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Preparing for University: An Applied Analysis on the Efficacy of 4U and University Level Preparatory STEM Courses

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Preparing for University: An Applied Analysis on the Efficacy of 4U and University Level Preparatory STEM Courses

Abstract
The following report addresses the impact of preparatory education on first year science grades at two Ontario-based universities. Specifically, the impact of high school and university level preparatory courses on their respective first year university grades will be addressed. A variety of analytic and visualization-based strategies will be employed to outline a narrative about who is taking such courses, and the impact of these courses on student learning. Overall, conclusions point to the usefulness of preparatory education, and for institutions to continue to provide supplementary courses as scaffolding for undergraduate students.

Le rapport qui suit traite de l'impact de la formation préparatoire sur les notes des étudiants en sciences de première année dans deux universités de l'Ontario. En particulier, il s'agira d'examiner l'impact des cours préparatoires aux niveaux secondaire et universitaire sur les notes obtenues en première année à l'université. Diverses stratégies analytiques et de visualisation seront employées pour brosser les grandes lignes afin d'expliquer qui sont ceux qui suivent de tels cours et l'impact de ces cours sur l'apprentissage des étudiants. D'une manière générale, les conclusions indiquent que la formation préparatoire est utile et préconisent que les établissements continuent à offrir des cours supplémentaires qui serviront de point de départ aux étudiants de premier cycle.

Keywords
preparatory education, regression, visualization, introductory science

Cover Page Footnote
Thank you to Dr. Michael Friendly, Dr. Hugh McCague, and Dr. Colin Montpetit for their insight and aid in this analysis. The support of the administrations of both the University of Guelph and the University of Ottawa are much appreciated. This study was initiated after a departmental undergraduate curriculum committee meeting where members were charged with determining whether to revise the first-year prerequisites for physics courses.

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Upon registering in many undergraduate programs, students are required to take a series of courses that are considered foundational to their success during their degree. For most science diplomas, these courses include introductory biology, chemistry, and physics. To help students prepare for these courses, the Ontario Ministry of Education (2000, 2008) has implemented a series of preparatory courses at the high school level, designated the "4U" or "fourth year of secondary school in preparation for university stream" curriculum. This program provides support for the aforementioned courses, with the goal of aiding students in their transition to university level requirements. One aim of the current research is to investigate the usefulness of the 4U program: do students who have taken the 4U courses at the high school level perform better in their first-year courses than students who have not?

Completion of the 4U curriculum is not always required for entrance into a university level program. Such students at two Canadian universities (University of Guelph and the University of Ottawa) are given the opportunity to register in a preliminary preparatory course at the university level, with the goal of giving the students enough foundation to succeed in their subsequent courses. Therefore, these courses serve as a replacement for the 4U course in high school. Student enrollment choices in high school are therefore likely to interact with enrollment choices in first-year university.

The objective of the present research is to evaluate student performance in the first-year science courses depending upon whether they took a preparatory course in high school or in university, across three areas of study (biology, chemistry, and physics). In assessing these relationships we hope that our analysis will be used to identify factors that contribute to these differences (e.g., course structure, learning outcomes, teaching and learning approaches, student experiences), whether they be positive or negative. The results of this study might help inform decisions regarding teaching and learning approaches to enhance the effectiveness of preparing students for first-year science courses and aid educators in making decisions about instituting "year-appropriate" learning outcomes. Knowledge about the effectiveness of preparatory courses will aid in the generation of activities and assessment strategies that could help students throughout their education. Finally, such insight could help administrators determine whether the 4U and/or preparatory courses are needed and how they could affect the present curriculum.

Prior Research

While the topic of preparatory education is important, there have been relatively few studies on assessing the benefits of such courses, especially within Ontario. Prominent papers in this area have focused on particular aspects of this issue. For instance, Hazari, Tai, and Sadler (2007) investigated the factors that might increase the number of females studying physics beyond the high school level and highlighted the importance of parental encouragement and previous success in mathematics as quintessential predictors. Similarly, Sadler and Tai (2001) also focused upon physics and noted that a substantial portion of the variability in college level physics grades can be accounted for by the effectiveness of their respective high school level courses (based upon a variety of factors, ranging from topic coverage, textbook use, and the number of labs provided, to percent of text covered). Other studies concentrated on other subjects such as calculus (Yushau, Omar, & Al-Attas, 2006) and found that performance in preparatory courses was an important predictor.

More generally, Chinlund (2013) looked at a program similar to 4U in New Zealand (the Certificate of University Preparation/CUP) and utilized various predictors to model first-year university achievement, noting that the "CUP programme was successful in preparing learners to achieve at university, by developing students' academic perseverance and sufficient preparatory study skills, which were empirically associated with achievement" (p. 92). In

modeling first-year university performance, certain student behaviours and characteristics, such as the development of study skills, importance of academic challenge, emphasis on academic support, degree of academic perseverance and their overall achievement in CUP, were all significant. Most notably, the students who took the CUP program did better overall in their first-year courses than the students who entered university directly from secondary school.

Another approach taken has been to track high school students as they apply for university and monitor their progress (e.g., Long, Conger, & Iatarola, 2012). This analysis focused upon the course selection factors that predicted academic success; the authors found that rigorous preparatory courses taken contributed significantly to the prediction of performance at the university level.

In all of this previously published research, the underlying goals were to determine: (a) if preparatory classes work, (b) who is taking advantage of these classes, and (c) if such an initiative could be bolstered. The research was all conducted within localized contexts. It is a goal of the present investigation to present comparable analyses as they pertain to students at two institutions in Ontario. Here we determine: (a) the frequency with which each preparatory course option is utilized, and (b) the relationship between performance in these preparatory course options and performance in their respective university level course.

Hypotheses

The primary question under study is whether students engaged in the university preparatory courses are out-performing those having taken them in high school, as assessed via their respective first-year university grades. Based upon previous research, it is hypothesized that the preparatory courses taken at the undergraduate level may better mirror the structure and content of the first-year course than the 4U courses. If not associated with an increase in grade, it is hypothesized that the university-level preparatory grades and the first-year grades will be more highly correlated than the first-year grades with the 4U grades.

Supplementary, since this discussion is entwined with first-year grades, it is of interest to discuss who is taking preparatory courses and whether there are any meaningful cohort effects. Analyses regarding the make-up of the dataset will also be provided.

Method

Data were obtained from two Ontario-based universities with similar curricula and admission requirements[1] pertaining to students enrolled in a science degree at that institution. All data were provided by the respective administrations of these institutions in an anonymized fashion from the registrars' records under the research ethics approval number 13JL017. In total, 13,745 cases were obtained: 5,788 from the University of Ottawa and 7,957 from the University of Guelph. Variables provided were school, cohort (year of entry, ranging from 2006 to 2012), gender, and three sets of grades[2] for biology, chemistry, and physics: one set at the

[1] Both institutions have an admission average minimum of 75%, and students must have completed at least two of the 4U science courses (biology, chemistry, physics for University of Guelph and an additional option of space and earth science for University of Ottawa).

[2] Grades from the University of Ottawa were provided as letters. Using the University of Ottawa's grading rubric (2010, sec. 10.1), each letter grade was converted to the mid-point numeric counterpart; for example, an A+ pertains to a grade between 90 and 100, and have been entered here as 95, and a C is given for 60-64 and is entered as 62.

4U level, another for the university prep courses (UPREP), and finally at the first-year university level. It should be noted that this dataset contains a substantial amount of missingness, since if a student did not register in a particular course (such as the university-level biology class), no grade could be recorded.

We incorporate the variable gender into our analyses because there is substantial research that demonstrating differential performance and choices by male and female students. For example, from elementary school to the final years of high school, female students outperform male students in all subjects (e.g., Hazari et al., 2008; Kerr, 2010; Pomerantz et al., 2002). Differences in choice are also correlated with gender where females are less likely to persist in physics courses than males (Hazari et al., 2008; Kerr, 2010) and university science and technology programs disproportionately attract male students (Kerr 2010).

As will be discussed, the particulars of this dataset were the source of concern throughout the analysis. Accordingly, an analytic strategy was devised that partitioned relevant hypotheses by statistical procedure. Contingency table analysis was used to describe the make-up of the sample. Multinomial regression was used to look at demographic characteristics of students on their choice of preparatory course. Correlation matrices illuminated the relationships between student grades at the 4U, university prep, and first-year levels across the three subjects. Two-way ANOVAs provided insight on mean differences for first-year final grades, assessing the influence of gender and preparatory choice. Multiple regression was used to assess the relationship between preparatory course selection, preparatory course grade, and gender on first-year performance. Finally, within-subject ANOVAs and lineplots were used to assess the trajectories of student grades over the three courses to see if there is any overall improvement.

Comments on Working with Institutional Datasets

It was apparent from the variety of the above approaches that the method of data collection has serious ramifications for analysis. As all the information was collected post-hoc, it is impossible to separate out the effects of having taken a particular prep course from general student aptitude. While we can and will compare students who did their first-year university course without having completed any prep beforehand against those who did so at either the 4U, the university-level, or both, we cannot claim that higher outcome grades are due to having taken a particular prep course, as this selection is conflated with student ability and self-selection bias. Students who are not feeling confident about their abilities in an area may be more inclined to take one or both of the prep courses, and so while taking the course may indeed have led to higher grades at the first-year level[3], they may still be lower than those of their more confident peers. Further, students were not randomly assigned to a preparatory choice condition, and it is not hard to imagine that there could be a multitude of underlying factors that might influence an individual to take a preparatory course (or not).

