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Patterns of Students' Success: How Engineering Students Progress through a Course Sequence

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Patterns of Students' Success: How Engineering Students Progress through a Course Sequence

Abstract

Increasing the number and diversity of graduates with undergraduate degrees in engineering continues to be highlighted in national reports. Improving the number of engineering graduates is not only a matter of recruitment but also a critical matter of retention. Currently, less than half of the students entering engineering persist and ultimately attain an engineering degree. Retention studies, in general, have evaluated cohorts related to specific lengths of time, such as first or second year retention. The studies have provided less information on patterns of student performance in courses in the engineering curricula and instead many times focus on success in a first course. The authors in this study examine how patterns of progression through course sequences might be used to improve retention in engineering.

This approach visualizes how engineering students are progressing through course sequences. Engineering curricula are complex with multiple required courses, many of which have one or more prerequisites. Success in each course sequence in a student's program study of engineering is a prerequisite for student success in engineering; that is, if they do not succeed in the course sequence, they do not succeed in their program of study. Studies of student progress through various course sequences can provide different perspectives and findings on student success in engineering. This paper reports on how student success in course sequences can be visualized and what information can be gained in this process.

Introduction

Studies related to engineering student retention tend to focus on who leaves engineering after periods of time (e.g., one year, two years, etc.), and why they leave. A number of retention studies have made important contributions to help frame challenges related to ethnic/racial or gender diversity, such as why certain groups leave at higher rates than others. Other studies have emphasized influences of student success in a first-year course, such as a mathematics course, and their relationships to retention in engineering. While studies of retention in engineering have contributed many valuable findings, other approaches to understanding student success in engineering may offer additional strategies for improving retention.

Many engineering curricula include multiple sequences of courses in which one course is a prerequisite for the next, which is a prerequisite for the follow-on course, and so forth[1]. These engineering science sequences, together with courses in mathematics and science, have been implemented in engineering curriculum designs to help students develop their expertise in specific areas of engineering to lead up the capstone design class. For example, the following sequence of courses can be found in mechanics: Statics, Dynamics, Mechanics of Materials, Solid Mechanics, and Capstone Design. This sequence is intended to develop efficacy in structural performance and safety analysis. Other examples of an engineering science course sequence include materials and thermodynamics/fluids. Other curricula, for example, science curricula, also contain multiple required sequences, but their prevalence in engineering curricula and their close relationship to specific expertise suggests that examination of student success in these sequences could provide insights into promoting student success in engineering.

To improve the number and diversity of students earning engineering degrees, it may be helpful to study patterns of student success in these required course sequences in engineering curricula. Charting engineering curricula with critical path analysis tools shows they present entering students with complex project management challenges because of multiple required courses, many of which have one or more prerequisites. In addition, there are sequences of prerequisite courses that students must follow. Visualizing student progress through the various course sequences provides insights helpful to understanding student success in engineering.

A sequence prevalent in engineering curricula is sequence in mathematics. Many engineering curricula include a mathematics sequence similar to the following: Calculus I, Calculus II, Multi-variable Calculus, and Differential Equations. Since the mathematics sequence occurs frequently at the beginning of engineering curricula, studying student progress in this course sequence may provide useful information about student progress through the entire engineering curriculum and student retention.

Background

There is extensive literature studying the retention and persistence of engineering students[2-5]. The literature includes studies focusing on retention and persistence of women in engineering[6] as well as retention and persistence of underrepresented racial/ethnic minority students[7,8]. However, in works related to student retention less attention has addressed how engineering students proceed through the engineering curricula. The authors have not found contributions charting patterns of student success through engineering degree programs. In addition, visualizing student progress through engineering curricula given the multiple required courses and the various ways of satisfying these requirements (e.g., advance placement, transfer courses, transfer students, course substitutions, etc.) has not been a focus in the body of knowledge.

It would be helpful to have quantitative, disaggregated visualizations of where engineering students enter the system and where they leave, in addition to accurate, disaggregated reports on the numbers and percentages of students leaving engineering. Displays similar to the way that Tufte[9] displayed the decrease of Napoleon's army during the Russian campaign would be very helpful in formulating effective interventions. This is the ultimate intent of very preliminary work presented in this paper.

