Investigating the Mathematical Background of Engineering Graduates to Improve Student Retention

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Abstract – We have found through the use of pretests that a significant number of the students entering into our core engineering classes do not have the proper mathematics background to succeed, requiring significant review of key concepts from prerequisite classes. The poor mathematical background of students is also a major contributing factor in the retention of students in our engineering programs. In an attempt to sort out the factors that contribute to this problem, this study looks at the grades of recent graduates (Summer 2002 through Spring 2004) of the College of Engineering and Applied Science at the University of Wisconsin-Milwaukee as a function of their mathematical background. It is hypothesized that the same pitfalls that affected those who barely graduated from our institution are reducing student retention. The relative success of students as a function of their initial math placement, their course sequence, their student status (full-time or part-time), and the institution taken were studied. Successful trends and problems were identified. Warning signs for the identification of students at risk were also found. Information gained from this study is being shared with our mathematics department, the faculty and staff within our engineering college, and with peer institutions having similar admission criteria, who are most likely dealing with similar issues involving student retention and quality.

Introduction

Engineering education over the next decade provides numerous challenges. One of the biggest of these is the retention of students. From our experience in the College of Engineering and Applied Science (CEAS) at the University of Wisconsin-Milwaukee (UWM), the courses that are most challenging from a mathematics perspective are the courses in which students have the most difficulty. As part of our continuous assessment process for ABET, we have found, through the use of pretests, that many of the students entering into these courses do not have the proper mathematics background from algebra, trigonometry, and calculus to succeed even after the completion of the required mathematics curriculum. These difficulties may be attributed to various possible sources including deficiencies in the student's high school mathematical instruction (H.S.), problems with their mathematical instruction at UWM (MathUWM), gaps in their mathematical background from transfer institutions (Transfer), or poor retention of mathematical material due to poor study skills (Skills) or length of time between instruction and application (Time). In an attempt to sort out the factors that contribute to this problem, this study looks at the grades of recent graduates (Summer 2002 through Spring 2004) of CEAS at UWM as a function of their mathematical background. It is hypothesized that the same pitfalls that affected those who barely graduated from our institution are reducing student retention. By studying these effects and determining trends, we should be able to help at-risk students resulting in increased student retention and improved student quality.

Characteristics of UWM Freshman Students

UWM is a commuter campus located in the city of Milwaukee with over 21,000 undergraduate students and over 1500 students in the engineering college (CEAS). It is part of the larger

University of Wisconsin System, which includes 13 four-year universities and 13 two-year universities. Since UWM is only one of three schools in the system offering undergraduate engineering degrees, UWM receives a large number of transfer students from other schools in the UW system as well as from other schools in the region. Due to its urban location, UWM also attracts a large number of nontraditional students. Most of our students work part-time and 30% of our students work full time. Like many other urban-13 schools, our admission standards are fairly low (top half of graduating class or ACT score of 21) in order to provide initial access to disadvantaged students. As a result, many of the incoming freshman engineering students do not have the background of traditional engineering students. This lack of background is demonstrated by the poor performance of incoming freshman engineering students on our Math Placement Test. Table 1 provides the initial math placement for a typical CEAS freshman class at UWM. Not quite a third of incoming freshman engineering students are calculus ready. About a third of those are lacking some aspect of algebra or trigonometry and are placed in a four-semester calculus series in which college algebra, trigonometry, and the first semester of calculus are covered in two semesters, followed by the final two semesters of the traditional calculus series. Over a third of the freshman, begin at the college algebra and/or trigonometry level. About a quarter of our students begin at the intermediate algebra level and less than 10% begin at levels below intermediate algebra.

