THE WSU MODEL FOR ENGINEERING MATHEMATICS EDUCATION: STUDENT PERFORMANCE, PERCEPTION AND RETENTION IN YEAR ONE

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1. OVERVIEW

This paper summarizes progress to date on the WSU model for engineering mathematics education, an NSF funded curriculum reform initiative at Wright State University (Klingbeil *et al*. 2004, 2005). The WSU model seeks to increase student retention, motivation and success in engineering through application-driven, just-in-time *engineering* math instruction. This paper provides an overview of the WSU model for engineering mathematics education, followed by an assessment of student performance, perception and retention through its first year of implementation.

2. MOTIVATION AND BACKGROUND

The traditional approach to engineering mathematics education begins with one year of freshman calculus as a prerequisite to subsequent core engineering courses. However, only about 42% of incoming freshmen who wish to pursue an engineering or computer science degree at Wright State University (WSU) ever complete the required calculus sequence. The remaining 58% either switch majors or leave the University. This problem is not unique to WSU; indeed, the inability of incoming students to successfully advance through the traditional freshman calculus sequence plagues engineering programs across the country.

Clearly, there are a variety of factors influencing student retention and success in engineering, the most notable being a lack of preparation in high school. Moreover, engineering retention is of particular concern among members of traditionally underrepresented groups, as well as among transfer students and nontraditional students returning to school from the workplace. This has led engineering educators to introduce early intervention programs, aimed at increasing retention among incoming students (e.g., Arenaz *et al*., 1999). The WrightSTEPP and Academic Advantage programs here at WSU are two such programs, which begin intervention with local high school students even before they begin their freshman years.

In addition to early intervention programs, there has been a strong emphasis in recent years on increasing the level of *engineering application* early in the curriculum, with the goal of increasing student motivation to study engineering. This has led to the development of problem-based freshman engineering courses (e.g., Dally and Zang, 1993; Corrandi *et al*. 1995; Clausing, 1998; Kellar *et al*. 2000, Richardson and Dantzler, 2002; Pomalaza-Raez *et al*., 2003), including the EGR 190 Fundamentals of Engineering course here at WSU. Such courses are typically designed to give students a broad, application-based introduction to the various engineering disciplines, so that they can begin to appreciate *why* they must endure the rigor of their subsequent engineering curricula.

Without a doubt, the introduction of early intervention programs and application-oriented freshman engineering courses are significant steps toward increasing student retention, motivation and success in engineering. *That said, the correlation between retention rates and the inability of incoming students to progress through the required calculus sequence cannot be ignored.* This problem is not unique to WSU, and has received substantial attention in the engineering education literature (e.g., Barrow and Fulling, 1998; Sathiananthan *et al*., 1999, McKenna *et al.,* 2000; Guzdial et al., 2001). The general consensus thus far is that the traditional approach of teaching students the required mathematical theory simply as a prerequisite to subsequent engineering application is unsatisfactory, and that a more integrated approach is required. Such integration has typically been achieved by injecting engineering application into the freshman calculus sequence, sometimes in concert with a freshman engineering course.

While integrating engineering application into the freshman calculus sequence is a step in the right direction, it is proposed herein that a more radical approach is required, involving a large-scale restructuring of the engineering curriculum. As emphasized in a recent presentation by the NSF Director of Engineering Education and Centers (Gabriele, 2005), 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 such, there is a drastic need for a proven model which eliminates the math-related constraints of the traditional engineering curriculum, yet can be readily adopted by any university.

3. THE WSU MODEL

The WSU model begins with the development of a freshman-level engineering mathematics course (EGR 101). Taught by *engineering* faculty, the course includes lecture, laboratory and recitation components. Using an application-oriented, hands-on approach, EGR 101 addresses only the salient math topics *actually used* in a variety of 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 engineering curriculum without having completed a traditional freshman calculus sequence. This has enabled a significant restructuring of the engineering curriculum, including the placement of formerly sophomore-level engineering courses within the freshman year. The WSU model concludes with the development of a revised engineering math sequence, to be taught by the math department later in the curriculum, in concert with College and ABET requirements. By removing traditional math prerequisites and moving core engineering courses earlier in the program, the WSU model 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 new math sequence.

3.1 EGR 101: Introductory Mathematics for Engineering Applications

The WSU model begins with the development of EGR 101, "Introductory Mathematics for Engineering Applications," 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 has opened the door for students to advance in the engineering curriculum without first completing the traditional calculus sequence.