Progress through a Four-course Mathematics Sequence

Like many engineering programs, undergraduate engineering curricula at Texas A&M University require four courses in mathematics: Calculus I, Calculus II, Multi-variable Calculus, and Differential Equations. Catalog descriptions of the curricula indicate these four courses are taken in a sequence in consecutive semesters. What percentages of students take and complete these four courses as presented in the course catalog? Figure 1 depicts results of 14,047 undergraduate engineering students who enrolled in Calculus I for the first time at Texas A&M in a fall semester.

The numbers along the top show the number of students taking Calculus I for the first time at Texas A&M. For each fall semester, the percentage of engineering students taking Calculus I for the first time at Texas A&M is shown as 100%. Working down from the top of the graph, the second line shows the percentage of students that pass Calculus I, that is, earn a grade of A, B, or C in Calculus I. As the second line shows, the percentage of students passing Calculus I has been increasing over the time span shown in the graph. The third line is the percentage of students who enroll in Calculus II the following semester. Every year the percentage that enrolled in Calculus II is about 10 points less than the percentage that passed Calculus I. That is, about 10% of the students who started in Calculus I do not even attempt to take Calculus II the following semester, even after earning a passing grade in Calculus I. The fourth line presents the percentage of the students who passed Calculus II. Subsequent lines show enrollment in Multi-variable Calculus, passing Multi-variable Calculus, enrollment in Differential Equations, and passing Differential Equations, or completing the mathematics sequence. As Figure 1 shows, the highest percentage of students that finished the mathematics sequence in consecutive semesters over the thirteen-year time space in the graph is about 40%.