Without any baseline understanding of each student's domain ability[4], it is extremely difficult to ascertain the benefits from having taken a prep course. This problem is exacerbated by the fact that the four groups (no prep, 4U, university prep, or both) are widely discrepant in sample sizes across each subject, with the majority of students falling in the 4U category across all subjects. These challenges are present within all institutional data sets and should not be

[3] This will be partially assessed by comparing 4U and UPREP courses. If they were self-selecting, a negative relationship (with lower UPREP) grades would be hypothesized.

[4] It should be noted that all students in the sample are rather homogeneous, as university entrance requirements stipulate that all new students have overall high school averages above 80%.

considered grounds for a lack of research. Implications and suggestions for future research will also be considered.

Data and Analysis

All analyses were conducted using R (Version 3.3.1; R Core Team, 2016). Due to the aforementioned issues with non-random allocation, missingness, and discrepant sample sizes, primary approaches for discussion will be visualization-based. Some hypotheses will be assessed via statistical procedures, specifically via multiple regression and ANOVA models, but due to the design issues raised above, such results must be interpreted with discretion.

Results

Descriptive Statistics

A few things should be noted about this particular dataset. First, the present data are not equal across schools, cohort, or gender. Data from the University of Ottawa were available from 2006-2012, and from the University of Guelph from 2010-2012. It is also apparent that the University of Guelph has a substantially larger program than the University of Ottawa, with approximately three times as many students in each cohort. Further, there are more females than males across each cohort; in fact, over 60% of the participants in the 2011 cohort were female (University of Guelph). Refer to Table 1 for the full breakdown of gender by year. For all analyses that use the cohort variable, only cases from 2010 onward were used from the University of Ottawa sample, to match the available data from the University of Guelph.

Table 1
Gender of Study Participants by School and Cohort

School	Gender	Cohort						
		2006	2007	2008	2009	2010	2011	2012
Ottawa	Female	431	474	433	471	468	480	550
	Male	302	337	354	372	371	348	397
Guelph	Female	*	*	*	*	1535	1718	1577
	Male	*	*	*	*	1034	1059	1034
Sum	Female	431	474	433	471	2003	2198	2127
	Male	302	337	354	372	1405	1407	1431

Note. * indicates that no data were available for these cells.

To reiterate, the structure of this dataset presents challenges for statistical analysis. We have differing numbers of students across the schools, different grade schemes for the university level courses, and differing numbers of males and females in all categories, while missing relevant information about the ability of the student or their reflections on the importance of the preparatory courses they have taken. Here we demonstrate the various analyses that can be run to get a sense of how these variables interact with one another. Understanding the way in which explanatory variables interact will influence our interpretation of the statistical analyses and hopefully elucidate key variables in explaining differences in student grades.

Preparatory courses taken at the 4U level. In terms of participation in preparatory coursework, it is interesting to note the percent of individuals who completed the 4U curricula before attending university. The vast majority (94.8%) of the present sample took at least one 4U course (N = 13,041), with approximately 40% of students having taken all three courses (refer to Table 2 for the full breakdown of 4U choice by gender and overall).

Table 2
4U Choices by Gender

4U Combination	Percent		
	Female	Male	Overall
Biology	8.4	4.2	6.7
Chemistry	1.7	2.4	2.0
Physics	0.8	3.6	2.0
Biology and Chemistry	41.6	26.3	35.3
Biology and Physics	1.0	1.9	1.4
Chemistry and Physics	2.8	14.5	7.5
Biology, Chemistry, and Physics	38.1	42.7	40.0
None	5.6	4.5	5.1

Looking at the gender by 4U selection cross-tabulation, a test of non-independence shows differences for almost every cell, with significantly large residuals for all combinations except two (female/chemistry and female/none), $\chi^2(7) = 1{,}093.8$, see Figure 1[5]. The most notable trend is that students tended to take more than one prep course (with many taking all three options). Of the second-order combinations, the two sets that included physics were less popular, with very few individuals taking the biology/physics combination in particular. The few areas that had more males than females enrolled were in the physics categories, specifically the physics-only choice, as well as the combination with biology *or* with chemistry. Females were more prevalent in every other category, including the third-order set.

Preparatory courses at the university level. Particularly relevant for this dataset is to look at 4U and university preparatory course selection in conjunction with each other. Table 3 presents the total number of students in the dataset who completed a first-year course in biology (N = 8,836), chemistry (N = 10,137), or physics (N = 3,563), broken down by their school, whether they had taken a preparatory course for that subject, and at what level.

[5] For interpretation of this mosaic plot, cells are sized proportional to their observed frequencies and are shaded based upon the magnitude of their studentized residual. Residuals larger than expected are shaded blue (under the assumptions of the null model), while those less than expected are red.

Figure 1. A mosaic plot indicating participation in 4U curricula by course and gender. For each row, B refers to Biology, C to Chemistry, and P to Physics, with combinations indicated by multiple symbols. Each cell is sized proportional to its observed frequency and shaded by the size of the Pearson residual.

Table 3
Enrollment for Each Level of University Preparatory Course by Subject and Course

School	Course	Both	University	4U	None	Sum
	Biology	4	52	4632	382	5070
Ottawa	Chemistry	27	40	4758	351	5176
	Physics	1	12	582	90	685
	Biology	5	43	3615	103	3766
Guelph	Chemistry	1	62	4805	93	4961
	Physics	5	1118	1462	293	2878
	Biology	9	95	8247	485	8836
Combined	Chemistry	28	102	9563	444	10137
	Physics	6	1130	2044	383	3563

For all three subjects, the vast majority of students took the prep course at the high school level. For Biology and Chemistry, more students decided to take the full university-level course rather than take *any* one preparatory course (e.g., 485 students failed to complete any biology prep, 95 took the university prep course and a mere 9 took both preparatory offerings). This trend is intriguing, since each program strongly encourages participation in a preparatory class prior to registration in the full course.

Physics stands out by having the lowest proportion of students entering the course with 4U level training (57.4%, while the biology and chemistry were 93.3% and 94.3%, respectively), and the highest proportion of students utilizing the university level preparatory course (31.7%). Otherwise, it is obvious to note that a minority of students took the university level preparatory courses, and even fewer took both (0.19% across the entire sample). As the

university preparatory curricula is specifically targeted at students who did not take 4U courses, the latter insight is not surprising, but it does indicate that there might be students who feel that the 4U program was not sufficient to prepare them for their first-year university curricula.

Enrollment in preparatory courses. A primary point of interest was to investigate which students take preparatory classes. The present analysis is limited due to the sparseness of usable demographic variables; however, it is still worthwhile to pursue. One line of analysis is: what demographic factors (gender, cohort, school, and their interactions) might be useful in predicting whether a student decided to enroll in a preparatory course, and do these relationships hold across the three domains?

The response variable of interest is preparatory participation with four categories: none (set as the reference group), 4U, university-level, and both. As these levels do not form a strict ordinal hierarchy, preparatory choice will be treated as a nominal variable and modeled using multinomial (polytomous) regression. The goal of such models is to estimate the probabilities of the *m* response categories directly as a set of $m - 1$ logits, against a set baseline category (Friendly & Meyer, 2016). Since the interactions between the predictor variables is of interest, the following models were run on a subset of the data (only cases from 2010-2012) as observations are only available from the University of Guelph for that period.

For each of the domain-specific models, the same procedure was followed: preparatory choice was declared a nominal variable, with no preparatory courses taken set as the baseline, and serves as the outcome of interest. A multinomial regression was performed using school, cohort, and gender as predictors, along with all of two- and three-way interactions. As this is exploratory work with the goal of obtaining the most parsimonious set, the models were then reduced by removing non-significant terms one at a time, beginning with the highest order interactions. Only the final models for each subject will be presented here. See Tables 4 and 5 for the Type II ANOVA results and regression coefficients for Biology, Tables 6 and 7 for Chemistry, and Tables 8 and 9 for Physics[6].

Table 4

Type II ANOVA Table for the Multinomial Regression Pertaining to Biology Students, Predicting the Participation in Preparatory Coursework Based upon School, Gender, and its Interaction

	LR Chisq	*df*	*p*
School	43.42	3	< .001
Gender	13.39	3	0.004
School by Gender	15.54	3	0.001

[6] Note that for multinomial regression, the degree of freedom terms for the effect of each variable is calculated differently than it is for standard multiple regression. In these models, *df* are calculated based upon the number levels of the response variable multiplied by the number of levels of the variable itself (minus one). For instance, the variable for school has two levels and is being used in three equations, which yields 3 *df*.

