AC 2008-1023: THE WSU MODEL FOR ENGINEERING MATHEMATICS EDUCATION: A MULTIYEAR ASSESSMENT AND EXPANSION TO COLLABORATING INSTITUTIONS

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The WSU Model for Engineering Mathematics Education: A Multiyear Assessment and Expansion to Collaborating Institutions

Abstract

The inability of incoming students to advance past the traditional first-year calculus sequence is a primary cause of attrition in engineering programs across the country. As a result, this paper will describe an NSF funded initiative at Wright State University to redefine the way engineering mathematics is taught, with the goal of increasing student retention, motivation and success in engineering. The WSU approach begins with the development of a novel first-year engineering mathematics course, EGR 101 "Introductory Mathematics for Engineering Applications." Taught by *engineering* faculty, the course includes lecture, laboratory and recitation components. Using an application-oriented, hands-on approach, the course addresses only the salient math topics *actually used* in core engineering courses. These include the traditional physics, engineering mechanics, electric circuits and computer programming sequences. The EGR 101 course replaces traditional math prerequisite requirements for the above core courses, so that students can advance in the curriculum without having completed a traditional first-year calculus sequence. The WSU model concludes with a revised engineering math sequence, taught by the math department later in the curriculum, in concert with College and ABET requirements. The result has shifted the traditional emphasis on math prerequisite requirements to an emphasis on *engineering motivation* for math, with a "just-in-time" structuring of the required math sequence. This paper includes significant updates since the approach was last reported, including a multiyear assessment at Wright State University and expansion of the program to collaborating institutions.

1.0 Introduction

The traditional approach to engineering mathematics education begins with at least one year of freshman calculus as a prerequisite to subsequent core engineering courses. However, the inability of incoming students to successfully advance past the traditional freshman calculus sequence plagues student retention and success in engineering programs across the country. Indeed, as noted by the NSF Director of Engineering Education and Centers[1], the traditional engineering curriculum has been essentially unchanged for half a century - heavily front-loaded with classical math prerequisites, with too little engineering early in the curriculum. This makes engineering unattractive to potential recruits, and difficult to endure for those brave enough to give it a try. This is particularly so for members of traditionally underrepresented groups, including women and minorities, whose enrollment and retention in engineering has not kept pace with the demands of an increasingly diverse society. As highlighted by the U.S. Department of Education[2] and more recently by the National Academies[3], the global competitiveness of our great nation may ultimately rest on our ability to rise above this gathering storm in engineering and STEM education. *As such, there is a drastic need for a proven model which eliminates the first-year mathematics bottleneck in the traditional engineering curriculum, yet can be readily adopted by engineering programs across the country.* Such is the focus of this work.

The WSU model was first implemented in 2004, and its effect on student retention, motivation and success has since been widely reported[4-18]. The current paper includes significant updates since the approach was reported one year ago, including the effect of EGR 101 on two-year student retention and subsequent performance in calculus, the introduction of EGR 100 as a precursor to EGR 101 for initially underprepared students, and the ongoing expansion of the WSU model to collaborating institutions.

2.0 Background - The WSU Model

This section provides an overview of the WSU model for engineering mathematics education, which involves three primary components: 1) The development of EGR 101, a novel freshman-level engineering mathematics course; 2) A large-scale restructuring of the engineering curriculum, where students can advance in the program without having completed a traditional freshman calculus sequence; 3) The development of a revised engineering mathematics sequence, offered later in the curriculum in a more just-in-time fashion.

2.1 EGR 101, "Introductory Mathematics for Engineering Applications"

The WSU model begins with the development of EGR 101, a novel freshman-level engineering mathematics course. *The goal of EGR 101 is to address only the salient mathematics topics actually used in the primary core engineering courses, thereby fulfilling math prerequisite requirements within the context of a single course.* This opens the door for students to advance in the engineering curriculum without first completing the traditional calculus sequence. The course content consists of the mathematical prerequisites for the following core engineering courses: PHY 240 (General Physics I), ME 212 (Statics), ME 213 (Dynamics), ME 313 (Strength of Materials), EE 301 (Circuit Analysis I), CEG 220 (C Programming), and EGR 153 (Fortran Programming). In the traditional curriculum, all of these courses require a minimum of Calculus I, while some require Calculus I-III and Differential Equations. However, only a handful of topics from these traditional math courses are actually applied in the above core engineering courses. Moreover, the above core courses also include engineering mathematics concepts not found in the traditional calculus sequence, including basic operations in vectors, complex numbers and matrix algebra.