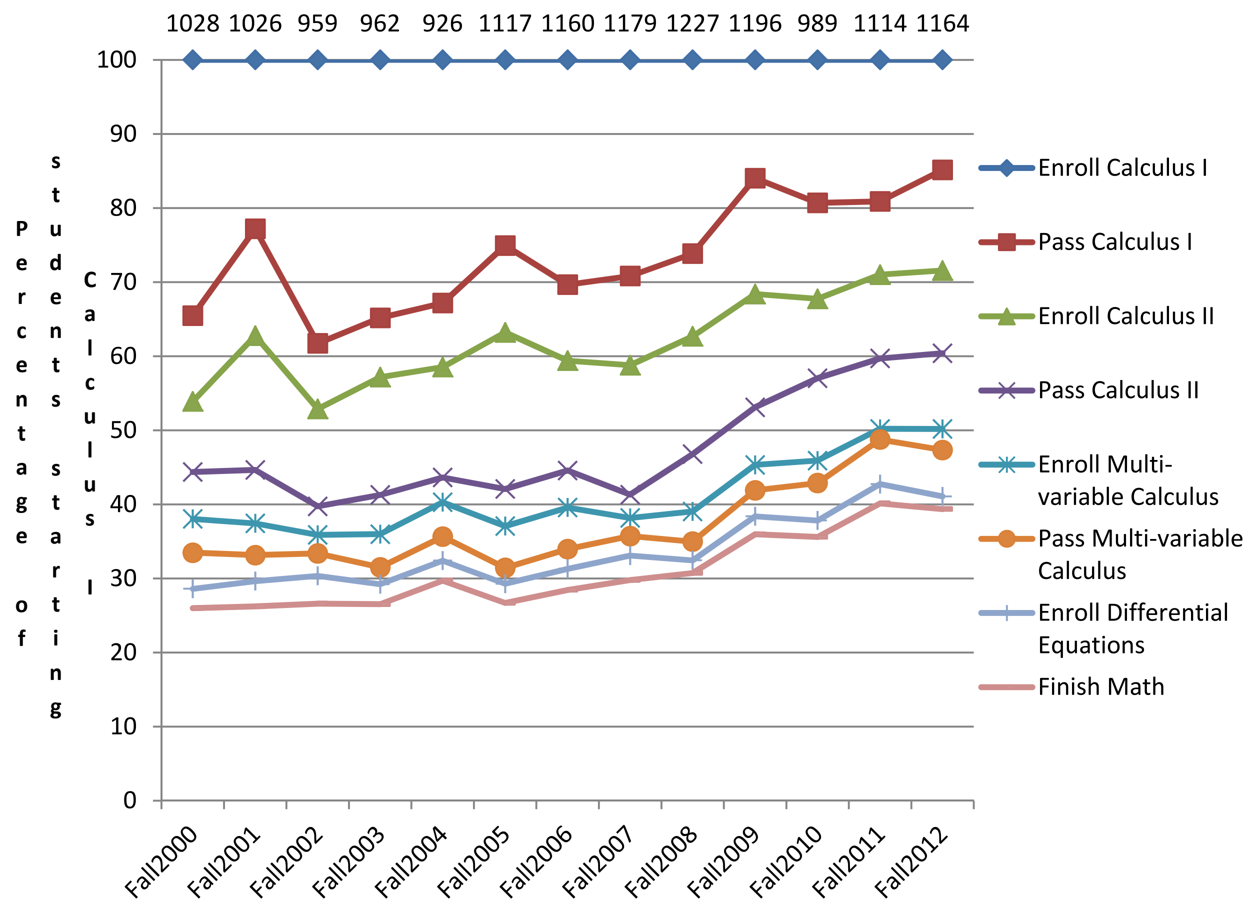

Figure 1. Engineering student progress through the four-course mathematics sequence in consecutive semesters.

As shown in the rightmost column of markers in Figure 1, for every 100 students who started Calculus I in fall 2012, 85 students passed Calculus, I, 71 students enrolled in Calculus II in spring 2013, 60 students passed Calculus II in spring 2013, and so on through the mathematics sequence.

Engineering students do not have to complete the four-course sequence at Texas A&M in consecutive semesters. They can take courses in the sequence after a one, two, or even more semester pause. They may not succeed the first time they take the course, but may be successful the second or third time they take the course. They can also complete courses at other institutions and transfer the course credit. To account for these options, Figure 2 starts with the same number of students each year as Figure 1 and shows this number as 100%. In this figure, however, completion of each of the courses in the mathematics sequence is counted whenever and however the next mathematics course was completed.

As expected, passing rates and subsequent enrollment percentages in Figure 2 are higher than Figure 1. For example, increases in the percentages of students enrolling and passing Calculus I increase by between 0 and 10 percentage points. The percentage of students completing the mathematics sequence has increased to about 50%. However, the increases from completing the courses in the mathematics sequence in consecutive semesters to completing the courses eventually are not huge. The bulk of the engineering students who complete the mathematics sequence do so by completing the courses in consecutive semesters.