Table 5

Multinomial Regression Coefficients for Prediction of the Participation in Preparatory Coursework for Biology Students, based upon Gender, School, and their Interaction

	Dependent Variable		
	4U (1)	University (2)	Both (3)
School (Guelph)	1.139***	0.468	42.247***
	(0.172)	(0.402)	(0.259)
Gender (Male)	0.265	0.309	-18.443***
	(0.183)	(0.435)	(0.568)
School by Gender	-0.811***	0.530	17.272***
	(0.272)	(0.575)	(0.568)
Constant	2.627***	-1.803***	-44.904***
	(0.109)	(0.279)	(0.259)
Akaike Inf. Crit.	2821.104	2821.104	2821.104

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Table 6

Final type II ANOVA Table for Chemistry Students Predicting Participation in Preparatory Coursework Based upon the Main Effects of School, Gender, and Cohort

	LR Chisq	*df*	Pr(>Chisq)
School	126.3	3	< .001
Gender	34.11	3	< .001
Cohort	24.25	6	< .001

Table 7

Multinomial Regression Coefficients for the Multinomial Regression Pertaining to the Prediction of Participation in Preparatory Coursework for Chemistry Students, based upon the Main Effects of School, Gender, and Cohort

	Dependent Variable		
	4U (1)	University (2)	Both (3)
School (Guelph)	1.214***	1.857***	-2.625**
	(0.137)	(0.312)	(1.033)
Gender (Male)	0.552***	1.412***	-0.624
	(0.151)	(0.274)	(0.574)
Cohort (2011)	-0.126	-0.525	-0.150
	(0.171)	(0.324)	(1.014)
Cohort (2012)	-0.234	-0.500	1.882**
	(0.168)	(0.319)	0.763)
Constant	2.695***	-2.473***	-2.872***
	(0.146)	(0.353)	(0.730)
Akaike Inf. Crit.	3057.955	3057.955	3057.955

Note: * $p < 0.10$; ** $p < 0.05$; *** $p < 0.01$

Table 8
Type II ANOVA Table for the Multinomial Regression Pertaining to Physics Students, Predicting Participation in Preparatory Coursework Based upon School, Gender, Cohort, and Significant Interactions

	LR Chisq	*df*	Pr(>Chisq)
School	207.3	3	< .001
Gender	11.96	3	0.008
Cohort	20.96	6	0.002
School by Cohort	15.77	6	0.015
Gender by Cohort	14.8	6	0.022

Table 9
Multinomial Regression Coefficients for Prediction of Participation in Preparatory Coursework for Physics Students, based upon School, Gender, Cohort, and Significant Interactions

	Dependent Variable		
	4U (1)	University (2)	Both (3)
School (Guelph)	0.519	4.557***	6.717
	(0.319)	(1.047)	(27.068)
Gender (Male)	0.739***	0.462	9.678
	(0.275)	(0.290)	(46.036)
Cohort (2011)	0.647	0.629	3.994
	(0.471)	(1.486)	(22.707)
Cohort (2012)	1.902***	1.746	1.996
	(0.575)	(1.524)	(25.385)
School by Gender	-0.725	-0.722	4.254
	(0.471)	(1.485)	(23.327)
School by Cohort (2011)	-2.083***	-2.177	-0.675
	(0.573)	(1.523)	(25.458)
School by Cohort (2012)	-0.523	-0.455	-16.838
	(0.345)	(0.361)	(56.640)
Gender by Cohort (2011)	-0.863**	-1.013***	-10.619
	(0.353)	(0.379)	(67.602)
Gender by Cohort (2012)	1.112***	-3.034***	-18.346
	(0.314)	(1.046)	(53.360)
Akaike Inf. Crit.	5721.603	5721.603	5721.603

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

Results from multinomial regressions follow a similar structure to those from ordinary least squares - predictor effects, which may be quantitative or categorical, are assessed using an ANOVA table, with significance ascertained via likelihood ratio chi-square tests. If a predictor has a significant effect, it is retained for the final model and will be used to obtain fitted coefficients for each response category except for the reference group. Each coefficient in the regression table pertains to a unit change in the predictor on the log odds that an observation had a response in a particular response category rather than the reference group (e.g., a positive coefficient for gender (male) would indicate that there are higher log odds for being in that particular response category). Results from these models when they use categorical predictors can be plotted using fitted probabilities on the y-axis, and stacked polygons to illustrate particular segmentations.

The final models are especially interesting due to the differences found across the three subjects. For biology, there is a significant interaction between school and gender with male students from Guelph more likely to have taken both preparatory courses and less likely to have taken 4U. As illustrated in Figure 2, the majority of students fall in the 4U category; however, males from Guelph were more likely to have taken the university preparatory course.

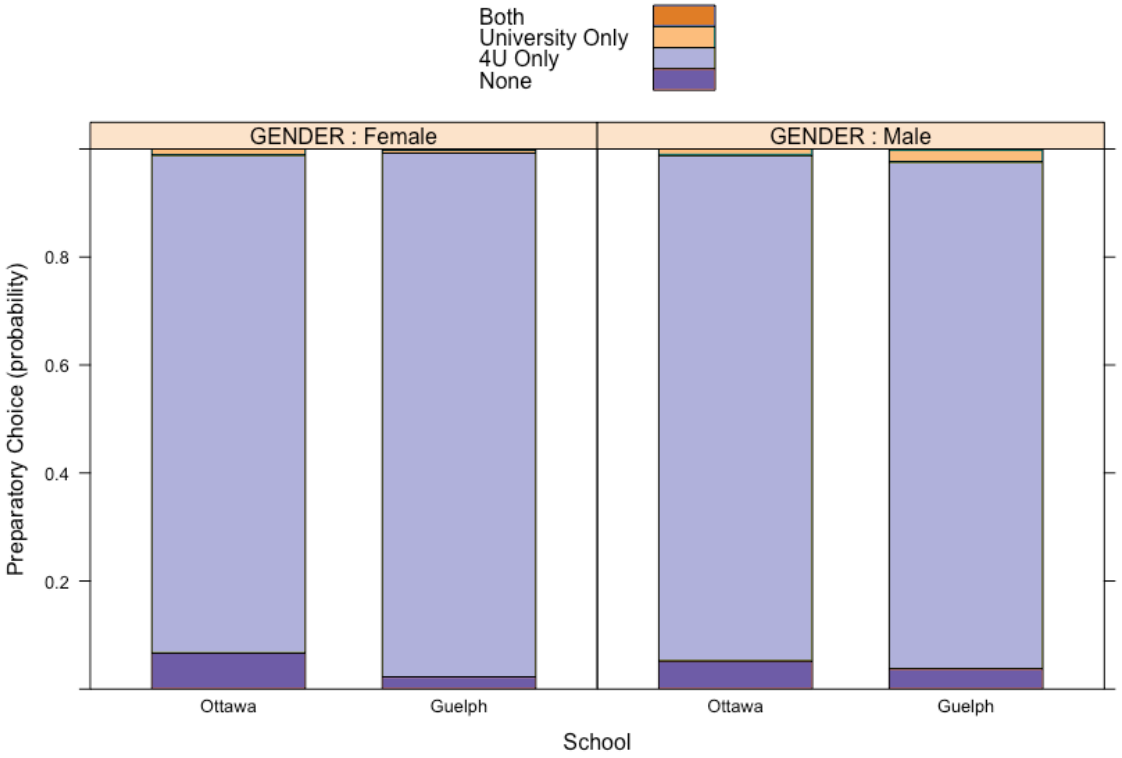

Figure 2. Effect plot for multinomial regression of school and gender on preparatory choice for biology. Cumulative fitted probabilities are indicated on the y-axis.

The results for chemistry are substantially different, as the final model only includes main effects for school, gender, and cohort (with 2010 set as the reference category). The effects plot is shown in Figure 3 and shows that females were more likely to take no preparatory course than males, students at the University of Ottawa were more likely to not take the preparatory course than those at the University of Guelph, and the proportion of students deciding to not take any preparatory courses increased over the three years.

Finally, for physics, there were two significant interactions: school by cohort and gender by cohort. The effect plot is provided in Figure 4, and many interesting trends can be highlighted; looking across schools, students at Guelph were more likely to take the university preparatory course than those at Ottawa. Further, students were less likely to take no preparatory courses with each passing year at Ottawa, while the opposite trend was true at Guelph. Across gender, it appears that males became increasingly likely to not take a preparatory course, while the female rate stayed about the same.