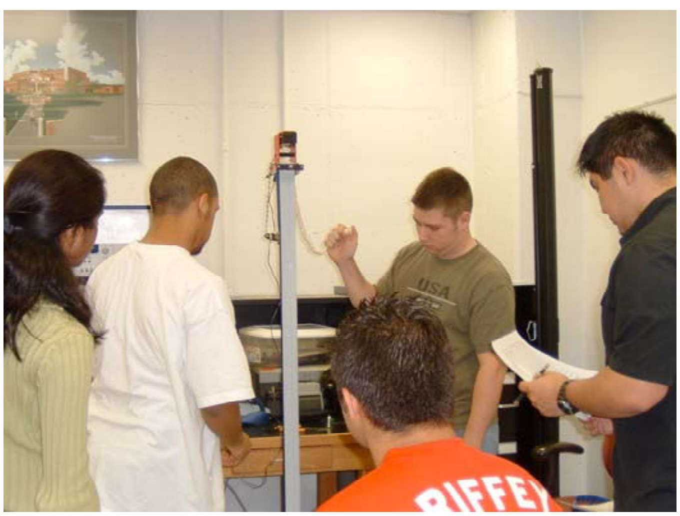


Figure 1. Derivative Lab

After consultation with faculty from around the College, the following topics were slated for inclusion in EGR 101: Linear and Quadratic Equations; Trigonometry; 2-D Vectors; Complex Numbers; Sinusoids and Harmonic Signals; Systems of Equations and Matrices; Basics of Differentiation; Basics of Integration; Linear Differential Equations with Constant Coefficients. The course is taught by engineering faculty, with all mathematical topics motivated by their direct application in the core engineering courses. Moreover, course material is emphasized by *physical* experiments in the classroom and laboratory, and is thoroughly integrated with the engineering analysis software Matlab.

The EGR 101 course structure includes lecture, laboratory and recitation sections. The lecture sections are completely driven by problem-based learning, while the laboratory and recitation sections offer extensive collaborative learning among the students. *As such, the course is strongly supported by the literature on how students learn*[19-23].

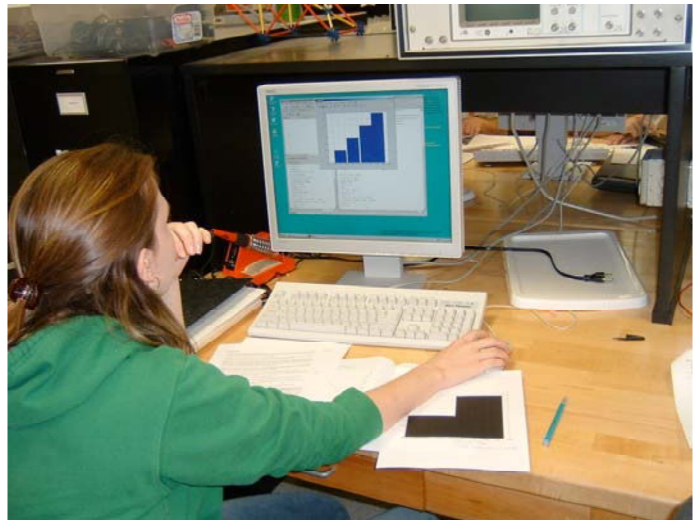


Figure 2. Integral Lab

Excerpts from the EGR 101 laboratory are shown in Figs. 1-2. Indeed, physical *measurement* of the derivative as the velocity in free-fall (Fig. 1), or of the integral as the area under the force-deflection curve (Fig. 2), provides a much greater conceptual understanding of the mathematical concepts than classroom lecture alone. The prerequisite requirement for incoming students to register for EGR 101 is a minimum mathematics background in Trigonometry, as indicated by a combination of math placement level (MPL) 5 and high school transcripts, or by the completion of MTH 131 Trigonometry at WSU. *This makes the core engineering curriculum immediately accessible to incoming students who are calculus-ready, as well as to those with a math placement level one course behind Calc I.*

