A Statistically Designed Educational Research Study

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Abstract
A three-year educational research study is being conducted to investigate the impact of a new instructional format on student learning outcomes in calculus. The study was also designed to assess the impact of faculty mentors and role models on the performance of science, technology, engineering and mathematics (STEM) majors, especially members of underrepresented groups. The study population is STEM students enrolled in the gate-keeper Calculus I course at a historically black college and university (HBCU). In the statistical study design, some of the calculus classes have received the standard instruction while other sections have received the FORCE (Financially Oriented Research Calculus Experience) instruction. All students take a departmental final exam and a course grade of "C" or higher is considered passing. Early study results indicate that the FORCE student population is performing slightly better in the course. The statistical analysis techniques and results to date will be presented.

Key Words: statistical design, educational research, data analysis

1. Introduction

A critical national imperative today is broadening participation and improving education and workforce development in Science, Technology, Engineering and Mathematics (STEM). Academic institutions, educators, professional societies, community organizations, and industrial partners are all endeavoring to create opportunities and develop innovative strategies to attract individuals from among diverse groups, especially members of underrepresented groups, to careers in STEM. In 2010 Hampton University implemented a three-year educational research study to investigate the impact of a new instructional format in a gate-keeper calculus course on the progression and retention of STEM majors. This collaborative effort between the School of Science and the School of Liberal Arts was designed to assess whether the integration of financial applications and new teaching strategies involving research mentors and role models into the calculus course will increase academic achievement and retention in STEM majors.

Hampton University is located in Hampton, VA and was founded April 1, 1868 as Hampton Normal and Agricultural Institute. Like most Historically Black College and Universities (HBCUs), the university was established prior to 1964 and its principal mission was, and is, the education of black Americans. As the school's academic programs grew with time, the school's name changed to Hampton Institute (1930) and then to Hampton University (1984). Today the university's enrollment is about 5402 with undergraduate enrollment at 4565. About ninety-one percent of the students are African Americans.

Hampton offers 68 undergraduate programs, 27 master's degree programs, 6 doctoral degree programs and 2 specialists in education degrees. The focus of the educational research study is primarily the STEM population of about 800 students. About 650 of the students are in the School of Science and with majors in the disciplines of biology, chemistry, computer science, marine and environmental science, mathematics and physics. In addition, the School of Engineering has about 120 majors in chemical, computer and electrical engineering.

HBCUs have a very impressive record of attracting, retaining and graduating African American STEM majors at the undergraduate level. They currently award more than 20% of the science and engineering bachelor degrees to African American students. In addition, they serve as the baccalaureate origins for one-quarter to one-third of Black science and engineering (S&E) doctorate recipients (NSF, 2011). Given the past track record of HBCUs in producing STEM graduates and our current human resource challenge, it is important that the best pathways to more gains in achievement, success and degree production in STEM for underrepresented minority populations at these institutions be identified, studied and implemented. Hence, it is important that such a study be conducted at Hampton given that a 2004 US Department of Education report noted that, as of 2001, HBCUs accounted for 13% of black higher education enrollment.

1.1 Educational Research Study Overview

The Financially Oriented Research Calculus Experience (FORCE) study was initiated in the 2010 spring semester and the focus of the investigation was the impact of new curricular instruction strategies involving financial applications and research faculty mentors and role models on STEM student performance in the MAT 151 Calculus I course. This four-semester hour course is the gate-keeper course for the STEM student population at Hampton. A grade of “C” or higher (74 or higher) is considered passing for this course. Prior to fall 2011 the course format had traditionally been lecture and the class sessions were held for fifty minutes at the same time on Monday through Friday. In fall 2011 the class meeting time was changed to fifty minutes on Monday and Wednesday and one hour and fifteen minutes on Tuesday and Thursday. Also the WebAssign website was introduced into the course and it was used for the homework assignments and to administer quizzes. All students must take a common departmental final exam and complete a writing assignment. The Department of Mathematics provides a free mathematics tutorial laboratory for all students. The text book used in the course is *Calculus Early Transcendentals*, 6th Edition by James Stewart.

The MAT 151 Calculus I course covers:
Introduction to limits, continuity, and derivatives. Rules of differentiation. Differentiation of algebraic, trigonometric, inverse trigonometric, exponential, and logarithmic functions. Differentials and tangent lines. Higher order derivatives. Implicit differentiation. Applications of Derivatives. Definite integral. Fundamental Theorem of calculus. Integration of elementary functions. The calculus of the transcendental functions.