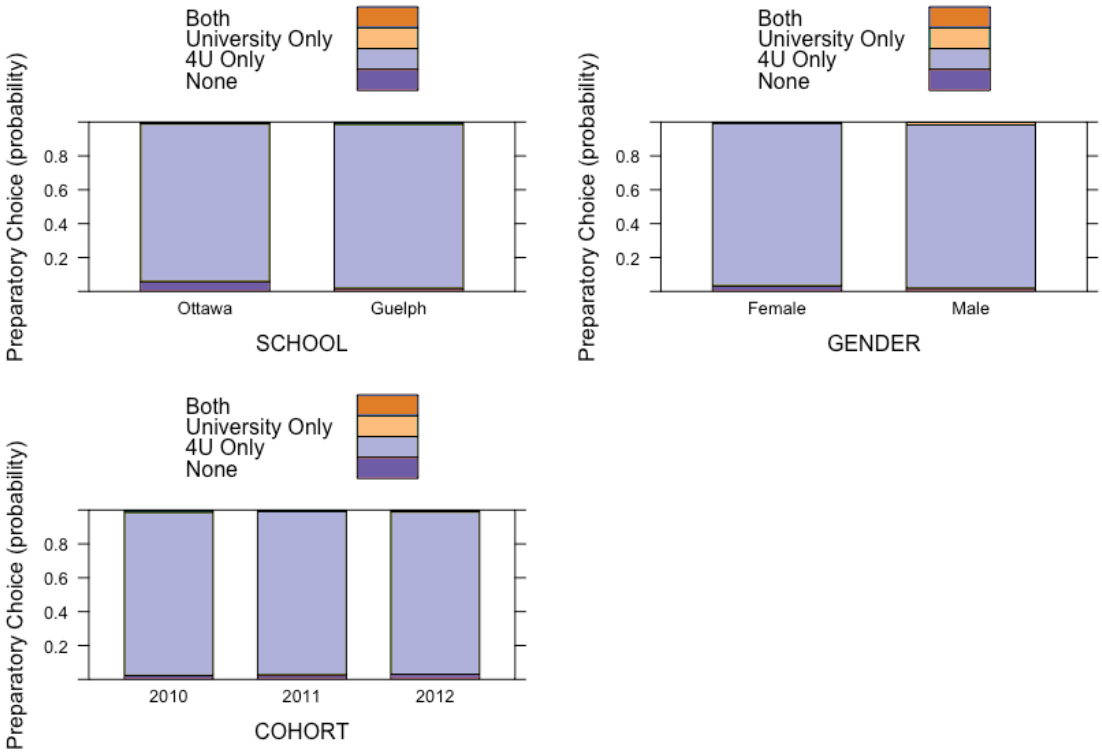

Figure 3. Effect plot for multinomial regression of school, gender, and cohort on preparatory choice for chemistry. Cumulative fitted probabilities are indicated on the y-axis.

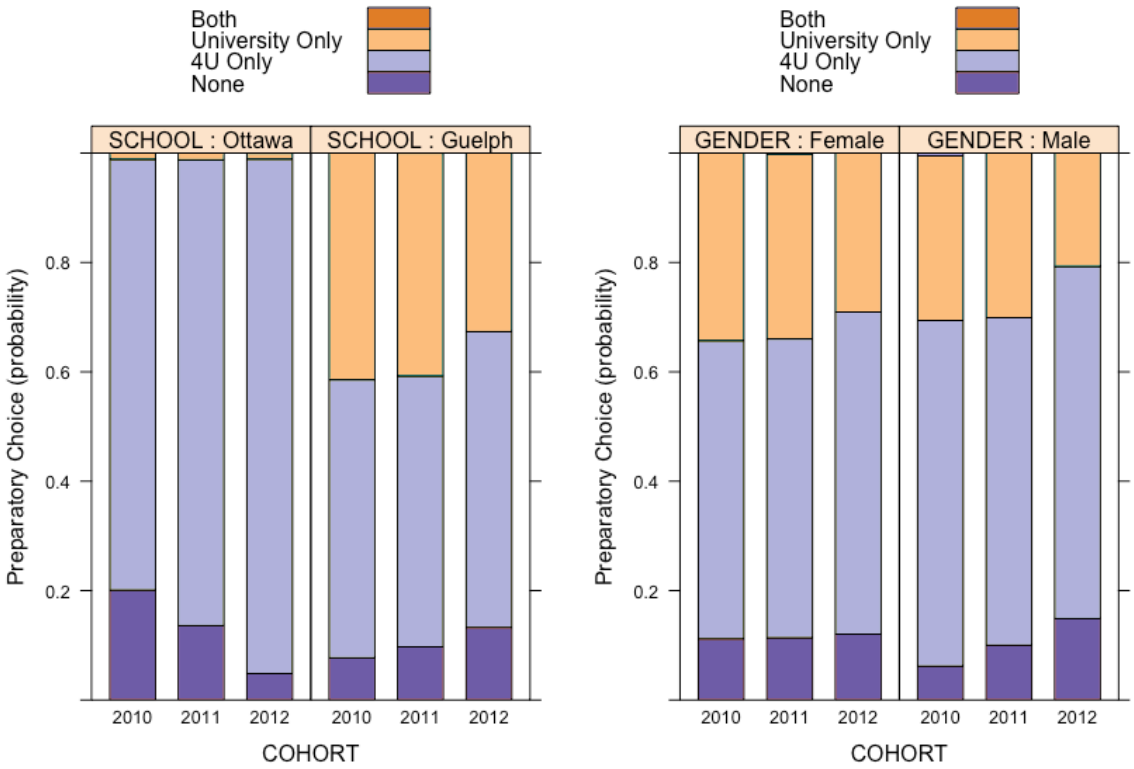

Figure 4. Effect plot for multinomial regression of school and gender on preparatory choice for physics. Cumulative fitted probabilities are indicated on the y-axis.

Overall, these models yield very different trends across the three subjects. While the primary findings from the demographics analysis hold true (very few students took both preparatory courses and are barely visible in any of the plots, and the vast majority of students did complete 4U training in their respective fields), the multinomial regressions yielded additional insights about possible gender and cohort effects. However, these models do not account for *performance* within the discipline.

Preparatory choice and first-year grades. While we were unable to partition out the effect of taking a particular preparatory course, we can still investigate the relationship between them. For example, are 4U or university prep grades more correlated with first-year grades? The correlation matrices, based upon all available pairwise data given that not all students participated in every preparatory course[7], for the three subjects are provided in Table 10. It is interesting to note that all of the correlations with first-year grade are significant and positive; better performance in a preparatory setting is generally linked to higher grades in the first-year course, regardless of subject. Also of interest is that the correlations between university prep and first-year grade are substantially stronger than those between 4U and university prep for chemistry and physics, indicating that more of the variability in those first-year grades is accounted for by the university prep grade.

Table 10
Correlations Between Grades for the 4U Preparatory Courses, the University Preparatory Courses, and the First-Year University Classes

	Biology		Chemistry		Physics	
	4U	UPREP	4U	UPREP	4U	UPREP
UPREP	0.24		0.55**		-0.18	
UNI	0.50***	0.52***	0.53***	0.72***	0.41***	0.65***

Note: *p<0.1; **p<0.05; ***p<0.01

Looking at actual performance, we can compare boxplots of the first-year grades, organized by preparatory choice (refer to Figures 5, 6, and 7 for biology, chemistry, and physics, respectively). It is interesting to note that students who took both preparatory courses generally had the lowest scores (indicated by the medians and general positions of the boxes). As a reminder of the discrepant make-up, sample sizes are indicated within each box.

[7] For exact sample sizes, please refer to the labels provided in Figures 5 through 7.

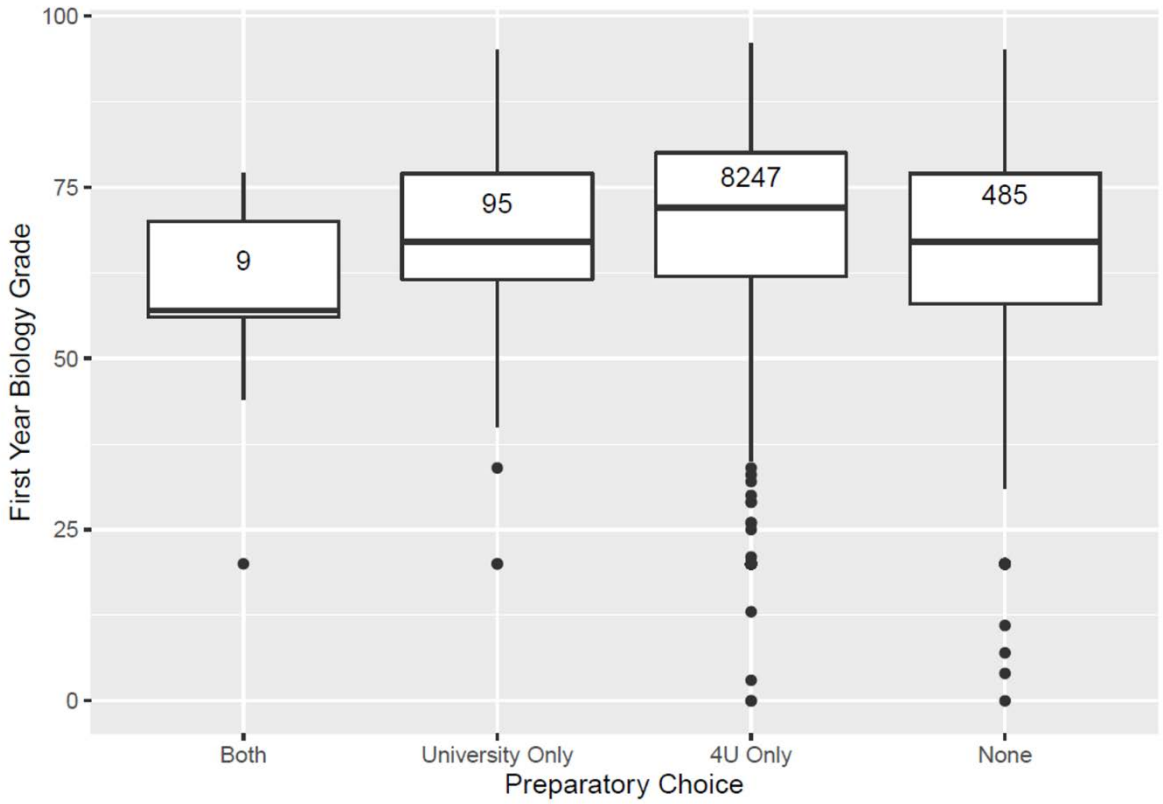

Figure 5. First-year biology grade by preparatory choice (both, university-level, 4U, and none). To aid in interpretation, sample sizes and the median (horizontal line) are indicated within each box.

