics degree in the last 9 years at FIU. Indicating that any female student that has declared physics major and/or have graduated with a physics degree, have a 100% likelihood of not failing to graduate with a physics degree even if they repeat courses. The difference in the survivor curves of male students versus female students is significant by the log-rank test, where $\chi^2 = 8.3$ ($p<0.01$). These graduation survival rates indicate that all the female students, even those from reformed introductory courses, have a higher likelihood of finishing their degree than male students.

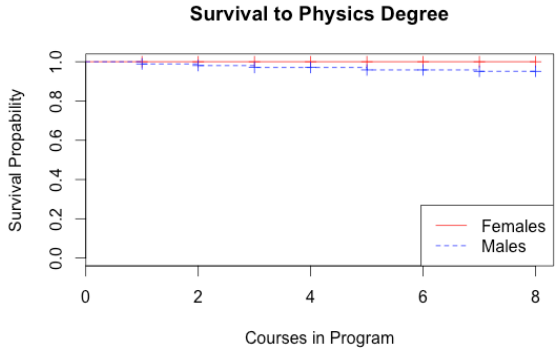


FIGURE 3. Male students have a 95% probability to survive the physics program to graduation while female students have a 100% probability to graduate with a physics degree once they have declared the major.

DISCUSSION AND CONCLUSION

Understanding the persistence of male and female students in upper-level physics courses at FIU has become confounded by differences in introductory classroom instruction. Our results show that while all 58 female students in the data have **not** failed to

graduate with a physics degree, and all female students overall have a higher likelihood of surviving courses better than male students, female students in the reformed introductory courses have different success rates than non-reformed female students.

Reformed active learning environments are, on average, a benefit for students at the introductory level but a clash of expectations, motivations, and learning objectives with more traditionally lecture-taught upper-level courses could be discouraging or at least not effectively serving the students who experience reformed introductory courses. The greater likelihood that female students who passed through MI will fail a course at some point in their career, though they will apparently persist nonetheless through to the completion of the degree may be a statement about the grit and perseverance that such female students gain because of their introductory experiences. Students in student-centered classroom are challenged to participate, discuss, argue, and test their conceptual understanding of physical phenomena. Sitting quietly in the back of a lecture hall is no longer an option. Such experiences foster strength of character. Female students that experience reform at FIU may also be a different population of students from those that take traditional introductory courses. Future work will delve into these outstanding issues.

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