AC 2011-405: FACTORS IMPACTING POOR PERFORMANCE IN PRE CALCULUS

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Factors Impacting Performance in Pre Calculus

Abstract

Efforts to increase the STEM workforce have often focused on the K-12 area to address interest and major selection. A neglected area involves examination of the success factors for students who have selected a STEM major but do not arrive in the university setting with strong and robust mathematics background. As a result, many of these students are placed in pre calculus in anticipation that this will allow them to build their mathematics skills in preparation for success in calculus. Unfortunately, although many of these students appear to be motivated for and capable of pre calculus success, they do not do well and this often results in changes of the major and loss of STEM career potential. This study explored student perceptions of success factors impacting pre calculus. Findings covered areas such as placement processes, impact of high school preparation, learning resources valued and used by students, and student views on strategic programs to enhance success.

Introduction

Efforts to increase the STEM (science, technology, engineering, and math) workforce by enhancing the selection of and success in engineering and science majors have addressed many ideas and directions. An area of particular interest and significant potential is to increase the success rate for those who have selected a STEM career. These efforts often fall under the banner of “retention” and frequently address success in mathematics courses. Actual retention rates are the subject of much discussion. A number of studies over the last 15-20 years generally indicate that the rate of retention in engineering ranges from 30% to 50% nationally¹ with an average of less than 50% of initial majors.^{2,3} On the other hand, a study which employed a National Science Foundation (NSF) funded database of undergraduate students between fall 1987 and 2005 at ten US universities reported that the average engineering retention rate was near 57% over eight semesters compared to 50% for arts and humanities, 41% for other STM majors, and 38% for computer science (individual institution numbers ranged from 37% to 67%).⁴ Although there is debate about the actual engineering retention numbers, there is little controversy that the number of engineering graduates needs to increase.

The reasons for the retention issue have also been widely studied and include diverse factors such as learning styles and psychological dispositions.⁵ Other studies have identified the issues of poor teaching and pedagogy as key factors in persistence.^{2,3} The close link between mathematics success and continued success in later engineering studies, ultimately translating into long term retention in the STEM major, is also documented in many papers.^{6,7,8} These studies generally identify that one of the more at risk groups is those students who have selected a STEM major but do not arrive in the university setting with strong and robust mathematics background, as evidenced by failure to be placed into calculus I in the first semester of freshman year. Many of these students are placed in pre calculus in anticipation that this will allow them to build their mathematics skills in preparation for success in calculus. Unfortunately, although many of these students appear to be motivated for and capable of pre calculus success, often they do not do well and this results in changes of the major and loss of potential STEM careers.

Another pertinent evaluation of the role of mathematics preparation in engineering student success made a conclusion that we have suspected qualitatively in advising students. They found it was not the math *level* at which the student started that determined success, but the *grade* they received.⁹ This indicates that how they *feel* about their ability to succeed impacts their perception of their ability and resultant wherewithal to continue as an engineering major. Had systems been in place to better support the student's ability to succeed at Pre calculus, we may have retained several more engineers.

Many approaches have been examined to improve the success of this group and they include learning communities and various intervention and learning support strategies.^{10,11,12} However one area in which the literature is largely silent is specific surveys of what students believe are the issues which have the most impact and the interventions which would be most useful. This paper contributes to that area of the literature by presenting the results of a survey of 87 engineering majors who took pre calculus. All had taken pre calculus within the past four semesters and only 11% of the respondents had received a D or F grade. Specifically, the survey explored the research questions in Table 1.