The content of EGR 101 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. Clearly, it is impossible to cover all topics in Calculus I-III and Differential Equations within a single course, let alone a freshman course. However, only a handful of these topics 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.

After consultation with faculty throughout the College, the following math topics were slated for inclusion in EGR 101: Basic Algebraic Manipulations; 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 structure is 5 credit hours (4 hours lecture, 1 hour lab), plus mandatory recitation sections. 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.

A detailed outline of the EGR 101 course content over a period of one 10 week quarter is outlined in Table 1 below:

Table 1. EGR 101 Course Outline

Week 1 **Lecture:** Course Introduction (1 hour); Application of Algebra in Engineering - Linear Equations (1.5 hours); Application of Algebra in Engineering - Quadratic Equations (1.5 hours) **Lab:** Introduction to MATLAB	**Week 2** **Lecture:** Trigonometry - One-Link Planar Robot (2 hours); Trigonometry - Two-Link Planar Robots (2 hours) **Lab:** Application of Algebra in Engineering: The One-Loop Circuit
Week 3 **Lecture:** 2-D Vectors in Engineering (2 hours); Complex Numbers in Engineering (2 hours); **Lab:** Measurement of Trigonometric Relationships in One and Two-Link Planar Robots	**Week 4** **Lecture:** Sinusoids and Harmonic Signals in Engineering (2 hours); Systems of Equations in Engineering (2 hours) **Lab:** Measurement and Analysis of Harmonic Signals

<u>Week 5</u> **<u>Lecture</u>:** Introduction to Derivatives in Engineering (2 hours); Application of Derivatives - Velocity and Acceleration (2 hours) **<u>Lab</u>:** Systems of Equations in Engineering: The Two-Loop Circuit	**<u>Week 6</u>** **<u>Lecture</u>:** Application of Derivatives - Electric Circuits (2 hours); Application of Derivatives - Deflection of Beams (2 hours) **<u>Lab</u>:** Derivatives in Engineering: Velocity and Acceleration in Free-Fall
<u>Week 7</u> **<u>Lecture</u>:** Introduction to Integrals in Engineering (2 hours); Application of Integrals in Statics (2 hours) **<u>Lab</u>:** Integrals in Engineering: Work and Stored Energy in a Spring	**<u>Week 8</u>** **<u>Lecture</u>:** Application of Integrals in Dynamics (2 hours); Application of Integrals in Electric Circuits (2 hours) **<u>Lab</u>:** Differential Equations in Engineering: The Leaking Bucket
<u>Week 9</u> **<u>Lecture</u>:** Introduction to Differential Equations: The Leaking Bucket (2 hours); Application of Differential Equations - Mechanical Systems (2 hours) **<u>Lab</u>:** Differential Equations in Engineering: Spring-Mass Vibration	**<u>Week 10</u>** **<u>Lecture</u>:** Application of Differential Equations - Electrical Systems (2 hours); Catch-up, Summary and Review (2 hours) **<u>Lab</u>:** Make-up laboratory session

Note that in the above course outline, all math topics are presented within the context of their engineering application, and reinforced through hands-on laboratory assignments. However, unlike typical engineering laboratory assignments, which are designed to illustrate *engineering physics*, all EGR 101 laboratory assignments are designed to illustrate *engineering mathematics*. Indeed, physical measurement of the derivative as the velocity in free-fall (Week 6), or of the integral as the area under the force-deflection curve (Week 7), provides a much greater conceptual understanding of the mathematical concepts than classroom lecture alone. In addition, all laboratory data is processed with MATLAB, so that the students can immediately appreciate the interconnection between classroom theory, laboratory measurement and numerical representation of their engineering results.

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 scores and high school transcripts, or by the completion of MTH 131 (Trigonometry) at WSU. Of the 270 incoming freshmen typically arriving each year, roughly one-third will satisfy the prerequisite requirements immediately in the Fall quarter. However, EGR 101 is scheduled to run every quarter, so that the remaining students can register immediately upon completion of the necessary prerequisite mathematics background.

3.2 Restructured Engineering Curriculum

The primary goal of EGR 101 is to facilitate a large-scale restructuring of the 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 2. 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 3. The EGR 101 course appears immediately in the Fall quarter. However, as previously noted, the course is scheduled to run 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).

Table 2. 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 3. 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
** First course in the revised engineering calculus sequence, with separate sections for engineers.