2.2 Restructured Curriculum

The primary goal of EGR 101 is to facilitate a large-scale restructuring of the early engineering curriculum, where students can advance in the program without having completed a traditional freshman calculus sequence. In order to emphasize the need for the proposed curriculum changes, the traditional freshman year curriculum for Mechanical Engineering is shown in Table 1. In order to advance into their sophomore years, students are expected to complete MTH 229 Calc I, MTH 230 Calc II and MTH 231 Calc III during their first three quarters at the University. This is the case for the remainder of engineering majors in the College, and is standard practice in engineering programs across the country. *No wonder students who struggle in calculus end up switching majors!*

The restructured alternative to the traditional freshman year curriculum is shown in Table 2. The EGR 101 course appears immediately in the Fall quarter. However, the course runs every quarter, so that those students who do not immediately qualify for EGR 101 can register as soon as they complete the necessary math background (Trigonometry). In addition, the only traditional calculus course remaining in the freshman year is MTH 229 Calc I, which has been moved to the Winter quarter (i.e., following the completion of EGR 101). *It should be noted that because EGR 101 is now the only math prerequisite for the core sophomore-level engineering courses, students who are not immediately successful in MTH 229 Calc I can still advance in their intended engineering programs.*

Table 1. Traditional Freshman Year (Mechanical Engineering)

Fall Quarter		**Winter Quarter**		**Spring Quarter**	
ENG 101	4	ENG 102	4	ME 199	3
EGR 190	4	EGR 153/CEG 220	4	PHY 240	5
CHM 121	5	GE	4	GE	4
MTH 229 Calc I*	5	MTH 230 Calc II*	5	MTH 231 Calc III*	5
	18		17		17

* Traditional freshman calculus sequence

Table 2. Restructured Freshman Year (Mechanical Engineering)

Fall Quarter		**Winter Quarter**		**Spring Quarter**	
ENG 101	4	ENG 102	4	ME 199	3
EGR 190	4	EGR 153/CEG 220	4	PHY 240	5
CHM 121	5	MTH 229 Calc I **	5	GE	4
EGR 101*	5	ME 220	3	ME 202	4
	18		16		16

* New freshman engineering mathematics course
** Only traditional calculus course in the freshman year, with separate sections for engineers

While Tables 1 and 2 are specific to Mechanical Engineering (ME), similar changes have been made for degree programs across the College of Engineering and Computer Science (CECS), including Materials Science and Engineering (MSE), Electrical Engineering (EE), Engineering Physics (EP), Biomedical Engineering (BME), and Industrial and Systems Engineering (ISE). In addition, revised math prerequisite requirements for the core sophomore-level engineering and physics courses previously summarized have been submitted and approved by the University. In all cases, the words "or EGR 101" have been appended to the traditional math prerequisite requirements; this automatically accounts for transfer and continuing students, who can advance in the program with either the traditional math sequence or the completion of EGR 101. *The result is a substantially more flexible and accessible engineering curriculum for all students - and one that received the full 6-year ABET accreditation in 2006!*

2.3 Revised Math Sequence

While EGR 101 provides an introduction to the salient math topics required to progress in the engineering curriculum, it is not intended to be a replacement for the calculus sequence and other traditional mathematics courses. As previously described, Calc I is part of the freshman curriculum, with the remaining courses delayed until the sophomore and junior years. The exact locations of the remaining courses are specific to each major in the College, as determined at the Department level. In Mechanical Engineering, Calc II and III now occur in the sophomore year, while Calc IV is reserved for the first quarter of junior year. In addition, the traditional Differential Equations and Matrix Algebra courses have been combined into a single 5-hour course, "MTH 235 Differential Equations with Matrix Algebra," offered during the sophomore year. This has recovered 3 of the 5 additional credit hours associated with the introduction of EGR 101, with the remaining 2 credit hours absorbed by the various degree programs. *Coupled with the restructured program guides previously described, the result of the new math sequence is a more just-in-time, application-oriented approach to engineering mathematics.*