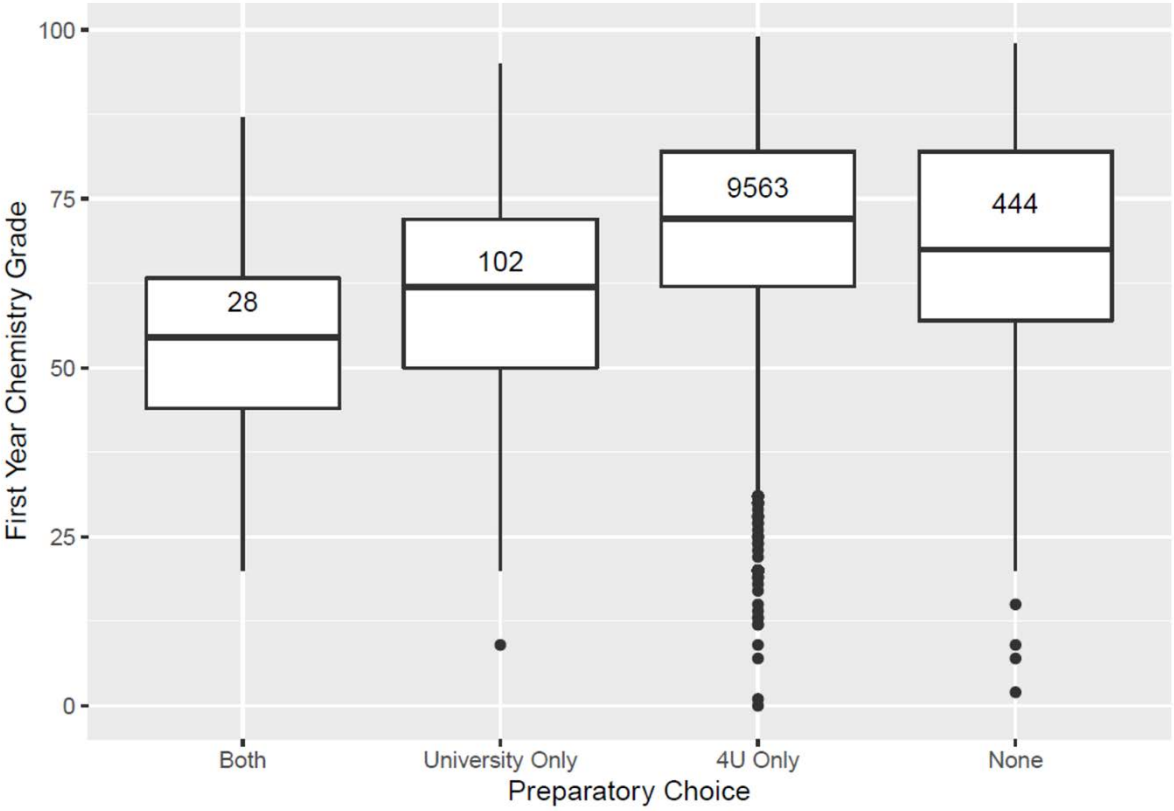

Figure 6. First-year chemistry grade by preparatory choice (both, university-level, 4U, and none). To aid in interpretation, sample sizes and the median (horizontal line) are indicated within each box.

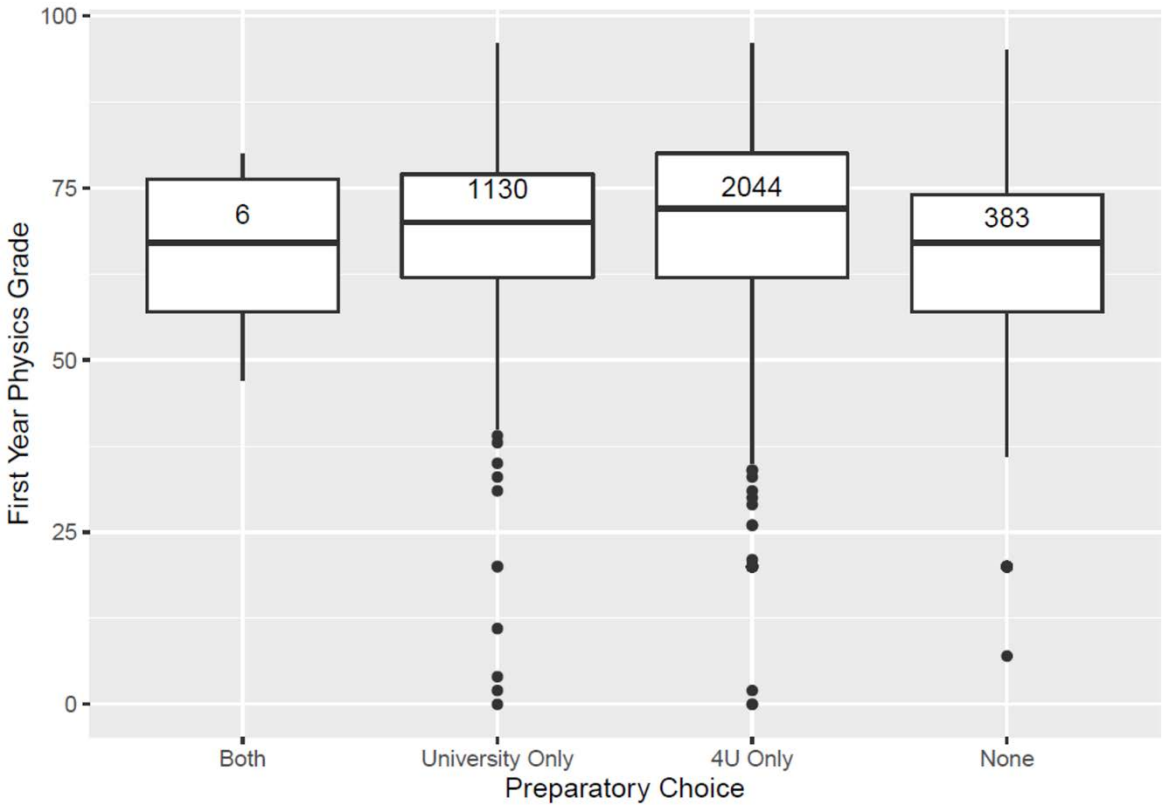

Figure 7. First-year physics grade by preparatory choice (both, university-level, 4U, and none). To aid in interpretation, sample sizes and the median (horizontal line) are indicated within each box.

Running two-way ANOVAs for preparatory choice by gender on first-year grade, there were significant main effects for both preparatory choice and gender for all three subjects and no significant interactions. However, the effect sizes from these analyses were minimal: ω^2 = .01 for biology, .01 for Chemistry, and .02 for Physics, and η^2 values ranged from .001 to .015. As such, they will not be presented in further detail here.

Preparatory grades and first-year performance. Our research hypothesis pertained to the difference between the 4U and the university preparatory course content in regard to adequately readying students for their first-year courses. To compare performance, regression models were run on a subsetted dataset, which only looked at students who took the 4U course *or* the university prep course. A continuous variable for preparatory grade, a categorical variable for preparatory course, and gender were used as predictors of first-year grades.

For each domain, the regression was significant, with moderately sized R^2 values: Biology, $F_{(3, 8338)}$ = 924.5, p < .001, R^2 = .25; Chemistry, $F_{(3, 9661)}$ = 1,311.2, p < .001, R^2 = .289; and Physics, $F_{(3, 3170)}$ = 370.1, p < .001, R^2 = .26. Refer to Table 11 for the full regression table for all three models. Interesting findings include significant negative coefficients for gender for biology and physics, with a strong relationship for the latter (with females having a 3.6-unit steeper slope than males). Preparatory grade was significantly related to first-year grades for all three domains, ranging from a slope of .548 (physics) to .812 (chemistry). Finally, the choice between 4U and university prep was examined. There was a significant negative relationship between taking 4U rather than university prep on first-year biology grades ($\beta = -2.88$), but a positive relationship for chemistry ($\beta = 5.73$). This may indicate that there is a differential in quality when comparing the 4U and university level preparatory courses between the two subjects. While the slope was negative for physics, this coefficient was not significant.