In addition to the presence of EGR 101, the new freshman year curriculum has a number of features which distinguish it from the traditional curriculum of Table 2. Most notably, the only Math department course in the freshman year is MTH 229 Calc I. This is the first course in the revised engineering calculus sequence, which now has separate sections designated for engineers. It should be noted that because EGR 101 is now the only math prerequisite for core sophomore year engineering courses, students who are not immediately successful in MTH 229 Calc I can still advance in the program.

Another key feature of the revised curriculum is the presence of formerly sophomore-level courses in the freshman year. In place of MTH 230 and 231 (the traditional Calc II and Calc III courses), both ME 220 Introduction to Manufacturing Processes and ME 202 Engineering Graphics have been moved to the freshman year. These are hands-on, application-oriented engineering courses which will go a long way toward making incoming students feel like they are actually *doing* engineering. This is in contrast to the traditional freshman calculus sequence, which effectively precludes all too many students from exposure to sophomore-level engineering courses.

While Tables 2 and 3 are specific to Mechanical Engineering, similar changes have been made for degree programs across the College. To date, restructured program guides have been developed for Mechanical Engineering (ME), Materials Science and Engineering (MSE), Electrical Engineering (EE), Engineering Physics (EP), Biomedical Engineering (BME), and Industrial and Systems Engineering (ISE). Each of these follows the freshman year model of Table 3, including the introduction of EGR 101, the removal of the second and third calculus courses from the freshman year, and the introduction of formerly sophomore-level engineering courses within the freshman year (as appropriate).

While the restructured curriculum is now recommended to all incoming students, it still provides a measure of flexibility with regard to the math sequence. For example, those students who might prefer to take MTH 229 Calc I and MTH 230 Calc II in immediate succession can still do so by taking MTH 230 in lieu of the GE course during the Spring quarter of freshman year. The GE requirement can always be made up later in the curriculum. Indeed, the restructured curriculum is intended to open the door for those students who might otherwise fall behind - not close the door to those students who might wish to get ahead!

Finally, revised math prerequisite requirements for the core 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.

3.3 Revised Engineering 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 subsequent mathematics courses. The traditional calculus sequence at WSU consists of four quarters of calculus: MTH 229 Calc I, MTH 230 Calc II, MTH 231 Calc III, and MTH 232 Calc IV. Each of these courses is 5 credit hours, including 4 hours lecture and 1 hour lab. In addition to this four quarter calculus sequence, the majority of majors in the College of Engineering and Computer Science have traditionally required a 5 credit hour course in Differential Equations, as well as a 3 credit hour course in Matrix Algebra.

In order to accommodate EGR 101, the various engineering departments have been required to free up additional credit hours in their respective degree programs. Towards this goal, it was initially proposed to streamline the existing calculus sequence into three quarters, with greater emphasis on engineering application. However, there was significant concern among members of the Department of Mathematics and Statistics that streamlining the calculus sequence cannot be done without jeopardizing student learning, including the development of problem solving skills so critical to engineering.

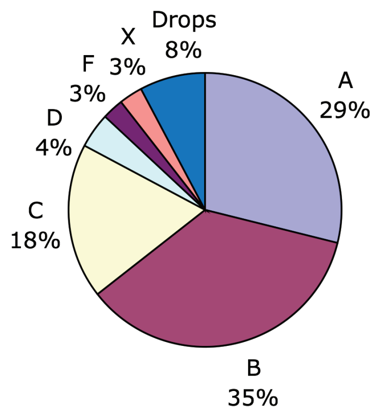
In light of these concerns, the revised engineering calculus sequence is to remain four quarters long, but with separate sections designated for engineering students (where possible), and with a greater emphasis on engineering application. As previously described, Calc I is part of the freshman curriculum, 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, the revised Calc II and III courses 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," which is offered during the sophomore year.

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. Compared to the traditional freshman calculus sequence, the benefits of such an approach are many. In the restructured curriculum, advanced math concepts are presented much closer to the time they are needed in the engineering curriculum. For example, while advanced concepts in calculus (e.g., the Divergence Theorem) are traditionally presented in the late freshman or early sophomore years, the application of such concepts in the engineering curriculum is typically not encountered until the junior or senior years. As a result, students can lose the connection between the mathematical theory and its relevant engineering application, which can result in a decreased motivation to study math. In contrast, the just-in-time structure of the revised math sequence will reinforce the students' motivation to study both math and engineering. Moreover, with the revised math sequence offered later in the curriculum, the students enrolled in calculus will be more mature, and will benefit from the problem solving skills already developed in their entry-level core engineering courses.