3.0 Multiyear Assessment at WSU

The EGR 101 course ran for the first time in Fall, 2004. All eligible incoming students in ME, MSE, EE, EP, BME and ISE were enrolled in the course, which has run each quarter since. Student performance, perception and fist-year retention following the initial implementation of the program have been widely reported[4-14], and are not reiterated here. In brief, results indicate that EGR 101 and the associated curriculum reforms have had a dramatic effect on student motivation and perceived chance of success in future math and engineering courses. For majors requiring EGR 101, this has been accompanied by a significant increase in first-year retention. What has remained to be seen (until now) was the effect of EGR 101 and the associated curriculum reforms on student retention and success through their first two years, including their subsequent performance in Calculus.

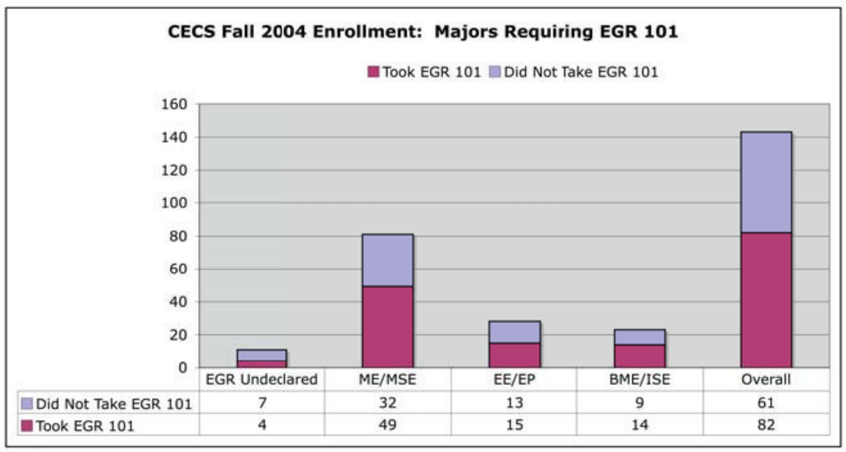


Figure 3. Fall 2004 Enrollment for Majors Requiring EGR 101

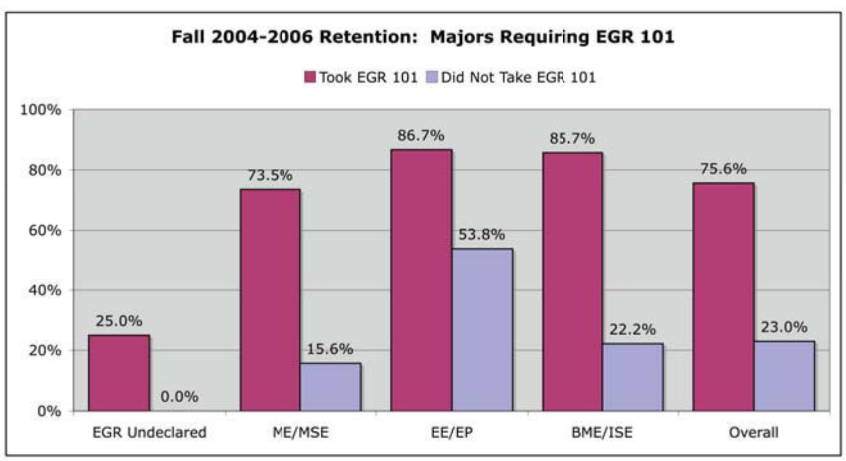


Figure 4. Two-Year Retention for Majors Requiring EGR 101

Figure 3 shows the Fall 2004 enrollment for majors requiring EGR 101, sorted by those who took EGR 101 and those who did not. Although EGR 101 is a degree program requirement, the results of Figure 3 reveal that only about 60% of incoming students ever took the course at any time in their first two years. Figure 4 shows two-year retention for majors requiring EGR 101, sorted by those who took the course and those who did not. Clearly, students who took EGR 101 at any time during their first two years had an enormous advantage, with a two-year retention rate of 75.6%, compared to an alarming 23.0% for those who did not.