Calculus (3 Semester)	Calc + Alg/Trig (4 Semester)	College Algebra + Trigonometry	Intermediate Algebra	< Intermediate Algebra
23%	7.5%	35.8%	25.7%	8%

Table 1. Typical Initial Math Placement CEAS freshman at UWM (Fall 1996)

Student Retention

One of the problems associated with having low admission standards is student retention. Table 2 gives the retention of freshman CEAS students over a five-year period as a function of high school ranking. It also tracks the retention of disadvantaged minority students. Nearly three-quarters of students from the top quarter of their high-school graduating class achieved junior status. Only half of those who graduated in the second quarter of their high-school graduating class achieved junior status. Disadvantaged Minorites faired similar to those in the bottom half of their high school graduating class, with less than a third achieving junior status. Due to the large number of nontraditional students at UWM, the median and average time to graduation with an engineering degree exceeds this 5-year retention study (6.00 and 6.79 years respectively). As a result, only 42.6% of those students who achieved junior status had graduated at the end of five years with another 42.6% still enrolled. Assuming all those still enrolled as of the spring 2002 survey graduated, over half of those who were in the top half of their class and achieved junior status will have obtained their engineering degree, while just less than a third will have obtained a degree from another college at UWM. Similarly for disadvantaged minorities who make junior status, over half are likely to obtain their engineering degree, however it appears to be taking them longer to graduate.

Use of Graduation Data

As can be seen from the above retention data, if the students reach their junior year at UWM, there is a high probability of graduation (~85% chance), although not necessarily in engineering (~55% chance). Again, the major hurdle for students in achieving junior status is the completion of the mathematics sequence. This is complicated by the fact that students have various levels of mathematical preparation when entering college and that less than half of our graduates take their entire mathematics sequence at UWM. Some transfer to UWM before the calculus series,

Group	Entering Students	Achieved Jr. Status	Graduated (CEAS)	Graduated (Other)	Still Enrolled Jr/Sr(CEAS)	Still Enrolled Jr/Sr (Other)
Total	373	195	54	29	51	32
Top 25% H.S.	125	93 (74.4%)	30 (24.0%)	14 (11.2%)	22 (17.6%)	13 (10.4%)
2nd 25% H.S.	139	69 (49.6%)	16 (11.5%)	13 (9.4%)	22 (15.8%)	7 (5.0%)
Bot. 50% H.S.	83	26 (31.3%)	4 (4.8%)	0 (0.0%)	7 (8.4%)	12 (14.5%)
Unknown	26	7 (26.9%)	4 (15.4%)	2 (7.7%)	0 (0.0%)	0 (0.0%)
Disadv. Minority	68	20 (29.4%)	5 (7.4%)	2 (2.9%)	6 (8.8%)	6 (8.8%)

Table 2. Five-year Retention of UWM Freshman Engineering Students entering Fall 1995 and Fall 1996 [1])

others mid-way through the calculus series, and still others after the completion of the calculus series. Some even take their differential equations and linear algebra coursework elsewhere, however, this is less common because our analytical methods of engineering class is somewhat different than the traditional differential equations and linear algebra class both in content and in approach. In addition to differential equations and linear algebra, this four-credit course, which is taught by engineering faculty, includes Laplace transforms, Fourier series, and complex numbers. The advantage of this approach is that while the students are learning about these mathematical techniques they can also be introduced to typical engineering applications.

To help identify student trends, this study carefully looks at the mathematics background of 287 engineering students who graduated in the last two years (Summer 2002 – Spring 2004) who either took all their post-high school mathematics courses at UWM (MathUWM) or transferred to UWM after taking some or all of their math coursework which was subdivided into the categories: prior, mid, post, or all (Table 3). Computer Science (CS) students who took the first circuits class (more computer engineering oriented) were also included in the study. Of the 128 MathUWM graduates, over three-quarters were calculus ready (38.3% initially placed in

