The Effect of Classroom Diversity on Conceptual Learning in Physics

T. Antimirova*, A. Noack**, and M. Milner-Bolotin*

**Department of Physics and *Department of Sociology, Ryerson University, Toronto, Canada, M5B 2K3*

Abstract. Hundreds of students are required to take introductory physics each year at our mid-size Canadian university. These students enter the course with diverse educational histories and demographic characteristics that reflect the diversity of the large, metropolitan city that the university is located in. In this project, we investigate how students' demographic and educational diversity is related to their conceptual learning in introductory university physics. Students' learning outcomes in introductory sciences courses often impact their later learning in undergraduate science degree programs. As expected, we found that the completion of a senior high school physics course is positively related to students' conceptual understanding of physics. The unexpected result was that gender remained a predictor of the students' conceptual understanding, even when the completion of high school physics was accounted for. Interestingly, other demographic characteristics, such as students' mother tongue and country of birth, seem not to matter. The results suggest that the impact of completing high school physics may extend far beyond the first year and that the gender gap continues to persist in SMET disciplines.

Keywords: Conceptual learning, FCI, undergraduate physics, gender gap.
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INTRODUCTION

In this paper we report the results of a pilot study investigating physics conceptual learning among first-year science students in a mid-size (23,000 students) Canadian metropolitan university. All students enrolled in the B.Sc. degrees in chemistry, biology, medical physics or general sciences at this university are required to take an introductory calculus-based physics course in their first year. In fall 2008, students were randomly assigned to one of three sections of the introductory physics course (130 students per section). Two of the sections (A & B) participated in this study; both were taught by professors employing various interactive engagement methods such as peer instruction, collaborative groups etc. [1-4]. We sought to investigate how student diversity is related to learning outcomes in introductory physics.

METHODOLOGY

In order to assess student conceptual learning, the Force Concept Inventory (FCI) was administered in each class in weeks 2 and 12 of the term [5]. Additionally, a socio-demographic survey developed by the researchers was distributed in week 2, along with the information about the research study and an informed consent form. These data were linked to the FCI scores using student identification numbers, which were subsequently removed from the final dataset. The surveys and tests were collected and processed by a researcher outside of the Physics Department, and neither course professor had access to students' information prior to the end of the course.

RESULTS

The results of the study fall into two distinct categories: descriptive demographic results that help shed light on the diversity of the science students taking first year physics courses, and a model identifying factors that are statistically significant predictors of students' conceptual physics learning.

Demographic Description

In total, 149 students from the two course sections completed a survey, a consent form, and an FCI test in week 2. At time 1 (t_1), the average FCI score was 29% (about 9 questions correct out of 30). Scores ranged from 3% to 80%. About 37% of students self-identified as visible minorities. More than half of all students (57%) were born outside Canada, and another

27% first generation Canadians. Only 16% of respondents had at least one parent who was born in Canada. For those students who were born outside of Canada, the average length of time here was about 7 years. The vast majority of students (89%), however, graduated from Canadian high schools, and so cannot be considered newcomers to the Canadian educational system. More than half of the respondents (54%) speak a language other than English as their mother tongue, and 43% of students primarily speak a non-English language at home. As is typical for this university, almost half of students (46%) report that neither of their parents have a university degree.

Almost all students (98%) started their degree in fall 2008, most of them majoring in Biology (57%). The science program does not require a senior physics course for admission, though it is recommended, and 71% of respondents reported successfully completing a Grade 11 or 12 physics course.

Overall, the average age of the sample was 19.6 years (s.d.=2.6 years) and 63% of the respondents were women. There were some significant interactions between gender and other demographic characteristics, suggesting that women who enter university science programs may be demographically distinct group. For instance, women were less likely to report being born in Canada, and less likely to report speaking English as the primary language in their homes. Men and women were equally likely to complete high school in Canada, but men were far more likely to report having taken a senior (Grade 11 or 12) physics course. Almost nine out of ten men (88%) report that they took a senior physics course, compared to only six out of ten women (61%).

Men were also more likely to say that they had already completed at least one university course (11% of men had previously completed a university-level course compared to only 3% of women). About 15% of respondents have some sort of additional education beyond high school, such as a college diploma or certificate, or an incomplete degree in another discipline or other university.