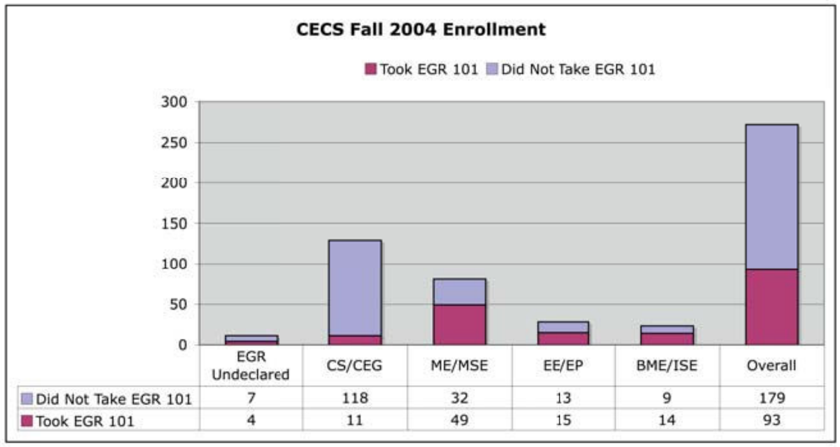
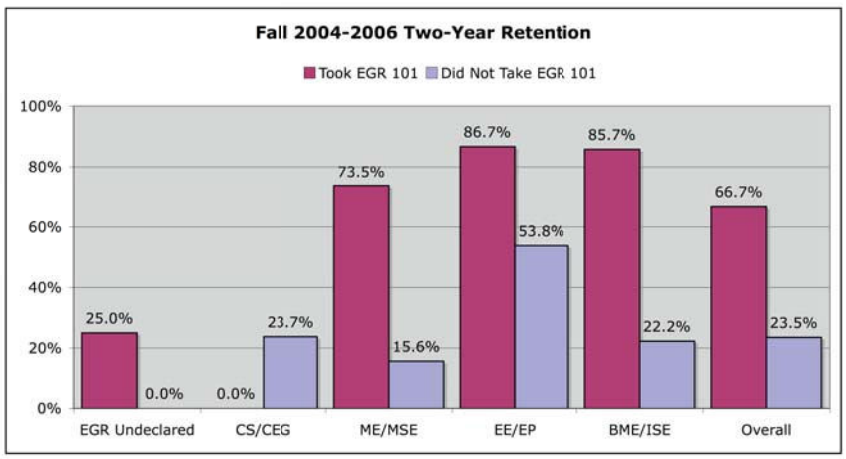


Figure 5. CECS Fall 2004 Enrollment (Including CS/CEG)



*NOTE: Of the 11 CS/CEG students who took EGR 101, none was retained in CS/CEG; however, 5 were retained in other CECS majors (44.5%).

Figure 6. CECS Fall 2004-2006 Two-Year Retention (College-Wide)

Figures 5 and 6 show similar data for the entire college (including CS/CEG). While CS/CEG majors are not required to take EGR 101, those who struggle in math or are somewhat undecided in their major can still choose to take the course, and these included 11 students from the incoming class of 2004. The results of Figure 6 show that including CS/CEG majors, students who took EGR 101 at any time in their first two years were retained at a rate of 66.7%, compared to 23.5% for those who did not.

According to Figure 5, only about 1/3 of the College's intending majors actually took EGR 101 at any time in their first two-years. Those who did not take EGR 101 included the overwhelming majority of CS/CEG majors, for whom EGR 101 is not required, as well as some 40% of students whose majors do in fact require the course. One explanation for this is that most of these students are so far behind in math that they never even qualify for EGR 101, which requires a math placement level of MPL 5. This might also suggest that the two-year retention results of Figs. 4 and 6 could be misleading, since those students who did not take EGR 101 because they were underprepared were much less likely to succeed to begin with.