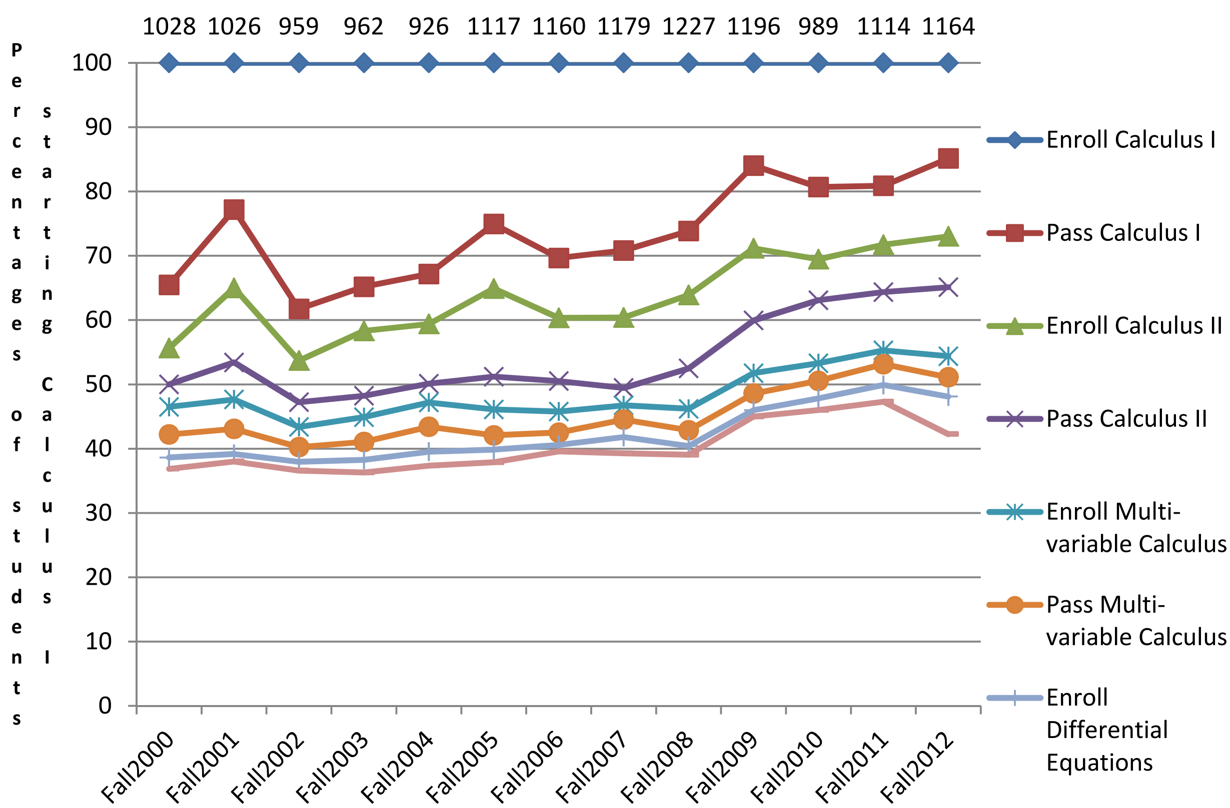

Figure 2. Engineering student progress through the four-course mathematics sequence without requiring completion in consecutive semesters.

What differences exist related to gender?

Figures 3 and 4 are the analogs for Figure 1 for male and female engineering students, respectively, with the focus of on-time completion. They show that, in general, female engineering students progress through the four-course mathematics sequence at higher rates than male engineering students, although specific exceptions can be found at various points. Analysis of statistical differences between male and female students has not yet been done.

How Much Difference Does the Grade in the First Mathematics Course Make?

Previous studies have already shown that grades students earn in their first mathematics course influences their retention in engineering[10,11]. How do the grades students earn influence their progress through the mathematics sequence? Figures 5, 6, and 7 show student progress through the courses in consecutive semesters after Calculus I for students earning an A (Figure 5), B (Figure 6), and C (Figure 7) in Calculus I.