Initial Placement	Math UWM	Transfer Prior to Calculus	Transfer Mid Calculus	Transfer Post Calculus	Transfer All Math	Overall
# Students	128	19	59	52	29	287
Calculus (3 Sem.)	49 (38.3%)	0 (0.0%)	17 (28.8%)	19 (36.5%)	12 (41.4%)	97 (33.8%)
Calc+CollAlg/Trig (4 Sem.)	49 (38.3%)	0 (0.0%)	1 (1.7%)	0 (0.0%)	0 (0.0%)	50 (17.4%)
College Alg/Trig.	10 (7.8%)	11 (57.9%)	25 (42.4%)	27 (51.9%)	11 (37.9%)	84 (29.3%)
Intermed. Alg. [before]	20[2] (15.6%)	8[6] (42.1%)	16[9] (27.1%)	6[3] (11.5%)	6[3] (20.7%)	56[23] (19.5%)

Table 3 Initial Math Placement CEAS Graduates (Summer 2002 – Spring 04)

both the 3 and 4 semester calculus series), with only 10 beginning in college algebra or trigonometry, 18 in intermediate algebra, and only 2 at a level below intermediate algebra (both CS majors). In contrast, over two-thirds of the 159 transfer students who graduated were initially placed at a level below calculus at their prior schools with 74 beginning in college algebra or trigonometry, 15 in intermediate algebra, and 21 below intermediate algebra. The breakdown of these students by their major is included in table 4. Note the total number of degrees here is 293 instead of 287 because of 4 double majors and 1 triple major.

Major	MATH-UWM*	Transfer Prior to Calculus	Transfer Mid Calculus	Transfer Post Calculus*	Transfer All Math*	Overall (293)*
Civil Engr.	23	2	14	12	6	57
Comp. Sci. (EE301 taken)	19	1	5	4	2	31
Elect. Engr..	35	4	16	15	10	80
Indust. Engr.	8	2	4	2	2	18
Matl.Engr.	2	0	1	0	1	4
Mech. Engr.	43	10	19	22	9	103

Table 4 Breakdown of CEAS Graduates by Major (*Includes double and triple majors)

Success versus mathematical background

Transfer Students

In order to compare the relative success of the 287 graduates as a function of their initial math placement, the mean, median and standard deviation of their degree grade point averages (GPA) were computed and are summarized in Table 5. The mean scores of their performance in the calculus series taken (3 semester or 4 semester) and in their differential equations class (analytical methods in engineering or equivalent) were also calculated. From this data, those graduates taking their entire mathematics coursework at UWM on average faired better, however, three-quarters of these students began in the 3 or 4 semester calculus series. All those who transferred to UWM prior to taking differential equations (Prior, Mid, and Post) had similar mean degree GPAs while those who transferred all their math (including differential equations) faired worse in differential equations and in slightly worse in mean degree GPA. Those students who transferred mid calculus faired the lowest in their mean calculus grades (CALCAVG) while those who took all their calculus at one institution faired the best. This is probably due to the fact that content of the individual calculus courses vary some from institution

Group	GPA mean	GPA median	Std. Dev	CALCAVG	Analytical Methods Engr.
UWM Math	3.138258	3.142	0.426783	2.998913	3.044492
Transfer Prior to Calc	2.938526	2.801	0.403978	2.744772	2.746842
Transfer Mid Calculus	2.932	2.851	0.466002	2.672701	2.881017
Transfer Post Calculus	2.966231	3.0915	0.474737	2.849359	2.796538
Transfer All	2.854862	2.786	0.487405	2.762299	2.581136

Table 5. Student GPA as a function of initial math placement

to institution, leaving the possibility of incomplete coverage. Some transfer students took their calculus at a local technical college to avoid the calculus series at UWM. It was found that although these students had higher calculus GPAs versus their counterpart transfer students who transferred post calculus (calculus GPA 3.44 versus 2.67), they performed much worse in their degree coursework (degree GPA 2.62 versus 3.03). In contrast, students transferring from other UW System Schools had a mean degree GPA of 2.95.