Predictors of Student Learning

For the purpose of this analysis, predictors of student conceptual learning have been divided into two groups: demographic characteristics and educational characteristics. A bivariate analysis between demographic characteristics and FCI scores shows that gender appears to have the largest influence on FCI scores at t_1, with women scoring about 14 percentage points lower than men, on average. There is also some indication that Canadian-born students do better than those born outside of Canada. Although this might be attributed to language difficulties, an assessment of language characteristics show that those with a non-English mother tongue who continue to speak that language at home do not do significantly worse than other students. Visible minority (racial) status appears to have no effect on initial scores. Among the educational characteristics of students, the single largest predictor was having completed a senior physics course in high school. Students who had completed Grade 11 or 12 physics did 17 percentage points better, on average, than students who did not complete such a course. No student without a senior high school physics course scored higher than 35% on the FCI. Students who were first generation university goers did not score significantly better or worse than those who were not. There were also no significant differences in initial scores between the two sections.

Since many of these bivariate predictors are correlated with each other, a regression model provides the most useful way of assessing the effect of individual characteristics, while controlling for the other factors in the model. Measures of overall model fit show that the demographic characteristics in the model account for about 18% of the variation in FCI scores, while educational characteristics account for about 13% of the variation in scores. Among the educational characteristics, the completion of a senior physics course is once again the strongest predictor of FCI scores at t_1 (see Table 1). Students who had taken a senior physics course scored about 14 percentage points higher than those who did not take a senior physics course (getting an additional 4 questions correct out of 30). Even accounting for men and women's differential participation in senior high school physics courses, women did significantly worse on the FCI. Being a woman was associated with an FCI scores that are about 10.5 percentage points lower than men despite the fact that there were no significant gender differences in the grades student's reported for senior physics courses. These results suggest that the typical educational strategies of encouraging young women to remain in the sciences at the high school level may not be enough to promote women's success in science.

Interestingly, being born outside of Canada was also associated with a t_1 FCI score that is 5 percentage points lower than that of Canadian born students. Concerns about acculturation to the Canadian educational system do not explain these results, since almost all respondents completed high school in Canada. Students born outside of Canada do not report doing significantly worse than their Canadian born counterparts in their senior high school physics course. Language differences also do not explain this difference since, in fact, having a non-English mother

tongue and continuing to speak a non-English language at home is associated with an increased FCI score. It is possible that students born outside of Canada have lower conceptual understanding because they have experienced a different science curriculum in their early education. An investigation of the relationship between length of time spent in Canada and students FCI scores shows a curvilinear relationship; students who immigrated between 5-12 years ago (during the elementary school education period), did significantly better than those students who immigrated more than 12 years ago or sooner than 5 years ago.

TABLE 1. Predictors of FCI Score in Week 2 (t_1) in Percentage Points (n=138); variables with low predicting power are omitted

	B	Std. Error	Beta	95% CI Lower Bound	95% CI Upper Bound
Intercept***	27.18	3.54	--	20.18	34.18
DEMOGRAPHIC CHARACTERISTICS					
Age, centered around 19 years	-0.76	0.50	-0.12	-1.74	0.22
Woman *(ref: men)* ***	-10.52	2.55	-0.30	-15.56	-5.48
Born outside of Canada *(ref: Canadian born)* *	-5.34	2.66	-0.16	-10.60	-0.09
Non-English mother tongue/home language *(ref: English mother tongue or home language)* †	4.67	2.67	0.14	-0.61	9.95
EDUCATIONAL CHARACTERISTICS					
Completed senior physics course *(ref: no course)* ***	14.23	2.70	0.39	8.89	19.58
Has additional education *(ref: no additional education)*	-2.01	3.75	-0.04	-9.43	5.41
Section B *(ref: Section A)*	1.05	2.46	0.03	-3.82	5.92

*** $p<0.001$ ** $p<0.01$ * $p<0.05$ † $p<0.10$

A key concern in this study was investigating predictors of student conceptual learning over the duration of their introductory physics class. In order to do this, students were administered the FCI in the final week of the term (t_2). A total of 111 of the 149 students in the original sample completed the second FCI. Students who did not complete the post-test had significantly lower scores on the FCI at t_1, and thus may represent students who dropped the course. Corresponding with those who did worse on the FCI at t_1, women and students born outside of Canada were less likely to complete the FCI at t_2.

A paired t-test shows that on average, students scores increased by 23 percentage points, or by about 7 questions ($p<0.001$). Six percent of students had no change, or scored worse on the FCI at t_2. Bivariate analysis and a regression model were used to investigate predictors of improvement at t_2. Few measured characteristics seem to be related to improvement at t_2. There is some evidence that those who were born in Canada seem to show greater gains than students born outside of Canada. Similarly, there is some evidence that those who have additional educational qualifications beyond just a high school diploma may be more likely to improve. Interestingly, there also seems to be a trend relative to geography, whereby students who live closer to campus show greater gains than those who live farther away (based on postal code). This geographic variable may be standing in as a proxy for course attendance, as students who live farther away from campus may be less likely to attend classes consistently.