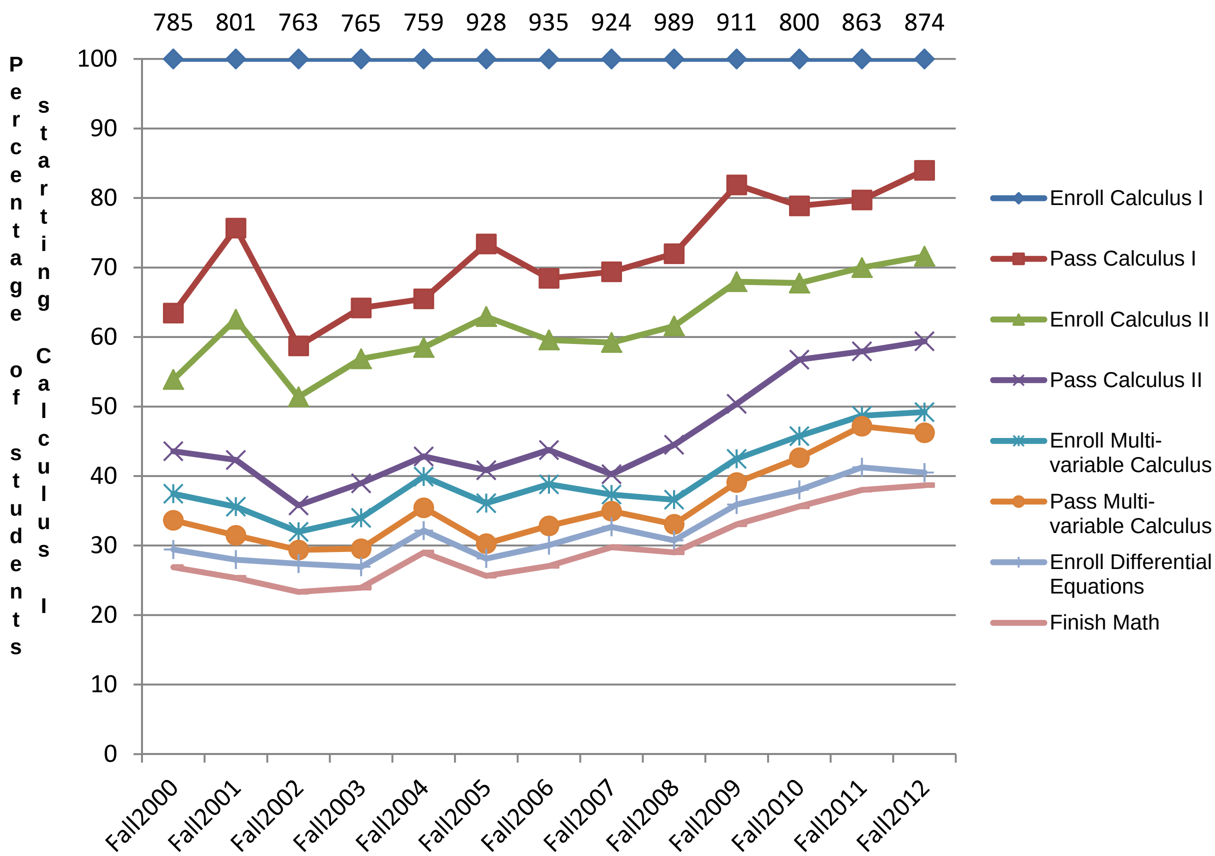

Figure 3. Male engineering student progress through the four-course mathematics sequence in consecutive semesters.

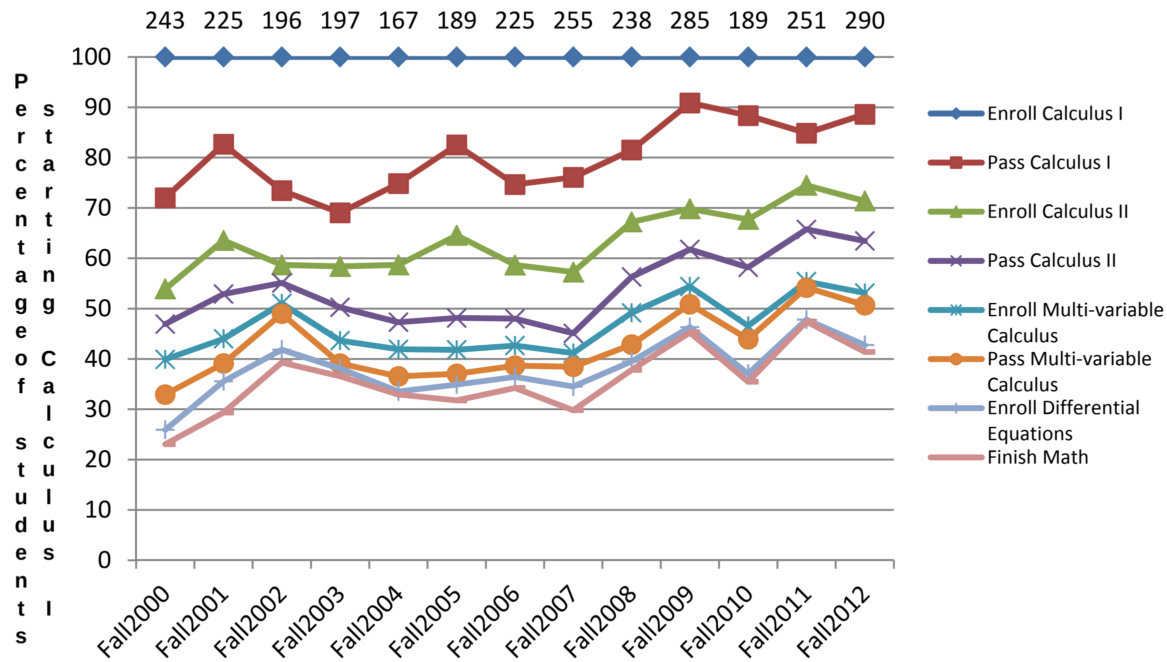

Figure 4. Female engineering student progress through the four-course mathematics sequence in consecutive semesters.