There were two study populations in the research investigation – FORCE and non-FORCE students. The students in the MAT 151 Calculus FORCE sections were exposed to the financial-application, problem-focused, active inquiry instruction; were assigned specific class and homework problems with a financial focus; and were mentored by research faculty role models in their discipline on a financial, major/discipline-related calculus writing project. Students enrolled in the non-FORCE sections received the traditional MAT 151 course instruction. The FORCE students were directed to meet with research mentors in their major/discipline on a regular basis. They were asked to work with the mentor on a writing project that described how calculus and finance were applied in their major.

The writing project was deemed to be very important because some students may not have had any interactions with a STEM professional prior to arriving at college. Quite often during the first year on a college campus the student's contact with a STEM professional is limited to meeting with the STEM advisor for registration. Studies have shown that mentoring is often the key to student retention in STEM disciplines. Gasman, Perna, et al. (2009) in *Standing on the Outside Looking In* describe the positive benefits of promoting student-faculty mentoring relationships at the undergraduate level for STEM students. They further assert that "these strong relationships may foster the self-confidence and support that students need to enter and complete future graduate study." The STEM students were provided with a research project rubric that outlined how the paper would be graded. A technical writing mentor was also provided to help the students with the writing project. In an effort to monitor and direct the writing project, each student was required to provide an abstract for the project early in the semester and other project deadlines were established throughout the semester.

1.2 Educational Research Study Methodology and Assessment Methods

The major performance metric of interest in this study was student performance in the MAT 151 Calculus course. Other key performance metrics were

STEM RETENTION (% of an entering class that remains in school and not transfer)

- For each calculus course, what was/is the difference in student retention before the FORCE and after the program started?
- How does the student retention compare for the FORCE (experimental group) sections versus non-FORCE (control) sections of the calculus courses?

STEM PROGRESSION (% entering class move from freshmen to sophomore status, …)

- For each calculus course, what was/is the difference in student progression before the FORCE program started and after the program started?
- How does the student progression compare for the FORCE sections versus non-FORCE sections of the calculus courses?

Both formative and summative assessments were conducted in the course. The primary formative assessments were homework assignment grades and classroom exams. Focus group meetings were held with the students employed as tutors in the tutorial laboratory to better understand how the students were progressing in the course and to determine how well the tutorial sessions were progressing. A pre-calculus readiness test was administered to the students in the MAT 151 course to get a measure of how mathematically prepared they were for the course. Some students had taken the calculus series in high school and others had completed the high school courses in algebra and trigonometry. Other students had completed the pre-requisite algebra and trigonometry courses after arriving at Hampton. The summative assessments used were student course survey results, retention rate (based on the number of course failures and withdrawals during the semester), progression rate (based on the student enrollment for the next course in the calculus sequence), and student grades (final exam, course, research projects). The post-calculus readiness test was again administered to each student at the end of the course but prior to the final exam to get another assessment of each student's algebra and trigonometry skills.

2. Data Analyses and Study Results

2.1 Demographic Data and Final Exam Grades

The major demographic study variables collected for each student in a MAT 151 class were the student name, major, classification, high school GPA (HSGPA), gender, race, ethnicity, age (AGE), SAT Math score, SAT Verbal score, pre-calculus readiness test score, post-calculus readiness test score, and final exam score. Table 1 provides a comparison of the means and standard deviations of the SAT verbal, SAT mathematics, high school GPA and final examination scores for the FORCE and non-FORCE student populations.

Table 1: Summary Statistics of Demographic Data

Variable	Non-FORCE Traditional Classroom			FORCE Financial-Infused Classroom Instruction		
	N	***M***	***SD***	***N***	***M***	***SD***
SAT Verbal	119	510.34	94.53	115	502.19	81.61
SAT Mathematics	119	563.19	89.37	115	531.81	72.15
High School GPA	119	3.24	.50	111	3.28	.48
Final Examination	121	57.93	24.44	109	59.52	23.95