Table 11
Multiple Regressions of Gender, Preparatory Group, and Preparatory Grade on First-Year Grades

	Dependent variable		
	Biology	Chemistry	Physics
Intercept	9.094***	-1.099	28.192***
	(1.618)	(1.575)	(1.363)
Gender (Male)	-0.998***	0.026	-3.600***
	(0.258)	(0.259)	(0.417)
Preparatory grade	0.772***	0.812***	0.548***
	(0.015)	(0.013)	(0.017)
Prep Choice (Bio – 4U)	-2.877***		
	(1.177)		
Prep Choice (Chem – 4U)		5.732***	
		(1.233)	
Prep Choice (Phys – 4U)			-0.578
			(0.426)
Observations	8342	9665	3174
R^2	0.250	0.289	0.259
Adjusted R^2	0.249	0.289	0.259
Residual Std. Error	11.339	12.354	11.290
F Statistic	924.456***	1311.222***	370.081***

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$

An interesting way to visualize the relationship between the preparatory grades and the first-year grades is with a faceted scatterplot. Figures 8, 9, and 10 show a different slice of the data than the above regression analyses (as they include students who took both preparatory courses at both high school and university). These plots show the relationship between preparatory grade (4U on the left-hand side, university prep on the right) and first-year university grade in biology, chemistry, and physics, respectively. Red lines indicate the linear regression of preparatory grade on first-year grade for students who took both prep courses, green for those who took the university class, and blue indicates those who took the high school preparatory course. While it is again apparent that the vast majority of the sample falls into the 4U category, it is interesting to visually compare the slopes of these lines. As expected, the general trend is positive; as preparatory grade increases, so does final grade. However, there is one surprising result: for students who completed both preparatory courses in physics, higher performance in the university prep was positively related to first-year grade, but 4U performance was *negatively* related to first-year performance. However, this subsample is extremely small ($N = 6$), so this may simply be an artifact of the sample.

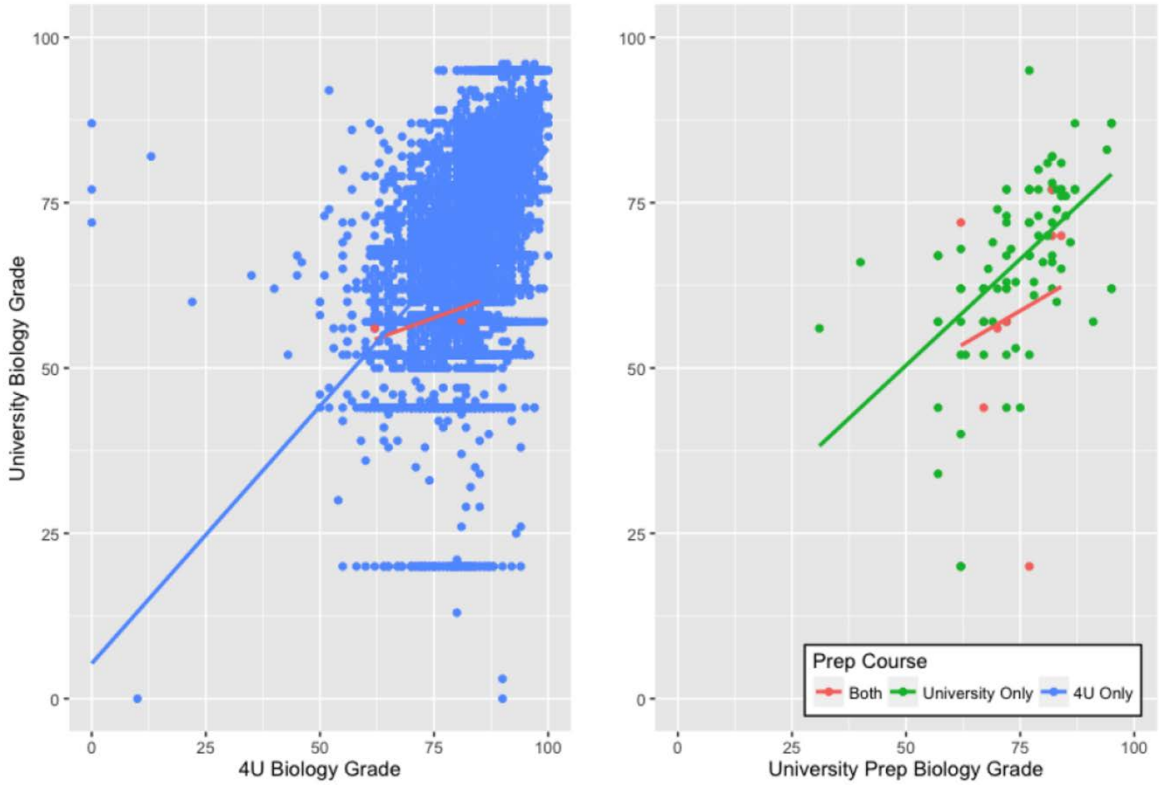

Figure 8. Relationship between preparatory grade and first-year grade for biology. Students who took multiple both prep courses are plotted in red.

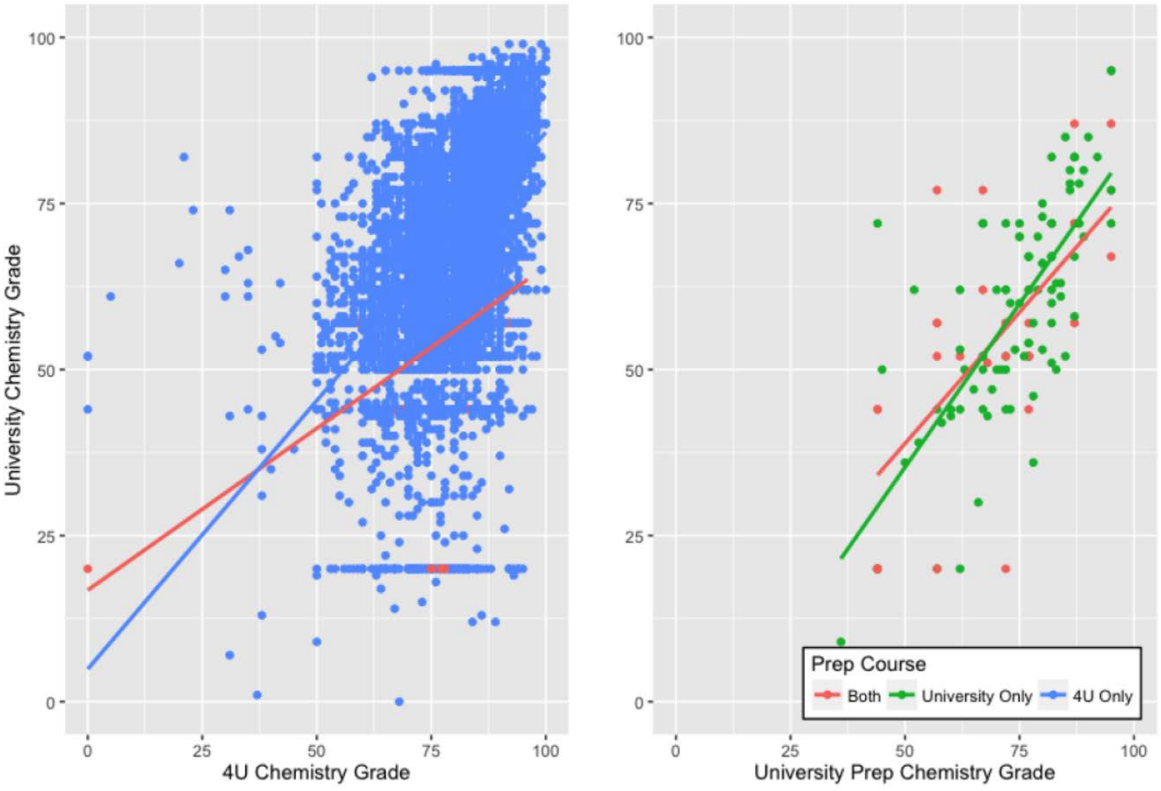

Figure 9. Relationship between preparatory grade and first-year grade for chemistry. Students who took multiple both prep courses are plotted in red.

