Research Study to Assess Whether Mentors and Research Projects Positively Impact Student Performance

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Abstract

A three-year NSF educational research study of the impact of a new instructional format on student learning outcomes in calculus has been completed. The study specifically addressed the impact of faculty mentors, role models and research projects on the performance of science, technology, engineering and mathematics (STEM) majors in the gatekeeper Calculus I course at a historically black college and university (HBCU). While some of the calculus classes have received the standard instruction, other sections have received the FORCE (Financially Oriented Research Calculus Experience) instruction. Student pre- and post-calculus test scores and final exam scores were used to assess student performance in the course for the two study groups. The 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: education, research study, assessment

1. Introduction

The National Science Foundation Historically Black Colleges and Universities Undergraduate Program (**HBCU-UP**) Financially Oriented Research Calculus Experience (**FORCE**) educational research study was designed to investigate the impact of integrating mentors and real-world research projects that incorporate aspects of design, analysis, and finance on student progression and retention for members of an underrepresented group. The study addressed the Hampton University (HU) undergraduate science, technology, engineering and mathematics (STEM) majors enrolled in the gatekeeper MAT 151 Calculus I course. Some of the students received the FORCE instruction but the students in the other sections received the standard course instruction. While Hampton University was undertaking a study to investigate the impact of the incorporation of financial literacy on student outcomes in the Schools of Liberal Arts and Journalism, the Principal Investigators (PIs), Dr. Carolyn Morgan (Department of Mathematics) and Dr. Anne Pierce (Department of Humanities), implemented this initiative that incorporates financial topics in a new student-centered calculus curriculum for STEM students. This endeavor provided an opportunity to obtain research data to qualitatively and quantitatively assess the effect of this new model of instruction on increasing the calculus achievement of STEM students in the Schools of Science, Engineering and Technology, and Business.

1.1 Project Overview

A major component of the FORCE project was the replacement of the current, often non-technical, writing assignment in the MAT 151 calculus course with a real-world discipline-related research project that encompasses aspects of design, analysis, and finance. The project topic was developed based on discussions between the student and a faculty mentor in the student's major department. This fostered an opportunity for students to become more engaged with their major department, faculty and the bibliographic resources of the discipline. It was hypothesized that establishing this early linkage between a student and the department increased student retention. The study benefitted both the students and faculty. From the faculty advisors it was reported that the FORCE experience highlighted students who could perform well in later research laboratory experiences as they progressed toward their degree. Students also learned about research areas or fields of study which they may not be exposed to in the classroom.

1.2 Educational Research Study

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 course. The MAT 151 four-semester hour course is often the gatekeeper course for the STEM student population at Hampton. A grade of "C" or higher (74 or higher) is considered passing for this course. As part of the University's "Writing Across the Curriculum" initiative, there is a course writing project. In addition, all students must take a common departmental final exam. 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 online homework and testing management system was introduced into the course and it was used for the homework assignments and to administer quizzes. The Department of Mathematics provides a free mathematics tutorial laboratory for all students and funding from this grant was used to pay student tutors in this laboratory. 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.

The FORCE project provided an opportunity to introduce students to realistic problems within the context of their major that require the use of their calculus skills. The cost function was taught in class and the students were challenged to use it in their projects. Many of the students were surprised to see how cost components impact scientific investigations. In this program the PIs have monitored the production of over 170 student research reports on how calculus and finance were important in a STEM discipline-related research activity. The PIs have worked in collaboration with a team of over twelve STEM faculty members from the School of Science (biology, marine science, chemistry, physics and mathematics), School of Business and the School of Engineering and Technology (chemical and electrical engineering) who have served as research mentors for the students and assisted them with their projects. Furthermore, this project clearly demonstrated the importance of having both good writing skills in support of strong technical skills. The PIs provided technical writing support to the students in the writing of the abstract for the paper and the preparation of the final paper. The PIs were able to identify other funding support to invite a technical writing expert from the Georgia Institute of Technology to give a workshop for the students.

1.3 Educational Research Study Methodology and Assessment

The major performance metric of interest in this study was student performance in the MAT 151 Calculus course. Some baseline data on student performance in the MAT 151 course prior to the study was available. 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 failure 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 calculus readiness test was again administered to each student at the end of the course but, prior to the final exam, to get another post assessment of each student's algebra and trigonometry skills.

2. Data Analyses and Study Results

2.1 Student Performance

It was important to track student performance in the MAT 151 Calculus I gatekeeper course for each semester. Baseline data on the percentage of students with failing grades and the percentage of students with grades of "C-" or lower were obtained for each semester beginning with fall 2004. The data are presented in Table 1. During most of the semesters in the study period, there was a smaller percentage of the FORCE students with a failing grade or a grade of "C-" or lower in comparison to the non-FORCE students. More of the FORCE students were able to progress to the next course – MAT 152 Calculus II – in the calculus series.

Table 1. MAT 151 Calculus Student Performance (% failing) Data by Semester		
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
Fall 2012		
All Sections	22	47
Non- FORCE	20	40
FORCE	24	56
Spring 2013		
All Sections	30	57
Non- FORCE	42	58
FORCE	24	56

2.2 Retention and Course Withdrawals

Retention is another important performance metric for this study. The infusion of mentors and role models to guide students in a discipline-related research project with a financial focus should serve to reduce the number of student withdrawals from the gatekeeper course and hence increase the number of students remaining in the STEM disciplines.

After about ten weeks during the semester, a student could withdraw from the course with a passing grade (WP) or withdraw with a failing (WF) grade. For the study period which began in spring 2010, data were captured each semester on the percentage of students withdrawing from the FORCE and non-FORCE sections of the course. Historically, prior to spring 2010, about 14% to 32% of students withdrew from the MAT 151 course. In spring 2010, approximately 7% of FORCE students withdrew from the course and 9% of the non-FORCE students. In fall 2010, 8% of the FORCE students withdrew. Again, for most of the semesters, the percentage of FORCE students withdrawing from the course was smaller than the percentage of non-FORCE students as highlighted in Table 2.