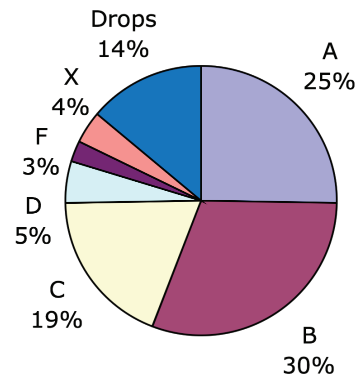
4. RESULTS OF YEAR ONE

The EGR 101 course ran for the first time in the Fall quarter of 2004, following the course outline of Table 1. Nearly all eligible incoming freshmen in Mechanical Engineering, Materials Science and Engineering, Industrial Engineering, Biomedical Engineering, Electrical Engineering and Engineering Physics were enrolled in the course. The total enrollment was 76 students, who were divided between 2 lecture sections, 6 laboratory sections and 9 recitation sections. The lecture sections were administered by the authors N. Klingbeil and K. Rattan, while the laboratory and recitation sections were staffed by a total of 5 graduate teaching assistants. Student performance was assessed through graded homework and labs, block midterm exams in weeks 5 and 8, and a block final exam following week 10. Final grades were administered according to a standard University scale (A: 90-100, B: 80-89, C: 70-79, D: 60-69, F: <60), with minor adjustments for borderline cases.

The final grade distribution for the first run of EGR 101 is shown in Figure 1a. In short, student performance was extremely encouraging. Of the 76 students enrolled, over 80% completed the course with a grade of "C" or better. This includes those students who either dropped or failed to complete the course (grade of "X" in Fig. 1). The EGR 101 course has run each quarter since Fall of 2004, with similar success. Since the enrollment in the Winter and Spring quarters was composed largely of students not immediately eligible in the Fall, a decline in student performance was anticipated. Even so, student performance in subsequent quarters has continued to surpass our expectations. Through the Spring of 2005, a total of 158 students were enrolled in EGR 101, with over 74% completing the course with a grade of "C" or better (Figure 1b). This suggests the potential for a dramatic improvement over the 42% of engineering students who have traditionally advanced past the freshman calculus sequence at WSU.



a) Fall 2004, 76 Students



b) Cumulative, 158 Students

Figure 1. Student Performance in EGR 101 a) Fall 2004 and b) Cumulative (Fall 04-Spring 05)

In addition to student performance, an assessment of student perception was obtained through surveys distributed at the end of the course. 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.