Table 1: Summary of Survey Research Questions

<ol style="list-style-type: none"> 1. Do students believe they were placed in pre calculus appropriately? <ol style="list-style-type: none"> a. Is this substantiated by the correlation of the test score and the grade? 2. What is the role of high school preparation and how should this influence the course content focus? <ol style="list-style-type: none"> a. linear, quadratic, polynomial functions b. logarithmic and exponential functions c. Trigonometric functions 3. What do students believe about the effectiveness of learning resources and approaches? <ol style="list-style-type: none"> a. Textbook b. Computer based or on line homework c. Use of learning aids for on line homework d. Required attendance 4. What do students think are effective success strategies? <ol style="list-style-type: none"> a. Required attendance b. Summer prep course c. Problem solving session in place of an hour of lecture
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Our motivation in examining the questions in Table 1 is to improve the performance of our students in this important gateway course. Ultimately, we hope to impact the broader success of STEM majors in pre calculus, more clearly highlight real from perceived issues, and identify interventions which have high potential for success rate improvement. The following sections of the paper address these research questions and the responses.

Placement

Math placement testing is intended to determine the level of preparation a student has for the required classes. Proper math placement is crucial for engineering success, yet no consistently successful indicator has been found to precisely place students in their first college level math

class. The potential for inconsistent results can be seen by contrasting a recent study which found that while college math placement scores do a better job at placing students than do SAT scores¹³ this does not consistently relate to the performance of the student in the class.^{10,11}

We currently use the ALEKS¹⁴ test system to determine the level of calculus-readiness of a freshman student entering our program. ALEKS is an online placement test taken by entering freshmen at home prior to arrival on campus; it is not supervised. The results of the test determine whether the student is placed into college algebra, pre calculus, or calculus 1. Figure 1 shows that 64% agreed or strongly agreed they had been correctly placed and only 11% did not believe they were placed in the appropriate math class.

Figure 1 ALEKS Placement Test Responses

As shown in Figure 2, the number of students receiving D's and F's has gone down from 62% to 29% since implementing the current placement test in 2007. These results indicate that the students responding to the survey were appropriately challenged by placement in pre calculus.

Figure 2 Grade Distributions in Pre Calculus

High School Preparation

The second research question involved student perceptions of the adequacy of their high school preparation in mathematics. The survey asked students to evaluate their preparation for pre calculus based upon their exposure to three topical areas in high school math classes: 1) linear, quadratic, and polynomial functions; 2) exponential and logarithmic functions; 3) trigonometric functions. Figure 3 shows that 80% agreed or strongly agreed their background in linear, quadratic and polynomial equations was adequate for pre calculus, 68% agreed or strongly agreed on logarithmic and exponential equations, and only 56% agreed or strongly agreed on trigonometry. This declining confidence verified a perception of engineering faculty that high school courses neglect exponential, logarithmic, and trigonometric content – important areas for success in engineering.

Figure 3 Student Responses on High School Preparation

We found a relationship between the highest math course taken in high school and the impact on where the student places based on the math placement test. Table 2 shows where students placed based upon the highest level of math taken in high school. It shows students who have not taken any pre calculus or trig in high school are much more likely to place into college algebra or pre calculus than those who have taken pre calculus or calculus.

Table 2 Math Placement Distribution Based on High School Mathematics

HS Math Level	College Algebra	Pre Calculus	Calculus I
Advanced functions or less	35%	36%	29%
Pre calculus, calculus, or trigonometry	24%	26%	50%

As noted above, students were asked what grade they received in the course or, for those still enrolled in the course, what grade they anticipate receiving (only 11% noted a D or F). As shown in Figure 4, 5, and 6, we were not able to relate the grade earned or received in the course and the level of self-reported preparedness in the underlying areas. Future research will include more representation from students who did not do well.

Figure 4 Correlation of grade earned with preparedness rating: linear, quadratic, and polynomial functions

Figure 5 Grades earned with preparedness in exponential and logarithmic functions

Figure 6 Grades earned with preparedness in trigonometric functions

The key point from this series of questions remains the issue of preparation: 80% of respondents felt prepared in the area of linear, quadratic, and exponential functions, only 68% felt prepared in the area of exponential functions and logarithms, and only 56% of students felt prepared in the area of trigonometry. It is clear from the self report data that students on average are least confident about their preparedness to use trigonometric functions. We plan to further study student preparedness based upon a more objective metrics (such as an initial exam) and compare this to the self reported data.