A regression model predicting the differences in students' scores shows much less explanatory power than the model predicting students' initial FCI scores. Given access to the same course material, we might expect that students who initially scored low on the FCI would show greater gains. This is borne out to some extent (see Table 2); the higher t_1 scores are significantly associated with less absolute improvement at t_2. However, students' initial scores only account for about 3% of the variation in outcomes at the FCI post-test. Demographic and educational characteristics account for another 2.5% and 3.9% of the variation respectively. Among the demographic characteristics, those born outside of Canada were less likely to show conceptual gains. This is particularly concerning, especially since these students were also less likely to score high on the FCI at t_1. This may reflect the lack of internal motivation of the students, who may be enrolled in this program at the urging of their parents. Notably, women score lower than men at t_1, and are not more likely than men to show gains at t_2. This result suggests that the gender gap that exists coming out of high school may remain relatively constant throughout first year physics courses. A similar effect exists for students who did not complete a senior high school physics course. One might expect that students who did not complete a senior physics course might show bigger gains in their first year physics course, but this is not supported by the data. The gap between those who completed high school physics and those who did not appears to remain constant. The only educational characteristic that appears to make a difference in predicting t_2 FCI

scores is having additional educational qualifications. Students who entered the course with some additional education beyond high school were more likely to improve their conceptual understanding. Although age itself does not have a significant effect on improvement, these students are likely to be mature students and thus may be more motivated to get the most from their university education.

TABLE 2. Predictors of Change in FCI Score in Week 12 (t_2) in Percentage Points[1] (n=103)

	B	Std. Error	Beta	95% CI Lower Bound	95% CI Upper Bound
Intercept	49.18	12.05	--	25.24	73.11
Time 1 FCI Score*	-0.20	0.09	-0.26	-0.38	-0.02
DEMOGRAPHIC CHARACTERISTICS					
Age, centered around 19 years	-0.86	0.59	-0.17	-2.03	0.32
Woman *(ref: men)*	-2.41	2.79	-0.09	-7.95	3.13
Born outside of Canada *(ref: Canadian born)**	-7.50	2.95	-0.28	-13.36	-1.64
Non-English mother tongue/home language *(ref: English mother tongue or home language)*	4.09	3.00	0.15	-1.87	10.06
EDUCATIONAL CHARACTERISTICS					
Completed senior physics course *(ref: no course)*	1.16	3.34	0.04	-5.48	7.79
Has additional education *(ref: no additional education)**	10.48	4.56	0.27	1.43	19.54
Section B *(ref: Section A)*	-3.27	2.73	-0.12	-8.68	2.15

[1] The percentage point difference scores were calculated by subtracting each student's FCI t_1 score from their FCI t_2 score, and dividing the result by 30 (maximum FCI score). *** p<0.001 **p<0.01 *p<0.05 † p<0.10

SUMMARY

What is most interesting about these results is the relative scarcity of predictors for students' educational gain at t_2. Many demographic and educational predictors, such as age, gender, visible minority status, and parents' university educational status appear to have no effect on students' learning gains. The conclusion that is most strongly supported by these results is that the differences in conceptual learning that students enter their first-year physics course with are sustained throughout the course. This is especially detrimental for women who score significantly lower at the entry point and thus end up disadvantaged compared to their male counterparts. These results are consistent with other early findings in this area [6]. This is despite the use of interactive teaching methods, suggesting that there are substantial limitations in terms of the goals that first-year physics instructors can expect.

In the context of increasingly diverse introductory physics classrooms at universities across North America, the effect of gender and country of birth on students' t_1 scores, even accounting for whether students have successfully completed Grade 12 physics suggests that there is still substantial inequality within the educational system. In part, these differences may reflect differences in student motivation to learn physics and the skills needed to do so effectively. The students who have some additional educational qualifications beyond high school are more likely to improve over the course of the term. These students might be better equipped to deal with the post-secondary educational environment and more committed to their learning.

The limited sample size of this study restricts warranted generalizations. It is, nevertheless valuable to corroborate the results of the US findings with the Canadian data. In the future, we will further explore the complex interactions between students' demographics, attitudes and motivation and their conceptual learning in introductory physics courses.

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