Overall, the experimental group consisted of 115 (N) students (54 males and 61 females; 112 identifying as Black, Non-Hispanic) with a mean age of 19.03, mean (M) high school GPA of 3.28 , standard deviation (SD) of 0.48 and a mean SAT Math score of 531.81. The control group consisted of 124 students (69 males and 55 females; 118 identifying as Black, Non-Hispanic) with a mean age of 19.13, mean high school GPA of 3.24 and a mean SAT Math score of 536.13. Generally, the experimental group scored higher on the final examination as compared to the control group even though the control group had a higher mean score on the SAT Math and the mean high school GPAs were very similar for both groups. In separate analyses to compare the mean final exam grades of the two groups for each semester, a significant finding between the two groups was only found during the spring 2010 semester with the experimental group scoring higher than the control group ($t(43.241) = -2.322$, $p = .025$, with a medium effect size of Cohen's $d = .63$). An independent sample t-test was conducted to evaluate the hypothesis of equal means for the two groups. Equal variances could not be assumed based upon the Levene's test for equality of variances, $F(226.997) = 4.617$, $p = .033$. The t-test, not assuming equal variances, was not significant, $t(226.997) = -.461$, $p = .645$, with a negligible effect size. The group of students receiving FORCE instruction with the infusion of finance into the coursework scored higher on the final examination ($M = 59.52$, $SD = 23.95$) than the group of students receiving normal instruction ($M = 57.93$, $SD = 24.44$) but the results were not statistically significant.

In a follow-up analysis, an analysis of covariance was conducted to compare the two methods of instruction (FORCE versus non-FORCE) while controlling for previous performance of students, SAT Mathematics scores (or the equivalent ACT score), SAT Verbal scores (or the equivalent ACT score), and HSGPA (high school GPA). The analysis of covariance was not significant, F (1, 210) = .022, MSE = 13.724, p = .883, with a negligible effect size. While controlling for previous performance, the FORCE group of students scored higher on the final examination (estimated marginal M=58.66) than the group of students receiving the traditional instruction (estimated marginal M=58.15) but it was not statistically significant. Although there was no statistically significant finding, the FORCE group with lower mean SAT Math scores did score higher on the common final examination. (It should be noted that there were changes in final exam preparer and final exam format during the study.)

2.2 Student Performance Data

A grade of "C" or higher was considered passing in this course for STEM majors. Some baseline data on the percentage of students with a grade of "F" and the percentage of students with a grade of "C-" or less in the MAT 151 course prior to the study was available and is provided in Table 2. In addition, similar data are also provided on the FORCE and non-FORCE student populations during the time period of the study. For all semesters except spring 2010 and spring 2012 the percentage of FORCE students with final grades less than "C-" was less than the percentage of non-FORCE students. The spring 2012 data is very interesting given the percentage of students not obtaining a grade of "C" or higher is very large for both population groups.

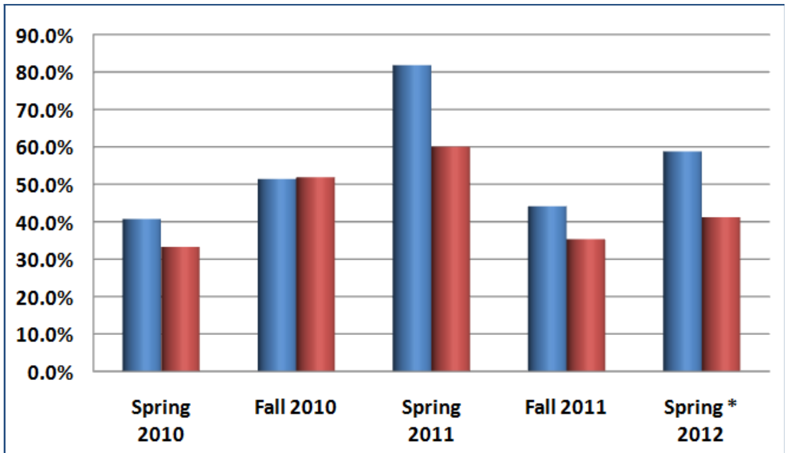
Data were also collected on the percentage of students withdrawing from the course. Students could withdraw from the course with either a grade of withdraw passing (WP) or withdraw failing (WF). Given that the goal of the FORCE study was to attract and keep the STEM majors, this was an important metric. As show in Table 3, fewer of the FORCE students withdrew from the MAT 151 course each semester.

Table 2: Student Performance (% failing) Data by Semester		
MAT 151 Calculus I		
Semester	***% F Grades***	***% Grades "C-" and Below***
Fall 2004	10	41
Spring 2005	10	42
Fall 2005	13	27
Spring 2006	9	26
Fall 2006	21	37
Spring 2007	8	16
Fall 2008	12	38
Spring 2009	24	32
Fall 2009	17	30
Spring 2010		
All Sections	12	38
Non- FORCE	21	46
FORCE	0	30
Fall 2010		
All Sections	16	35
Non- FORCE	21	34
FORCE	8	36
Spring 2011		
All Sections	20	32
Non- FORCE	36	36
FORCE	6	29
Fall 2011		
All Sections	26	36
Non- FORCE	33	42
FORCE	21	30
Spring 2012		
All Sections	19	48
Non- FORCE	27	45
FORCE	10	50