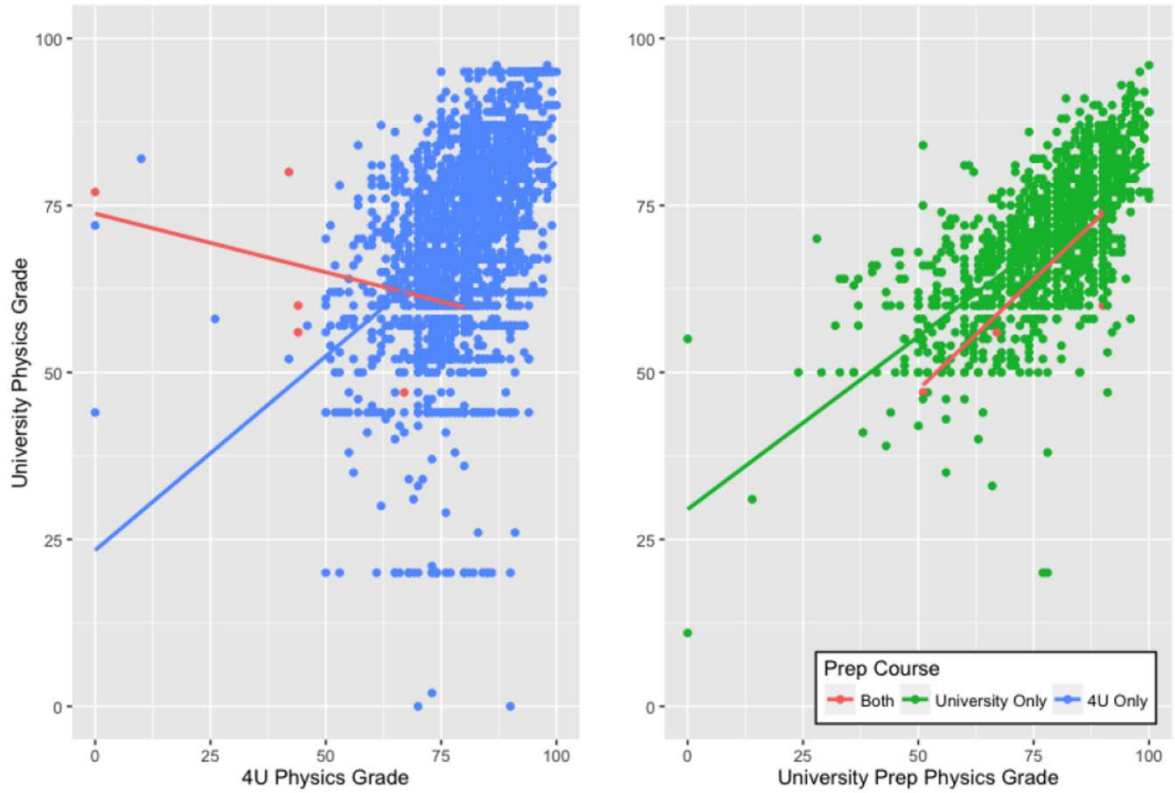

Figure 10. Relationship between preparatory grade and first-year grade for physics. Students who took multiple both prep courses are plotted in red.

Performance trajectories. A final topic of interest was to focus upon the trajectories of students who took both preparatory courses before their first-year class. The goal was to see if grades steadily improve, on average. These can be visualized using lineplots with time (4U, university prep, and first-year grade) on the x-axis. Refer to Figures 11, 12, and 13 for biology (N = 9), chemistry (N = 28), and physics (N = 6), respectively.

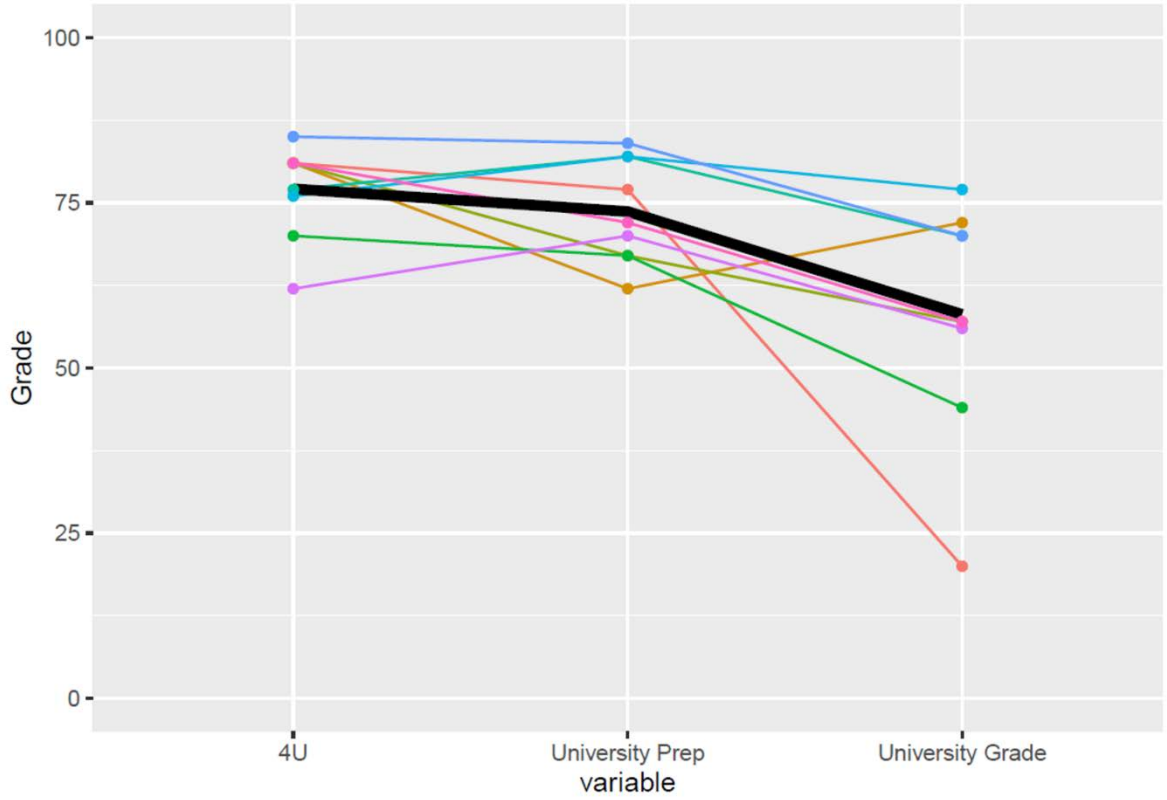

Figure 11. Individual performance trajectories for biology students who took both preparatory courses, with average trajectory indicated in black.

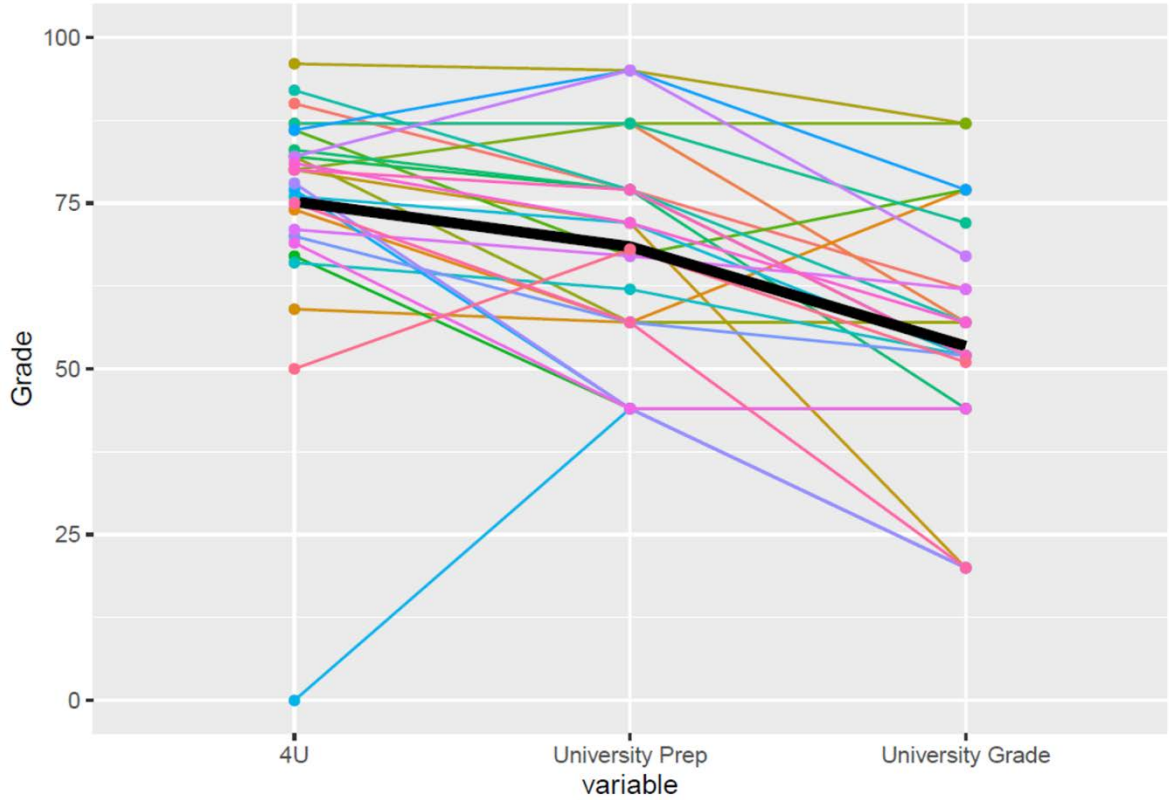

Figure 12. Individual performance trajectories for chemistry students who took both

preparatory courses, with average trajectory indicated in black.