As such, it is useful to examine the populations of students who did and did not take EGR 101, as sorted by incoming MPL score. Such data are illustrated in Figure 7. Clearly, the majority of students who took EGR 101 had an MPL 5 or 7, which means they were immediately qualified upon entering WSU. However, a significant number of underprepared (MPL 3 and 4) students also eventually took the course, as did one student who entered at the developmental math level (MPL 0-2). The results of Figure 8 show two-year retention for each incoming MPL level, sorted by those who did and did not take EGR 101. These results overwhelmingly indicate that EGR 101 and the associated curriculum reforms have provided a significant advantage for incoming students at ALL math placement levels.

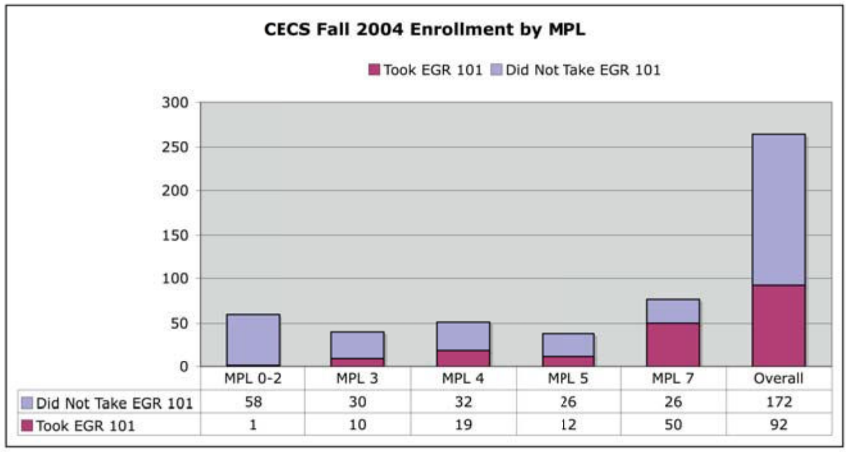


Figure 7. College-Wide Fall 2004 Enrollment Sorted by Math Placement Level (MPL)

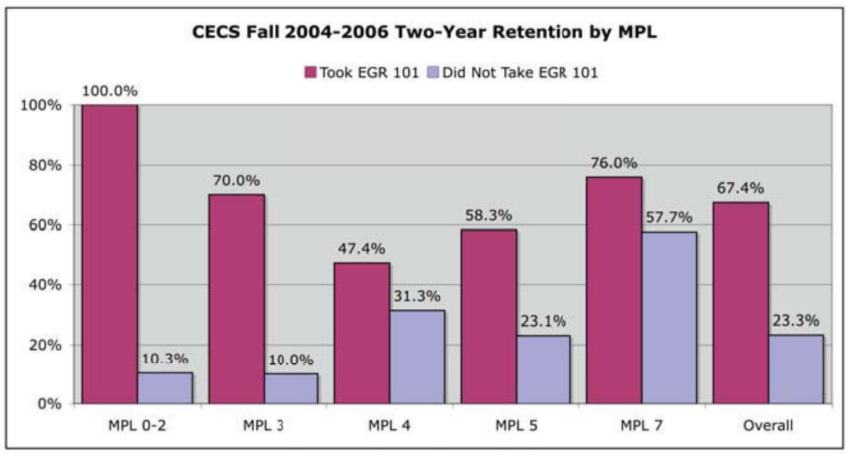


Figure 8. Two-Year Retention Sorted by Math Placement Level (MPL)

In addition to two-year retention, EGR 101 and the associated just-in-time structuring of the required math sequence have had a significant impact on student performance in calculus. Grade distributions for students of the incoming class of 2004 who took MTH 229 Calc I at any time in their first two years are shown in Figure 9. Of the

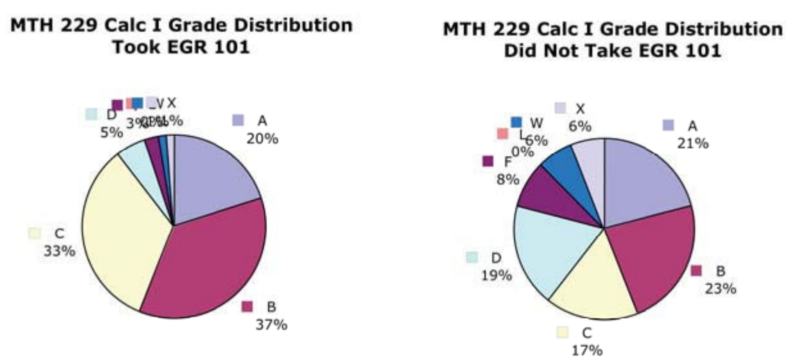


Figure 9. Effect of EGR 101 on Student Performance in Calculus

students ultimately enrolled in Calc I, 89% of those who had formerly taken EGR 101 earned a "C" or better, compared to only 60% of those who had not.