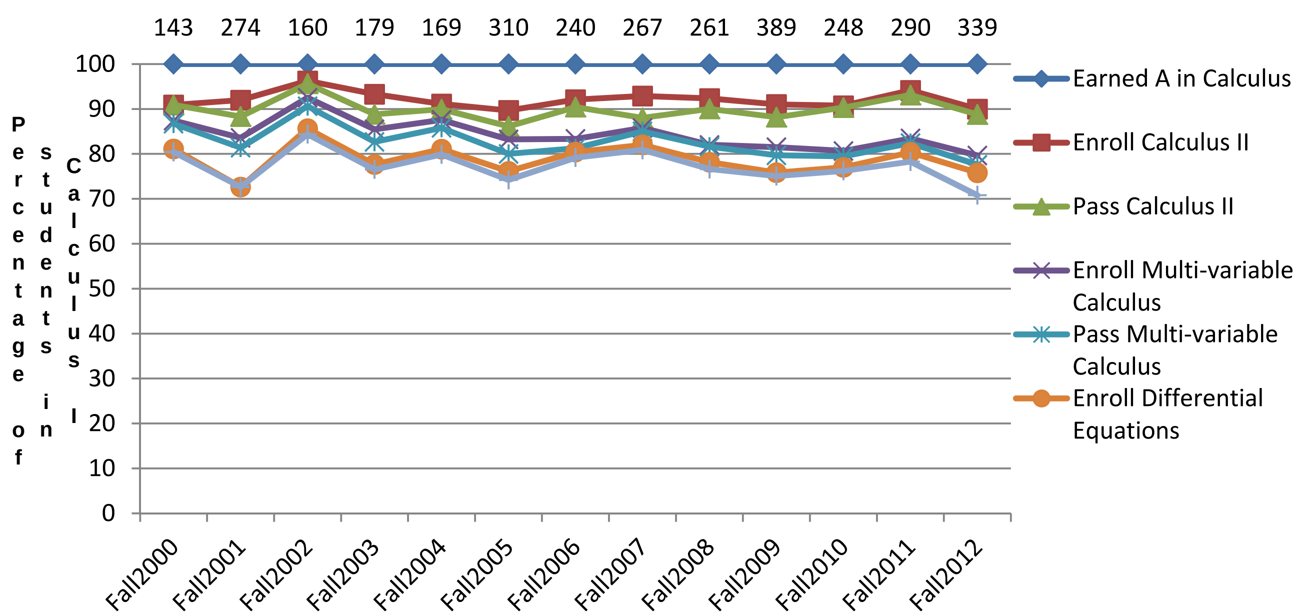

Figure 5. Engineering student progress through the mathematics sequence after earning an A in Calculus I.