Time to Graduation

Most of our students work at least part-time and not quite a third work full time. As a result, it usually takes our students longer to complete their degrees than at most schools. In addition, we have a larger number of transfer students than most schools. In order to assess the effect of this longer length of completion time on student performance, the mean, median, and standard deviations of degree GPA were calculated as a function of time to complete their degree (Table 6). The results in Table 6 show a significant decrease in performance for those students taking longer than 5 years to finish their degree. Between 5 and 10 years the mean and median degree GPAs slowly decrease while their standard deviations tend to increase. Many of those taking over 10 years to finish were part-time students who finally persevered. These results were consistent with our previous study comparing the success of EE students as a function of their math background [2].

Time (287 students)	Mean	Median	Std Dev
< 5 years (37)	3.400649	3.389	0.321585
5- 5.75 years (99)	3.073152	3.029	0.382569
6- 6.75 years (67)	2.954632	2.886	0.482663
7 - 7.75 years (31)	2.833839	2.736	0.450065
8- 10.0 years (21)	2.790714	2.584	0.505743
> 10 years (31)	2.907	2.786	0.474435

Table 6. Degree GPA as a function of time to degree. (Mean 6.79 yrs., Median 6.00 yrs.)

Success versus Course Grades

In order to determine the importance of specific classes to engineering majors, the mean degree GPAs were calculated for groups of students according to their performance in these classes. The trends observed are summarized in Table 7. Currently a C or better is only required for those taking Calculus I and Calculus II at UWM and does not appear to be required of transfer students. In addition, no grade restrictions have been placed on Calculus III and Analytical Methods in Engineering. Close to 10% of those students who graduated from our programs moved on in their programs without obtaining a C in Calculus III and 7% moved on without obtaining a C in Analytical Methods in Engineering.

Courses Retaken

At UWM students are able to retake courses and have only the best grade counted in the calculation of their GPA. The ability of a student to retake a course without penalty is a good thing if the student better understands the subject matter afterwards. Many students however use this resource to satisfy the minimum requirement without having a good grasp of the subject matter. Table 8 gives the degree GPA of students who are only achieving the minimum in specific mathematics courses. While over 60% of the students never repeated a single class in the calculus/differential equation series, 15% either repeat multiple classes within the series or a single class more than once (most likely Calculus I or II since a C or better is required to advance at UWM).

Course (Overall # Students)	Criteria	Mean GPA if Criteria met	Mean GPA Criteria not met (# students)
Intermediate algebra	Grade of B or better before advancing	3.017	2.600 (10)
College algebra	Grade of B- or better before advancing	3.078	2.685 (40)
Trigonometry	Grade of B- or better before advancing	3.071	2.612 (30)
Calculus I	C or better	2.998	2.631 (13)
Calculus II	C or better	3.007	2.972 (11)
Calculus III	C or better	3.029	2.768 (27)
Analytical Methods in Engineering	C or better	3.067	2.695 (20)

Table 7. Trends determined for specific math courses .

Course (# Students)	Criteria	Degree GPA
Calculus I (12)	Retake:Grade of C not exceeded	2.564
Calculus II (22)	Retake:Grade of C not exceeded	2.716
Calculus III (14)	Retake:Grade of C not exceeded	2.808
Calc/Diff. Eqn. Series (174)	No Classes Repeated	3.144
Calc/Diff. Eqn. Series (69)	1 Class Repeated	2.869
Calc/Diff. Eqn. Series (44)	2 or more Classes Repeated	2.784

Table 8. Degree GPA for mathematics courses retaken

Discussion and Conclusions

Although there are significant differences in engineering student retention within the first two years as a function of past high school performance, the overall graduation rate as a percentage of those who achieve junior status within CEAS was found to be fairly independent of high school performance or racial background (with ~55% receiving an engineering degree with another ~30% receiving a different UWM degree). Therefore to increase engineering student retention we need to focus on getting students through the first two years. For many students the insurmountable barrier is the mathematics curriculum. Many just want to survive and do just the minimum to pass. At the end of this process, many of these students do not retain the mathematical skills they need to succeed in their upper division engineering classes.