4.0 Introduction of EGR 100 for Underprepared Students

At this point it can be concluded that the introduction of EGR 101 and the associated curriculum reforms have had a dramatic effect on student retention and success in engineering at WSU, but that this effect is limited by the proportion of students who ultimately take the course. Indeed, the average incoming engineering student at WSU has a math placement level of roughly 4.4, so that EGR 101 (which requires an MPL 5) is not even immediately accessible to our AVERAGE incoming student. As a result of this finding, we have recently developed EGR 100 "Preparatory Mathematics for Engineering and Computer Science," the inaugural offering of which enrolled over one hundred MPL 3 and 4 students in Fall, 2007 (under temporary course number EGR 199). The course content consists entirely of high school math, from algebra through trigonometry, with all topics presented in the context of their application in core engineering courses. The EGR 100 course serves the following two purposes:

1. For majors requiring EGR 101, EGR 100 serves as an alternative prerequisite requirement, which allows MPL 3 and 4 students to enroll in EGR 101 and begin advancement in their chosen degree programs as early as their second quarter at WSU.

2. For all CECS majors (including CS/CEG), EGR 100 provides a comprehensive review of high school math topics, and culminates in a retest of the math placement exam at the end of the quarter. *This provides an opportunity for initially underprepared students to avoid as many as 3 remedial math department courses before advancing in their chosen degree programs.*

The results of the MPL retest following the Fall 2007 offering of EGR 100/199 are shown in Figure 10. Over half of the enrolled students increased their MPL score at the end of the quarter, some by as many as 3 levels. Roughly 30% of the students remained at the same MPL level, while a small number either decreased their MPL score or failed to retake the exam.

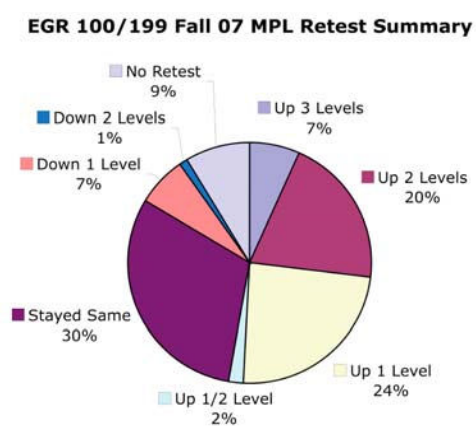


Figure 10. Results of Fall 2007 MPL Retest Following EGR 100/199

In the traditional curriculum, students entering at an MPL 3 would have been required to take MTH 126, MTH 130 and MTH 131 before even beginning the required calculus sequence. Assuming they were still around, those same students would not likely be enrolled in EGR 101 until the beginning of their second year. With the introduction of EGR 100/199, students entering at an MPL 3 can enroll in EGR 101 the very next quarter, regardless of whether they improve their MPL score. As a result, the Winter 2008 enrollment of EGR 101 was up by more than 50 students from prior Winter offerings. The majority of these additional students came in at an MPL 3 or 4, and in prior years may never have made it to EGR 101. For this reason, the 2007 introduction of EGR 100 is expected to have an even greater impact on student retention and success than the initial 2004 implementation of EGR 101.

5.0 Expansion to Collaborating Institutions

As part of an NSF CCLI Phase 2 initiative, aspects of the WSU model have been adopted by both the University of Cincinnati and the University of Toledo. The University of Cincinnati has adapted the WSU approach specifically for Civil and Environmental Engineering, which is not offered at WSU. The University of Toledo has incorporated aspects of EGR 101 into a first-year offering for initially underprepared students, including additional modules specifically for Chemical Engineering (also not offered at WSU). The UT implementation is also on a semester basis, as opposed to the quarter system used at both WSU and UC. As part of an NSF STEP Type 1 program, the WSU model has also been adopted by Sinclair Community College, with the goal of increasing both first-year retention of community college engineering students and their ultimate articulation to the university level.