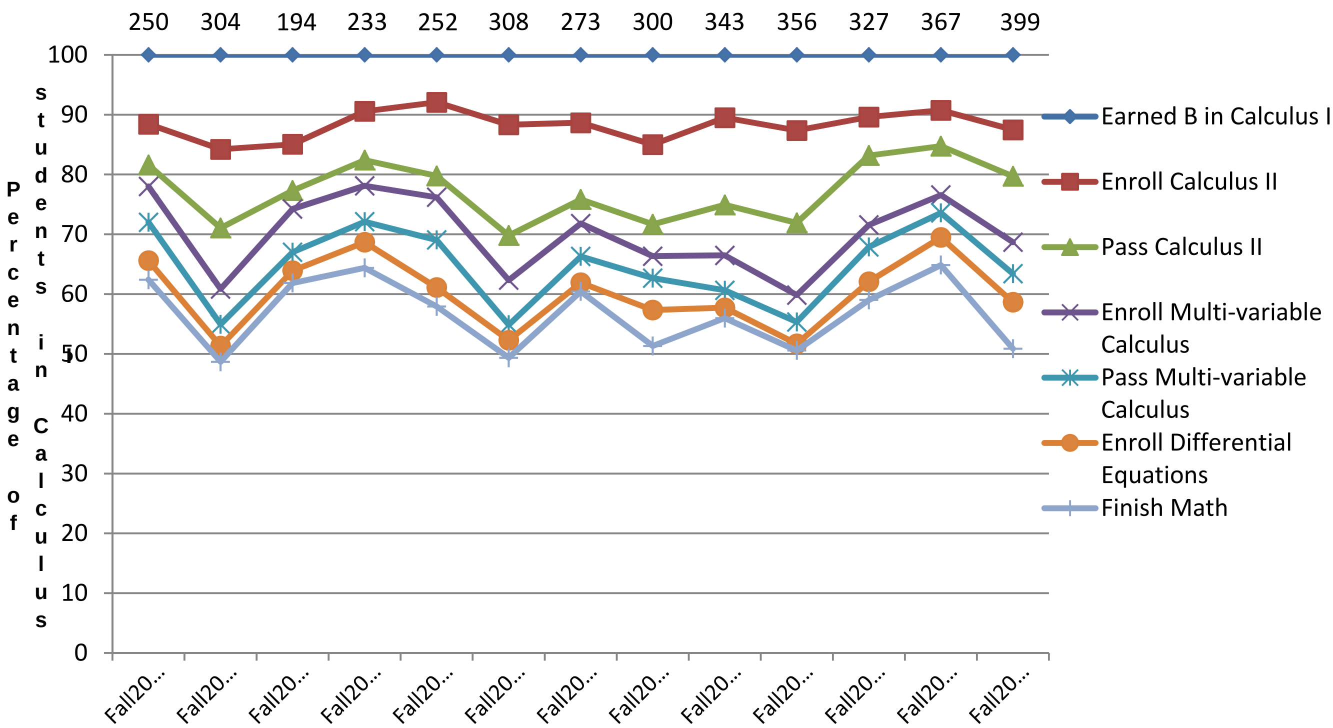

Figure 6. Engineering student progress through the mathematics sequence after earning a B in Calculus I.

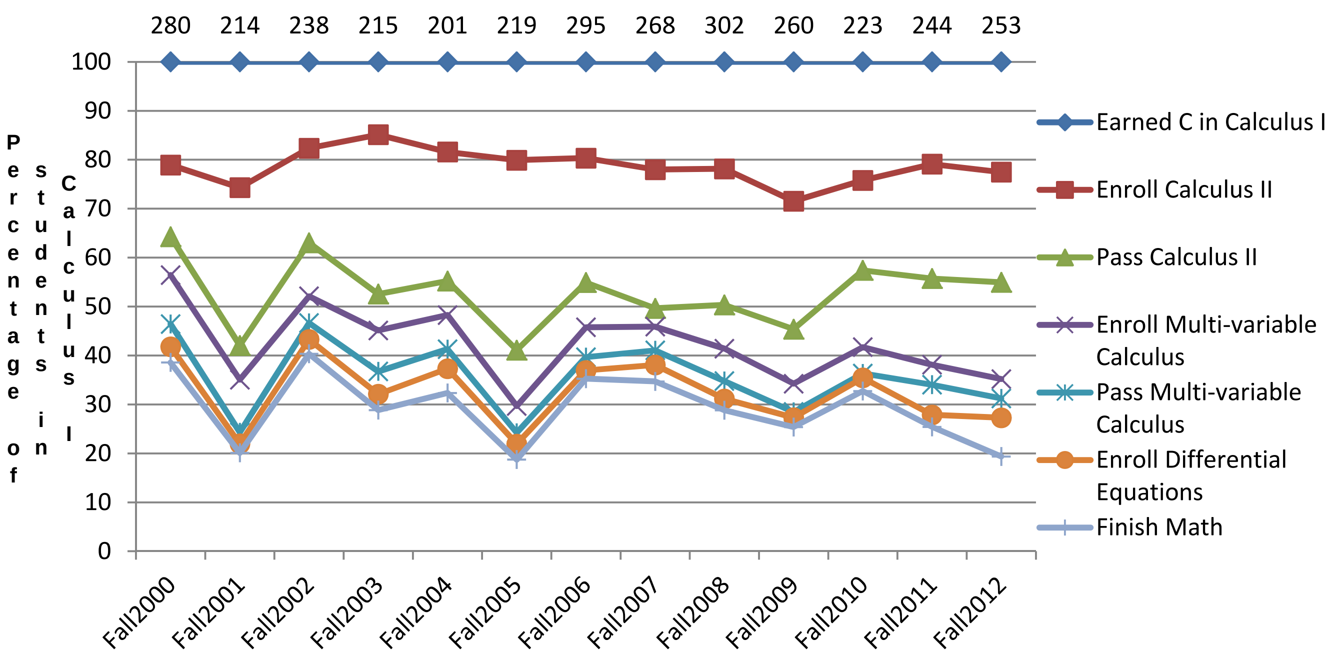

Figure 7. Engineering student progress through the mathematics sequence after earning a C in Calculus I.

In these three graphs, the line at 100% is the number of students who earned an A, B, or C in Calculus I. The next line down is the percentage of students who ever enrolled in Calculus II. The third line down is the percentage of students who passed Calculus II, and so on. As shown in the rightmost column of markers in Figure 5, for every 100 students who started Calculus I in fall 2012 and earned an A, 90 students enrolled in Calculus II in spring 2013, 89 students passed Calculus II in spring 2013, and so on through the mathematics sequence.