Many of the trends seen in this study were similar to those observed in my preliminary study, which was restricted to only EE majors [2]. Those students with low initial placement achieved better success if they do well in their remedial classes and if these classes are taken with experienced instructors (usually found at two-year or undergraduate-only schools that have permanent staff devoted to this purpose). Transfer students have their best success if their entire calculus series is completed at a single institution. Care must be taken however to evaluate the transcripts of these students, however. Some of the transfer students in this study achieved less than a 2.0 in their calculus and differential equation/linear algebra classes taken at other institutions. Other students went out of their way to take calculus and differential equations at another school or technical college to get a better grade only to find later that they were ill-prepared for their upper-division engineering coursework to follow. One more similar trend observed was the night and day difference in the degree GPAs between those who finished in less than 5 years and those who finished in 5 years or greater as shown in Table 6.

The first plan of action is to share these results with our mathematics department and the director of student services for our engineering college. Then they will be shared with our faculty and at institutions with similar admission requirements to ours who are most likely dealing with similar issues. The trends seen here will hopefully be used to help at-risk students early in their career. The criteria in table 7 should provide a starting point. In this study, it appears that some courses are more important than others for all engineers to succeed in their undergraduate work. From this study the mathematics portion of this more important list should include algebra, trigonometry, calculus I, and analytical methods for engineers. However, additional classes need to be added to this list for certain programs or specialty areas within a program and this list would need to be made known to the students. Our data indicates that Calculus II and Calculus III, although very important, do not tend to be uniformly important to all engineers. For example a good understanding of Calculus III is essential for electrical engineering students who study electromagnetics, a required class, while this may be less important to some civil engineers. It is therefore no surprise that EE students made up only a small percentage (7%) of those not achieving a C in Calculus III. The recent re-establishment of the advancement to major should be helpful in this process. Students should have a good understanding of the key material needed for their program before moving on to their upper division engineering classes. If necessary, the students should be required to repeat classes containing these key concepts before progressing to the next level. One way to mandate this would be the placement of program dependent prerequisite grade requirements on these key classes.

The results in table 6 demonstrate that our current curriculum works well for traditional full-time students who are calculus ready when they arrive and can complete the curriculum in less than 5 years. However most of the remaining 87% of our students are having trouble retaining information long term. Part of this trouble is due to long periods of time between the current class and the prerequisites. Perhaps some repetition of key concepts should be designed into the curriculum. In addition, more practical hands on assignments could also be added to help students to gain a better overall understanding and hopefully retain the information long term.

Another portion of the trouble is that students have holes in their mathematical background. This combined with their poor retention of information results in poor scores on mathematical placement tests and low initial math placement. Since most of our engineering courses require completion of the calculus series as a prerequisite, many students feel isolated and give up prior to achieving junior status. Our curriculum should allow students to build upon the key mathematical concepts learned in their early mathematical coursework and apply them to practical engineering problems. Currently we do some of this in analytical methods of

engineering, but students do not get there until after they have completed the entire calculus sequence. Wright state university is trying to address this problem in a unique way. They are redeveloping their engineering curriculum to make it concurrent with the calculus series [3]. As part of this they are planning to teach the math on a need to know basis. Another approach is to fill in the gaps in a student's background to reduce the length of time spent obtaining their required mathematical skills. Unfortunately, there are many problems with staffing low-level math classes at a research university. Usually these are relegated to those with the least teaching experience: New Teaching Assistants. As seen in Table 3, the retention of students with initial placement below the three and four semester calculus series are quite low at UWM. Mathematical software has been recently developed by McGraw-Hill (Aleks) for the purpose of identifying and filling in the gaps in a student's background in the areas of algebra and trigonometry. It is currently being tested in the teaching of some algebra and trigonometry courses at UWM as an alternative. Louisiana Tech has had initial success using this software to supplement their calculus series [4]. However, no matter what approach is used, success will depend upon qualified and dedicated faculty and staff to make sure that the program is implemented properly.

References

[1] University of Wisconsin-Milwaukee 1998-99 Department Profiles

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