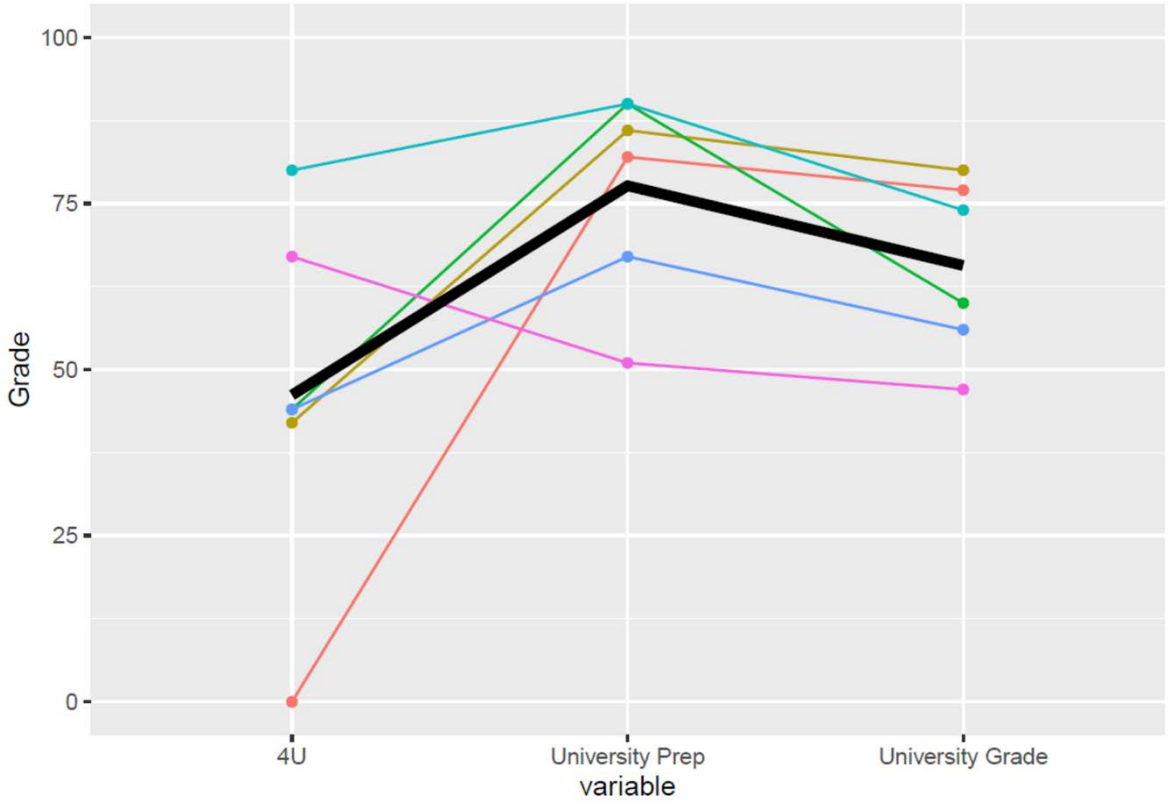

Figure 13. Individual performance trajectories for physics students who took both preparatory courses, with average trajectory indicated in black.

This trend could be analyzed using a within-participants repeated measures ANOVA, and was insignificant for biology, $F(8,16) = 1.41$, $p = .264$, and physics, $F(5, 10) = 0.89$, $p = .525$. It was, however, significant for chemistry, $F(27, 54) = 4.53$, $p < .001$. For this subject, grades consistently decreased, from 4U ($M = 75.21$) to university prep ($M = 68.43$) to first-year grade ($M = 53.43$). Using the Bonferroni correction, the difference between 4U and the university prep grade was found to be not significant ($p = .11$), but both prep courses were significantly higher than the first-year course ($p < .001$).

Discussion

The available data were segmented along two sets of categorical outcomes: subject area within school, and preparatory course choice. Each student whose data were analyzed had participated in a core science class at the first-year university level in at least one of three fields: biology, chemistry, or physics, at either the University of Ottawa or the University of Guelph between 2006 and 2012.

Additionally, preparatory courses were offered to each student at two levels: during high school (the 4U curriculum) and during the first-year of university. Although not a common occurrence, students were able to take both options. This means that going into any first-year science course, a particular student could have taken one prep course (at either level), two prep courses (at both levels), or perhaps neglected to take any prep courses.

Again, this implies that the present data has substantial sparseness—many students did not take the university level preparatory courses and so have missingness on those particular variables, or perhaps took a prep course at the high school level for a particular course but

neglected to pursue that subject further. Course selection is inherently self-selecting, and due to the limits of the data acquisition strategy, we cannot control for the particular combinations taken or for other variables usually of interest (such as household income, ethnicity, home location) that might contribute to such choices.

As such, each of the three subject domains were investigated separately, with inclusion criteria based upon the completion of a first-year university course in that particular area. This study was designed to use administration level data to assess the impact of preparatory courses given at the high school level and those at the university level. One of the most important realizations of this analysis was the sparseness of the data and the challenges it presents for the applied researcher. Administrative records only provide the bare minimum required to evaluate the influence of these courses, and it is difficult to tease apart effects due to selection bias (only students who need the remedial courses at the university level will take them) from actual gains in the population.

That being said, the results of the above analyses do yield some insights into the underlying phenomena. Many high school students are taking the 4U curricula, with many doing all three courses prior to attending university. And if, for example, a student attends university having missed taking their 4U course, they are more likely to attempt the full course than take the offered preparatory course in both chemistry and biology. The multinomial regressions highlight drastically different models for the three domains, using school, gender, and cohort to predict preparatory choice. For all three subjects, the university level preparatory courses were more utilized at the University of Guelph than the University of Ottawa. Perhaps this is indicative of the level of promotion for the courses within the department, or a testament of their quality. The physics preparatory course at the university level was the most utilized, especially at University Guelph. This could be indicative of a decline in the availability of 4U physics courses across Ontario. Both universities do not require specific science courses for general entry to the Bachelor of Science programs. Rather, students are required to at complete at least two of the 4U level science courses. The University of Guelph provides a choice from Biology, Chemistry, and Physics, and the University of Ottawa provides an additional option of Earth and Space Science. Therefore, differences in enrollment in physics University preparatory courses across institutions are not likely to be related to differences in enrollment requirements.

The gender differences in 4U preparatory course selection supports the discipline-wide gender segregations trends observed in science. Females are more often associated with biological science than physical science (see Ecklund et al., 2012). Though most students, male or female, chose to take the three 4U science courses, when only two were taken, females were more likely to choose to not take physics whereas males were more likely to not take biology.

A different analytic approach focused on first-year grades for the three subjects, and their relationship with both preparatory grades and choices. As was expected, better preparatory grades were associated with higher first-year results. Across the subjects, the university preparatory and first-year grade correlations were stronger than those with 4U, with an especially large difference between the university prep grade and final grade in chemistry (r = .72 versus r = .53) and in physics (r = .65 and r = .41). If taken on face value, this would indicate that university prep courses may be more in line with the first-year courses than the 4U courses; however, it must also be reiterated that there are substantial differences in sample sizes between these groups, and there is also the lag in time between 4U/university prep completion and undergoing the first-year class. Either of these could substantially bias these results, and so they should be interpreted with caution.

First-year grades are extremely variable, and the ANOVA models that used gender and preparatory choice, while significant, revealed little in terms of practical effects. A more salient approach was to model the relationship between gender, preparatory grade, and preparatory

choice (4U or university-level) on the first-year grades. These models accounted for a fair amount of the variability in first-year grades, and again highlighted the positive relationship between preparatory and first-year grade. Of particular interest, the choice between 4U and university prep was examined and there was a negative relationship between taking 4U rather than university prep for biology, but a positive relationship for chemistry.

The final analysis looked at the performance trajectories of the students who took both preparatory classes before taking their respective first-year university class. If the preparatory courses are adequate, it would be hoped that students would be able to either maintain or improve their average grade at each interval. This model was only significant for physics, where grades systematically decreased with time. This might indicate that the preparatory courses are not providing enough foundation for success, or that the expectations differ between the three contexts. In any case, it would be worthwhile to investigate what is happening further.

Opportunities for Future Research

If pursued, research in this area could be improved by obtaining substantially more nuanced student information. In order to properly model performance gains due to the preparatory courses, more background variables should be collected. Variables such as overall high school average may be useful to control for general student aptitude, despite having relatively little variability due to the university acceptance policies. Though the homogeneity of high school average grades enrolled in first-year university programs may not help us account for the variability in the models.

Another method that could be used as a proxy for student aptitude would be to provide a subject-specific concept inventory test at the beginning of the university-level course. This could serve as a baseline, along with the information about which preparatory course was taken beforehand.

Other demographic variables might provide more nuanced analyses: collecting information on home location, high school location, age, or race/ethnicity may be insightful to investigate. It is naive to believe that all 4U courses are of equivalent quality, for example. There are documented interactions between the effect of preparatory education and societal characteristics, with disadvantaged youth and students attending disadvantaged schools seeing the largest effects (Long et al., 2012).

Further, this kind of study would benefit from the use of qualitative techniques to garner more personal information on the helpfulness of the preparatory courses. It would be extremely useful to have students complete a survey at the start of their first-year university course on which they could indicate the preparatory work they have each completed and rate each course on its usefulness.

Conclusion

This paper outlined a variety of methods for assessing administrative level data pertaining to student performance. Specifically, we were interested in the influence of preparatory courses (at the high school and university levels) on first-year grades, across the three core sciences. Some goals were met: various statistical and visualization-based approaches were utilized to discern trends within the data. Most notably, evidence suggests that preparatory work is a worthwhile endeavor, and student performance in these courses is extremely useful for the prediction of their first-year progress. As Chinlund (2013) also found, “providing students with a second chance to gain the skills, knowledge, and behaviors required for university can be a genuinely valuable opportunity to improve students’ academic capability” (p. 92). Though students who took the biology and chemistry university preparatory courses did not achieve

grades higher than those who did not take any preparatory courses, it seems prudent for university level preparatory courses to continue to be offered by these academic institutions within Ontario, especially in physics where there was a positive effect of the university preparatory course.

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