Effectiveness of Learning Resources

Exponential functions and logarithms and particularly trigonometry are topics that are central to pre calculus courses. Lack of adequate preparation in these topics could go a long way towards explaining why students are failing to place into calculus in the first place and then could also account for why these students are not successful in pre calculus during their freshman year. To try and understand why some students are successful in pre calculus and some are not, the survey included questions pertaining to learning resources students used. The results reveal which resources the students deemed to most effective.

The learning resources available to students were listed as class lectures, homework, the textbook, tutoring centers, and study groups. The survey results showed the majority of students believed homework to be most important for their learning and the textbook to be essentially irrelevant. More specifically, the results displayed in figure 7 show that 60% of students believed that doing their homework was most important for their learning of the material, 27% thought class lectures were most important, and only 5% of the students indicated that they learned the most from studying the textbook. Moreover, when asked how often they studied the textbook, only 8% of the students responded that they used the textbook regularly while 51%

responded that they never used it, 30% occasionally, and 11% only before tests. See Figure 8 for these results. Figure 9 shows that of the 92% of the students that did not regularly use the textbook, 47% believed the textbook wasn't necessary for completing their homework and 28% didn't use it because they already understood the material from attending class.

Figure 7 Sources for Learning Course Material

Figure 8 Use of Textbook

Figure 9 Reasons for Lack of Textbook Use

It is not surprising that the students believed homework to be the most effective way to learn pre calculus – most math instructors would agree that this is the best way for students to succeed. It is perhaps more surprising that the students were doing homework without consulting their textbooks. However, 86 of the 87 students who took the survey were doing web-based homework so instead of needing the textbook as a resource, these students could turn to online resources for help instead. The next survey questions examine student perceptions of on-line homework and of the learning aids that accompany it.

The student's response in general to on-line homework was extremely positive. Figure 10 shows that 79% of the students believed on-line homework to be effective for learning math and succeeding in pre calculus (30% strongly agreed, 49% agreed). Figure 11 indicates that they made use of the learning aids that go with it such as "Help me solve this" or "Show an example" (36% always used them, 59% occasionally). Without these resources, the students indicated they would try to get assistance from a variety of alternate sources (including the textbook) but nothing stands out as something a majority of the students would use – see Figure 12.

Figure 10 Online Homework Perceptions

Figure 11 Frequency of Use of Learning Aids

Figure 12 Preferred Sources for Additional Help

As noted in the conclusions below, most of the students in the survey passed pre calculus with the grade of A, B, or C. We can thus draw some conclusions from the survey about what it takes to succeed in the class. Doing homework is very important. The web-based homework was well received by students, causing them to be more engaged and thus more successful in the class. But what does the survey indicate about those students that aren't successful in pre calculus? Why does this course remain a barrier for so many students who wish to pursue careers in STEM fields?

These results could be interpreted to confirm what many people teaching college mathematics courses, including Pre-Calculus and Calculus, observe in the classroom: often students rely entirely on imitation and memorization as their only learning tools.¹⁵ Indeed, 60% of the students said that most of what they learn in a class occurs while doing homework; there is nothing alarming in this per se, but, when we look at how students work on their homework, we find that almost all of the students do it with the help of "Help Buttons" (36% always use them, 59% occasionally). It has to be explained here that "Help Buttons", such as Pearson's "Help me solve this" and "Show an example", in most, if not all on-line homework systems, provide students with solutions to problems identical with the homework problems, only the numbers are

different. This enables students to do their homework by simply changing the numbers, without understanding the concepts involved and the reasoning of the solutions that were provided to them. And thus, doing the homework can turn into a superficial process with limited “learning” potential.