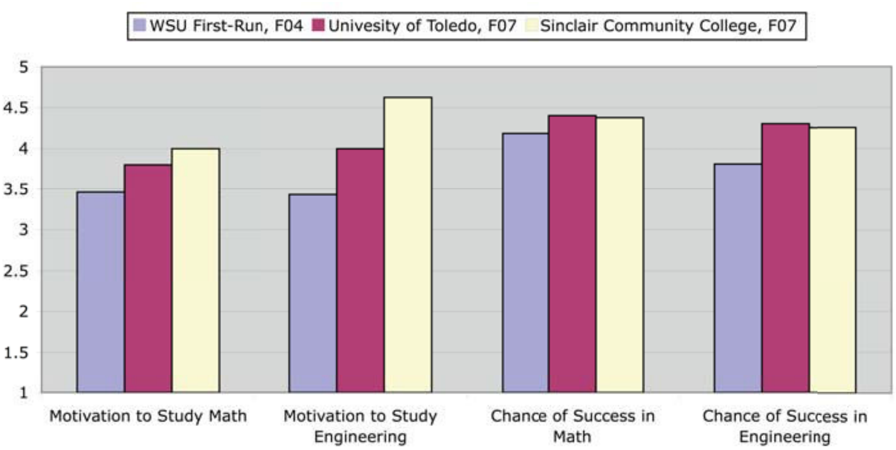


Figure 11. Comparison of Student Perception Following Initial WSU and Collaborator Implementations

While assessment is still ongoing, results of student surveys following the initial Fall 2007 implementations of EGR 101 at both Toledo and Sinclair are compared to those following the Fall 2004 offering at WSU in Figure 11. Specifically, students were asked whether EGR 101 had increased their motivation to study math and engineering, and whether EGR 101 had increased their chances of success in future math and engineering courses. Answers were given on a scale of 1 (strongly disagree) to 5 (strongly agree), with 3 being neutral. As seen in Fig. 11, student perception following the Fall 2007 implementations at both Toledo and Sinclair was even stronger than that following the initial Fall 2004 offering at WSU.

It should finally be noted that a nationwide expansion of the WSU model is planned as part of a pending NSF CCLI Phase 3 proposal. The nationwide team includes 17 diverse institutions (primarily university but also at the high school and community college levels) representing strategic pockets of interest in some of our nation’s most STEM critical regions. In addition to Ohio, these include Michigan, Texas, Oklahoma, California, Washington, Maryland, and Virginia. The State of Texas has been especially proactive, having issued a 2007 RFP for course redesign with a specific focus on adoption of the WSU model. More information on the Texas course redesign project can be found at http://www.thecb.state.tx.us/AAR/courseredesign/.

6.0 Summary

The WSU model for engineering mathematics education seeks to increase student retention, motivation and success in engineering by removing the first-year bottleneck associated with the traditional freshman calculus sequence. The approach includes the development of a novel freshman engineering mathematics course, EGR 101 "Introductory Mathematics for Engineering Applications," along with a substantial restructuring of the early engineering curriculum. The WSU approach can be readily adopted by any university employing a traditional engineering curriculum, and proposes an immediate solution to math-related attrition in engineering. The approach has already had a dramatic effect on student motivation and success in engineering at Wright State University, and is currently being piloted by collaborating institutions at both the university and community college levels. With the introduction of EGR 100 as a precursor to EGR 101 for initially underprepared students, WSU has made the core engineering curriculum immediately accessible to roughly 80% of its first-year students. This is expected to have an even stronger impact on student retention and success than the initial implementation of EGR 101.

7.0 Acknowledgments

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8.0 Program Information

More information on the WSU model for engineering mathematics education (including all course materials for EGR 101) can be found on the program website:

http://www.engineering.wright.edu/cecs/engmath/

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