Table 2. Percentage of Students WP/WF Data by Semester

Semester	Section	% 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
Fall 2012	All Sections	4
	Non-FORCE	0
	FORCE	8
Spring 2013	All Sections	16
	Non-FORCE	33
	FORCE	8

2.3 Pre-Calculus and Post-Calculus Readiness Scores

The pre-calculus and post-calculus readiness test scores were analyzed for the FORCE students starting in fall 2010. A plot of the average scores is provided in Figure 1. For fall 2010 the average pre-calculus and post-calculus scores were about 58 and 68, respectively. The average pre-score for the spring 2011 students was the lowest obtained during the study. Generally, the average post-readiness test score was higher than the average pre-readiness score. The average post-readiness score was lower than the average pre-readiness score for the spring 2013 semester. It is also important to note that a smaller number of the students took the readiness tests during this semester.

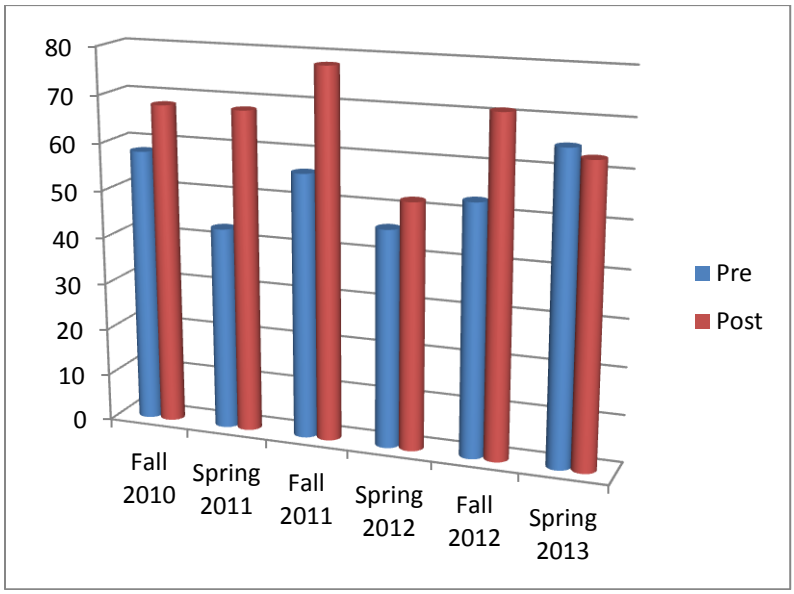

Figure 1: Average Pre- and Post-Calculus Readiness Test Scores for FORCE Students By Semester. Blue color denotes results of the test given to students at the beginning of each semester, and red color denotes results of the test given to students at the end of each semester.

Likewise, at the end of each semester, for each student the difference (post-readiness test score minus the pre-readiness test score) was computed and a paired t-test was conducted to test the null hypothesis that there was no difference in the scores. The t-test was analyzed with an alpha significance level of 0.05. The results of the paired t-test and the 95% confidence intervals are summarized in Table 3. For three of the semesters the null hypothesis was rejected. The 2011 spring and fall semesters gave strong support to the alternative hypothesis. The 95% confidence interval for the 2010 fall semester provides weak support that the null hypothesis should be rejected with zero being included in the interval.

Table 3. Summary of Paired t-test Results of Post-Pre Scores for FORCE students α=0.05

	Fall 2010	Spring 2011	Fall 2011	Spring 2012	Fall 2012	Spring 2013
n	26	22	23	12	16	15
t-value	1.76	5.66	3.94	1.48	2.60	-0.33
p-value	.045	.00000649	.000353	.083	.02	.748
95% Confidence Interval	(-.8824, 11.394)	(14.689, 31.775)	(8.7533, 28.253)	(-6.011, 30.844)	(3.19, 32.44)	(-17.60, 12.94)

3. Conclusion

There were several major challenges that were encountered in conducting this study. It was not possible to randomly assign students to sections of the MAT 151 Calculus I course or to control the time classes were held, departmental changes in the class format and the teacher assignments to the class sections. It was also not possible to monitor the degree of faculty and student interactions. The final exam scores for the students in the FORCE and non-FORCE sections of the course were evaluated. For the first semester of the study only, it was determined that there was indeed a significant difference (α=0.05) in the average exam scores for the FORCE and non-FORCE students. The exam scores for the FORCE students were higher than the scores for the non-FORCE students. The study findings revealed that during six of the seven semester study periods, there was a smaller percentage of the FORCE students failing the MAT 151 course with a grade of "F" and, during four of the seven semester study periods, a smaller percentage of the FORCE students received a course grade below "C" which mandates that the STEM student must retake the course. For six of the semesters, a smaller percentage of the FORCE students withdrew from the course and a larger percentage progressed to the next calculus course. A larger percentage of the FORCE students continued straight to the subsequent MAT 152 Calculus II and then progressed to the MAT 251 Calculus III and MAT 260 Differential Equations courses. Student evaluations of the FORCE sections of the MAT 151 course were also very good. Many of the student projects have been presented at the annual HU School of Science Research Symposium and displayed on posters at the 2010, 2011 and 2012 Joint Annual Meetings of the National Science Foundation. In summary, prolonged exposure to faculty in their discipline seemed to make the greatest impact on their motivation to do well in the calculus class and to register for the courses that followed MAT 151.

Acknowledgements

"This material is based upon work supported by the National Science Foundation under Grant No. 0928274

"Any opinions, findings and conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation (NSF)."

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