What happens when the buttons are disabled? The homework scores drop precipitously (generally the scores are in the 85%-100% range when the buttons are enabled and in the 40%-75% range when the buttons are disabled) and students seek outside help to complete the problems: 15% go to a tutoring center, 16% ask the instructor or a classmate and 15% simply skip problems they don’t know how to do. Only 31% of the students turn to a textbook for help with such problems (see Figure 12). In general 51% of the students never use the textbook, primarily (47%) because the homework can be done without reading the textbook by clicking on “Help me solve this”.

Of course, malfunctioning of “Help Buttons” is not the main difficulty in successfully teaching college mathematics today. It is one of the many indicators that the main problem may be that the majority of students throughout their high (and very likely elementary and middle) school years are taught to memorize and thoughtlessly imitate. By the time they reach college, this approach to learning mathematics is deeply rooted and this habit is difficult to break. An example of this resistance is embodied in a recent statement to one of our mathematics faculty: “Don’t explain it to us, just show how to do the homework!”

It appears this data indicates that students may not see a need to ask why. They learn to manipulate, sometimes correctly and often incorrectly, with mathematical symbols, but rarely have a clear understanding of what these symbols and manipulations mean. For example, most pre-calculus and calculus students know how to add fractions, but when asked why this is the way fractions should be added the most likely answer will be: “Our teacher told us so”. A recent experience of one of the co-authors who had a calculus class with 1/3 of the students regarding $\sin x$ as the product of $\sin$ and x and therefore simplifying $(\sin x) / x$ to $\sin$!

This survey information has highlighted the well known problem of how to teach mathematics to achieve conceptual understanding. A popular approach, at least in theory, is “to teach the skills first, understanding later”. In practice, however, it reduces to “teach the skills only” with the probable results described above. It is clear that it would take system wide efforts to teach “the skills together with understanding” on all stages of mathematical education to achieve any significant improvements.

It is not realistic to expect the students to go back to studying their textbooks while their homework is on-line and there are so many alternative resources available on the web. Also on-line homework does have distinct advantages – the students getting immediate feedback on their work being one of them. But the following should be considered when using web-based homework to make it even more effective in increasing student’s understanding:

- Develop on-line homework systems in such way that while providing students with assistance they would also require students to think. For example, if “Help Buttons” should show students complete solutions, they should show solutions of similar problems, not problems identical with the homework problems.

- Also, develop on-line reading assignments to encourage students to read the textbook.

Additional Effective Success Strategies

The final set of questions examined student perceptions of success or intervention strategies. Required attendance is often discussed as a learning strategy. Surprisingly, Figure 13 shows that 65% agree or strongly agree this would promote student success in pre calculus. This supports the strong response in Figure 7 of the importance of the lecture as a learning tool. Figure 14 presents results of the question related to the impact of an on line summer preparation course. 65% agreed or strongly agreed that this would be an effective success tool. Finally, Figure 15 shows that 80% agreed or strongly agreed that a weekly problem solving session in place of a lecture would be effective.

Figure 13 Required Attendance

Figure 14 Possible Summer Preparation Course

Figure 15 Weekly Problem Solving Session

Summary and Conclusions

Our goal in this paper was to identify student perceptions related to issues which have the potential to enhance success in pre calculus. The students responding to this survey provided several high potential areas for consideration:

- Structured placement systems such as ALEKS appear to be generally well received and perceived as effective.
- High school preparation is an issue highlighted by this group of students. First it appears that high school mathematics may have a very narrow focus on polynomial and quadratic equations at the expense of trigonometric and exponential / logarithmic functions. This neglect has detrimental impact beyond pre calculus in engineering programs. This should be further explored and may provide guidance for a shift in emphasis for pre calculus.
- Learning resources valued by students are on line problems and related learning aids. In general students do not use the text and tend to learn by imitation and not by in depth understanding of concepts.
- Finally, students supported development of summer preparation courses (on line), integration of a problem solving recitation in lieu of a lecture every week, and required attendance policies to encourage lecture participation.

One of the issues with this study is that a small percentage of students with D or F grades participated. Consequently our findings relate to successful students' opinions. We plan to hold focus groups in the future to more deeply explore and understand the issues identified.

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