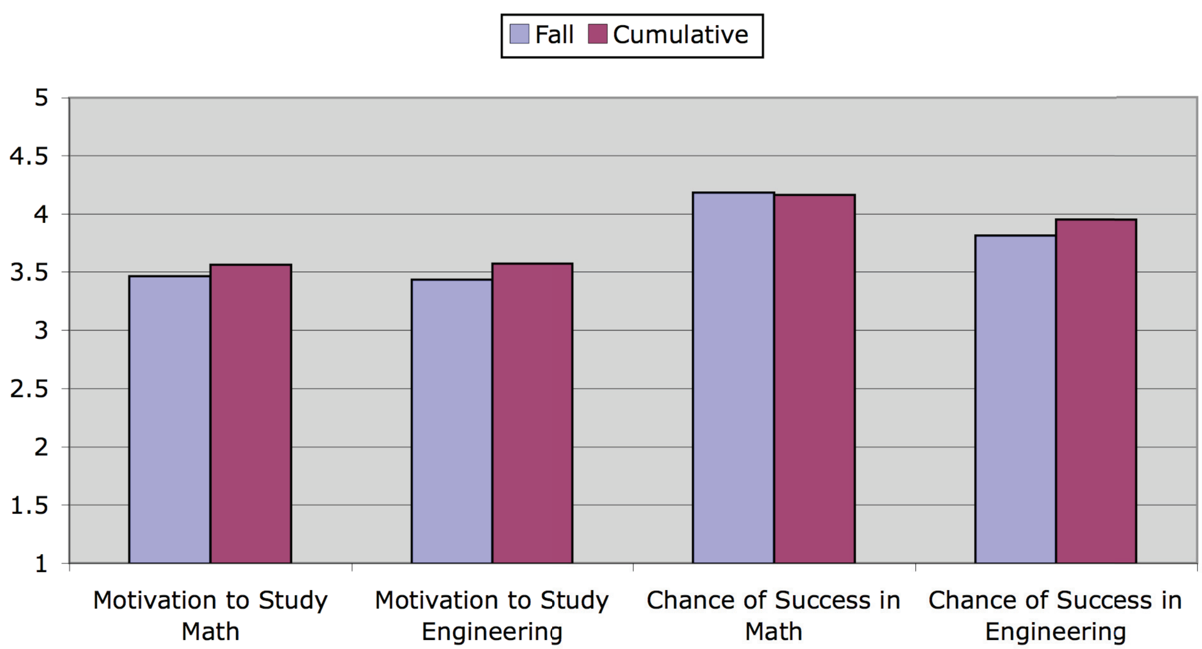


Figure 2. Student Perception of EGR 101: Fall 2004 and Cumulative (Fall 04-Spring 05)

The results of the student survey are shown in Figure 2. Student perception of EGR 101 following the initial Fall offering was very encouraging, with students reporting an increased motivation to study both math and engineering, as well as an increased chance of success in future math and engineering courses. Although the students enrolled in subsequent quarters were generally less prepared to be there, the cumulative perception of EGR 101 also remained strong, actually increasing in three of the four categories. Indeed, those students not immediately eligible for EGR 101 - who would be at substantial risk in the traditional curriculum - clearly recognized the opportunity it provided for their advancement in engineering. The strongest perception reported was an increased chance of success in future math courses, which is anticipated to have a significant effect on student retention through the revised math sequence.

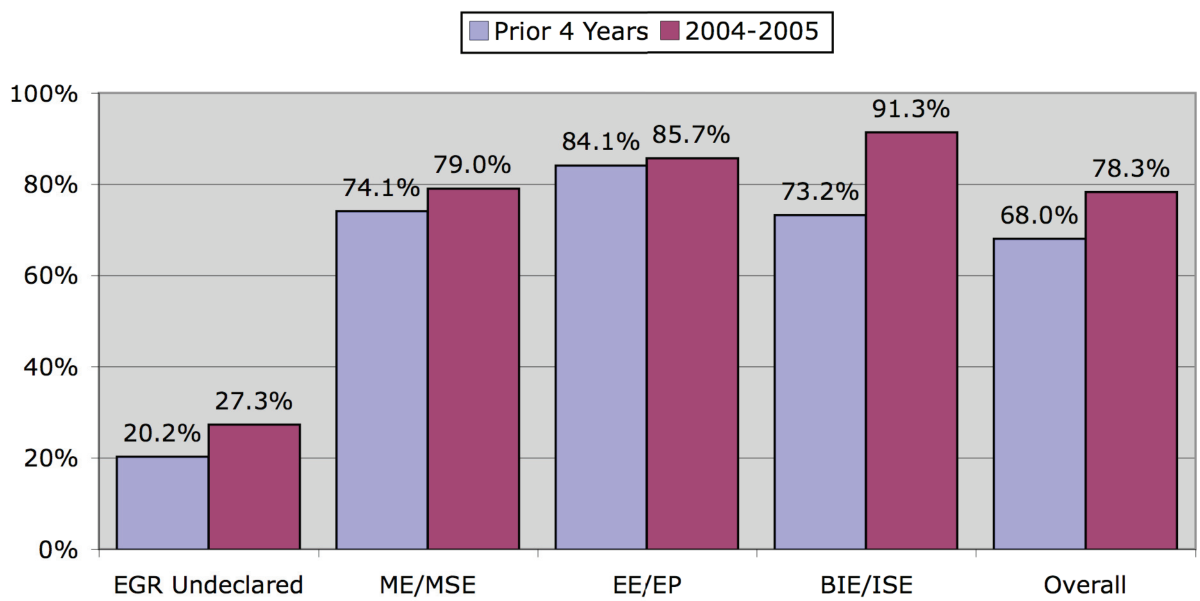


Figure 3. First Year Fall-to-Fall Retention for Majors Requiring EGR 101

As shown in Figure 3, the initial implementation of the program has already had a dramatic effect on first year retention in engineering at WSU. Every department requiring EGR 101 saw an increase in first year retention in 2004-2005, as compared to baseline data averaged over the prior four years. Overall, majors requiring EGR 101 saw first year retention increase from 68.0% to 78.3%. For this particular incoming class, this corresponds to about 15 additional sophomores in engineering. The success of these students as they advance through the newly restructured curriculum will be closely studied in the months and years to come.

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