Comparing Figures 5 6 and 7, it is apparent there are important differences between progressions through the mathematics sequence depending on grade received in that first mathematics course. Broadly, while 80% of the students who earned an A in Calculus I completed the four-course mathematics sequence, 60-70% of the students who earned a B in Calculus I completed the four-course mathematics sequence and 40-50% of the students who earned a C completed the four-course mathematics sequence. Since students must complete the four-course mathematics sequence to earn an engineering degree, the percentages of students who earned A, B, or C in Calculus I provides predictors about retention and graduation rates.

Fewer students progressed through the mathematics sequence after earning a B in Calculus I than after earning an A in Calculus I. The percentage of students who enrolled in Calculus II ranges between about 90 and 95% after earning an A in Calculus I. The percentage of students who enrolled in Calculus II ranges was between about 84 and 90% after earning an B in Calculus I. Almost all students who earned an A in Calculus I passed Calculus II. Between 2 and 7% of the students did not pass Calculus II after earning a B in Calculus I. About 80% of the students who earned an A in Calculus I completed the four-course mathematics sequence. Around 60 to 70% of the students who earned a “B” in Calculus I completed the mathematics sequence.

As shown in Figure 7, students who earned a C in Calculus I did worse in the rest of the mathematics sequence than students earning an A or B in that course. About 20% of the students who earned a C in Calculus I did not ever enroll in Calculus II. From the students who enrolled in Calculus II to the students who passed Calculus II, the percentages drop by 10 to 15%. The percentage of students who completed the mathematics sequence after earning a C in Calculus I ranged between 30 to 45%. Using this analysis, academic advice to students who earn a C in Calculus I possibly should be to retake Calculus I with the intent to earn an A. This is consistent with the academic advice given to students in the Meyerhoff Scholars Program at University of Maryland Baltimore County[12]. However, some provisions should be made to provide positive reinforcement for this advice. Conditions might be related to keeping scholarships and reducing tuition in view of possibly a longer time to complete an undergraduate engineering degree. Another focus would be to ensure proper placement into courses, such as Calculus I. For example, students not yet prepared to enter Calculus I might be better advised to enroll in a prerequisite mathematics course first. By helping students identify risk zones prior to enrolling in a course, the probability of being retained and ultimately graduating can be increased.

Conclusions

Studies of graduation rates of undergraduate engineering students show that about 55% of the students that enter the college of engineering in a given academic year graduate with a baccalaureate degree in engineering within six years. As shown in Figure 2, about 50% of the students that enroll in Calculus I in the fall semester of a given year complete the mathematics sequence. So, the percentage of students that eventually complete the mathematics sequence is a very rough approximation of the graduation rate. There are many reasons for the difference. In fall 2014 about two-thirds of the students entering engineering in a given year began by enrolling in Calculus I. Some students start their undergraduate study in pre-calculus. Others begin in Calculus II, Multi-variable Calculus, Differential Equations, or have completed the mathematics sequence before enrolling in Texas A&M. Also, students may graduate from the college of engineering with degrees that do not require the entire four-course mathematics sequence for graduation. These are some of the reasons for the differences between the college of engineering graduation rate and the percentage of students who start in Calculus I and complete the mathematics sequence. Nevertheless, it appears valuable to study student progress through the mathematics sequence.

Visualizing student progress through the mathematics sequence also provides some idea of the dependence of student success in the mathematics sequence on the grade that students earn in Calculus I. Based on this evidence, steps are being taken to improve student success in Calculus I. For example, work is being undertaken to identify students at risk early in the semester and advise corrective action. Further steps as far as academic advising for students earning a C in Calculus I or helping students identify proper course placement may need to be further evaluated.

Visualizing also allows study of differences between male and female students with respect to the success in the mathematics sequence. Graphs similar to Figures 5, 6, and 7 could be displayed separately for male and female students to evaluate differences in how students respond to the grade they earn in a course, such as Calculus I.

Students take many different paths through the engineering curricula. Developing tools, including visualization tools, to understand student progress will help to develop strategies to increase rates at which students succeed in engineering. It will also assist in determining common roadblocks students encounter in departmental-specific courses and highlight areas where further resources or changes in instruction might be needed. The approach presented in this paper is a very early attempt to provide new methods for visualizing student progress. The technique can be adopted for any sequence of required courses in engineering curricula.

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