Table 3: Percentage of Students WP/WF by Semester	
MAT 151 Calculus I	
Semester	% WP/WF
Spring 2010	
All Sections	8
Non- FORCE	9
FORCE	7
Fall 2010	
All Sections	9
Non- FORCE	10
FORCE	8
Spring 2011	
All Sections	16
Non- FORCE	32
FORCE	3
Fall 2011	
All Sections	21
Non- FORCE	33
FORCE	12
Spring 2012	
All Sections	16
Non- FORCE	24
FORCE	10

2.3 Student Progression in STEM

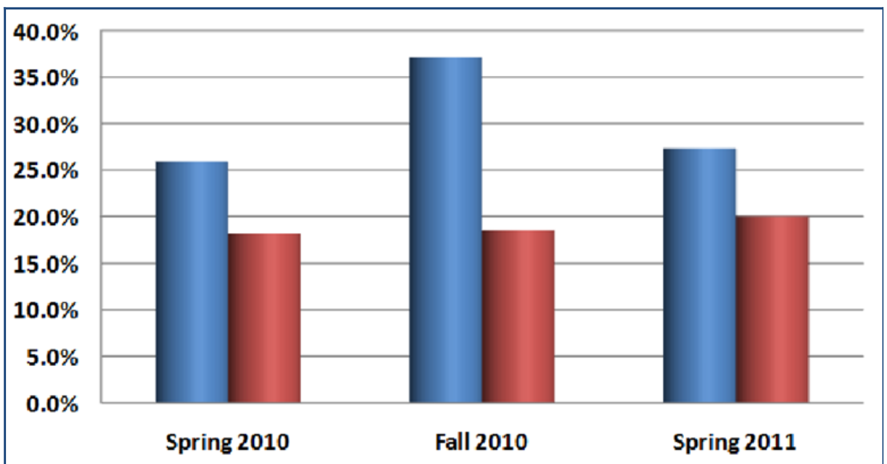
For this study it was critical to track student progression in STEM. Given the length of the study, it was not possible to track students to graduation. However, it was possible to track advancement through the sequence of calculus courses – MAT 152 Calculus II, MAT 251 Calculus III and MAT 260 Differential Equations - required for STEM majors. Figure 2 provides information, by semester, on the percentage of FORCE students and non-FORCE students who successfully complete the MAT 151 Calculus I course and then advance to the next calculus course in the sequence – MAT 152 Calculus II. (*Data for spring 2012 semester is tentative and based only on the successful completion (with a grade of at least "C") of the MAT 151 course in spring 2012.) The percentage of FORCE students who progress to the MAT152 Calculus course is much higher for each semester except fall 2010.



	Spring 2010	Fall 2010	Spring 2011	Fall 2011	Spring * 2012
FORCE Students	40.7%	51.4%	81.8%	44.1%	58.8%
Non-FORCE Students	33.3%	51.9%	60.0%	35.3%	41.2%

Figure 2: Percentage of the MAT 151 students who advance to the MAT 152 course after a successful completion of the MAT 151 course. Blue color denotes FORCE students, while red color denotes non-FORCE students.

The tracking data that highlights student progression through the MAT 152 Calculus II, MAT 151 Calculus III and MAT 260 sequence is provided in Figure 3. For the spring 2010, fall 2010 and spring 2011 semesters the percentage of FORCE students who advanced through the Calculus sequence was greater than the percentage on non-FORCE students.



	Spring 2010	Fall 2010	Spring 2011
FORCE Students	25.9%	37.1%	27.3%
Non-FORCE Students	18.2%	18.5%	20.0%

Figure 3: Percentage of the MAT 151 students who went on to take the MAT 152 course after a successful completion of the MAT 151 course and then went on to take the MAT 251/260 course after a successful completion of the MAT 152 course. Blue color denotes FORCE students, while red color denotes non-FORCE students.

3. Conclusions

Previous findings from this research study have been reported in Morgan, et al. (2011). As with most studies of this nature, it was not possible to randomly assign students to the MAT 151 course sections or to control for teachers, time of the class, teaching assignments, etc. The statistical analyses revealed that although the average final exam grade scores for the FORCE students was slightly higher than the scores for the non-FORCE students, the difference was not found to be statistically significant. A smaller percentage of the FORCE students had to retake the MAT 151 course. In addition, a larger percentage of the FORCE students continued straight to the MAT 152 course and then progressed onward through the MAT 251/260 calculus/differential equation sequence.

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