AC 2007-1116: A NATIONAL MODEL FOR ENGINEERING MATHEMATICS EDUCATION

Nathan Klingbeil, Wright State University
Nathan W. Klingbeil is an Associate Professor of Mechanical Engineering and Robert J. Kegerreis Distinguished Professor of Teaching at Wright State University. He is the lead PI for WSU's National Model for Engineering Mathematics Education. He is the recipient of numerous awards for his work in engineering education, including the CASE Ohio Professor of the Year Award (2005) and the ASEE North Central Section Outstanding Teacher Award (2004).

Kuldip Rattan, Wright State University
Kuldip S. Rattan is a Professor in the Department of Electrical Engineering at Wright State University. He is a Co-PI on WSU's National Model for Engineering Mathematics Education. He conducts research in the area of electrical control systems, and is active in engineering education reform. He has been the recipient of the CECS Excellence in Teaching Award at Wright State University in both 1985 and 1992, and of the CECS Excellence in Service Award in 1991, 1996 and 2003.

Michael Raymer, Wright State University
Michael L. Raymer is an Associate Professor in the Department of Computer Science & Engineering at Wright State University. He is a Co-PI on WSU's National Model for Engineering Mathematics Education, and has also led an NSF supported research project to develop the nation's first undergraduate curriculum in bioinformatics.

David Reynolds, Wright State University
David B. Reynolds is an Associate Professor in the Department of Biomedical, Industrial and Human Factors Engineering at Wright State University. He is a Co-PI on WSU's National Model for Engineering Mathematics Education, and has also conducted NSF supported research to develop human factors engineering undergraduate design projects for persons with disabilities.

Richard Mercer, Wright State University
Richard E. Mercer is an Associate Professor in the Department of Mathematics and Statistics at Wright State University. He is a Co-PI on WSU's National Model for Engineering Mathematics Education. He is active in curriculum reform, and has led an NSF supported effort to integrate Mathematica laboratory sessions into the freshman calculus sequence at Wright State University.

Anant Kukreti, University of Cincinnati
Anant R. Kukreti is Associate Dean for Engineering Education Research and Professor of Civil and Environmental Engineering at the University of Cincinnati (UC). He is the lead investigator for the UC adoption of WSU's National Model for Engineering Mathematics Education. He teaches structural engineering, with research in experimental and finite element analysis of structures. He has received two Professorships, and won four University and two ASEE Teaching Awards.

Brian Randolph, University of Toledo
Brian W. Randolph is the Associate Dean of Undergraduate Studies and Professor of Civil Engineering at the University of Toledo. He is the lead investigator for the UT adoption of WSU's National Model for Engineering Mathematics Education. He has received numerous awards for his teaching and professional activities, including the ASEE North Central Dow Outstanding Young Faculty Award, repeated department and college teaching awards and was named Toledo Engineer of the Year in 2005.

A National Model for Engineering Mathematics Education

Abstract

   The traditional approach to engineering mathematics education begins with one year of freshman calculus as a prerequisite to subsequent core engineering courses. However, the inability of incoming students to successfully advance through the traditional freshman calculus sequence is a primary cause of attrition in engineering programs across the country. As a result, this paper describes an NSF funded initiative at Wright State University to redefine the way in which engineering mathematics is taught, with the goal of increasing student retention, motivation and success in engineering.

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 initial implementation[1-4]. It also summarizes the scope of a recent NSF CCLI Phase 2 Expansion award, which involves a multiyear assessment at WSU, pilot adoption and assessment at two collaborating institutions, and a widespread dissemination of results.

Introduction

   Traditionally, 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 freshman calculus sequence. The remaining 58% either switch majors or leave the University. These numbers are not unique to WSU; indeed, the inability of incoming students to successfully advance through the traditional freshman calculus sequence is a primary cause of attrition in 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[5]. This has led engineering educators to introduce early intervention programs, aimed at increasing retention among incoming students[6,7]. 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[8-13], 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.

Certainly, 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 freshman calculus sequence cannot be ignored.* This problem is not unique to WSU, and in recent years has received substantial attention in the engineering education literature[14-20]. 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.

Indeed, as emphasized in a recent presentation by the NSF Director of Engineering Education and Centers[21], 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 engineering programs across the country.*

Approach

The WSU model begins with the development of a novel 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, the EGR 101 course 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. *Most importantly, 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 mathematics sequence, to be 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 new math sequence.

The WSU approach proposes an immediate solution to math-related attrition in engineering, and is designed to be readily adopted by any institution employing a traditional engineering curriculum. Initial NSF support has enabled the development and implementation of EGR 101 and associated large-scale curriculum reforms, the development of assessment methodologies for evaluating program performance, and the initial dissemination of results. The latter has resulted in the addition of collaborating institutions from across the State of Ohio, including the University of Cincinnati and the University of Toledo. The goal of the current CCLI Phase 2

Expansion program is to conduct a multiyear assessment of the program at WSU and its collaborating institutions, and to provide both the pedagogical basis and the dissemination strategy required for nationwide implementation of the program.

Overview: 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.

1) Development of EGR 101
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 opens 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 from around 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 math 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. Note that 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.

Table 1. EGR 101 Course Outline

Week 1	**Week 2**
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	**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	**Week 4**
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	**Lecture:** Sinusoids and Harmonic Signals in Engineering (2 hours); Systems of Equations in Engineering (2 hours) **Lab:** Measurement and Analysis of Harmonic Signals
Week 5	**Week 6**
Lecture: Introduction to Derivatives in Engineering (2 hours); Application of Derivatives - Velocity and Acceleration (2 hours) **Lab:** Systems of Equations in Engineering: The Two-Loop Circuit	**Lecture:** Application of Derivatives - Electric Circuits (2 hours); Application of Derivatives - Deflection of Beams (2 hours) **Lab:** Derivatives in Engineering: Velocity and Acceleration in Free-Fall
Week 7	**Week 8**
Lecture: Introduction to Integrals in Engineering (2 hours); Application of Integrals in Statics (2 hours) **Lab:** Integrals in Engineering: Work and Stored Energy in a Spring	**Lecture:** Application of Integrals in Dynamics (2 hours); Application of Integrals in Electric Circuits (2 hours) **Lab:** Differential Equations in Engineering: The Leaking Bucket
Week 9	**Week 10**
Lecture: Introduction to Differential Equations: The Leaking Bucket (2 hours); Application of Differential Equations - Mechanical Systems (2 hours) **Lab:** Differential Equations in Engineering: Spring-Mass Vibration	**Lecture:** Application of Differential Equations - Electrical Systems (2 hours); Catch-up, Summary and Review (2 hours) **Lab:** Make-up laboratory session

Prerequisite Requirements: 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 at WSU. Of the 250-300 incoming freshmen typically arriving each year, roughly one-third

satisfy the prerequisite requirements immediately in the Fall quarter. However, the EGR 101 course is scheduled to run every quarter, so that the remaining students can register immediately upon completion of the necessary prerequisite mathematics background.

2) Restructuring of the 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!

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.

The restructured alternative to the traditional freshman year curriculum is shown in Table 3. The new 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).

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 traditional mathematics 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 the core sophomore-level 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 engineering 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, Materials Science and Engineering, Electrical Engineering, Engineering Physics, Biomedical Engineering, and Industrial and Systems Engineering. 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 General Education (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) Development of a 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. Toward 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," 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. 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. 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.

Results of Initial Implementation

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 PI N. Klingbeil and Co-PI 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 was as shown in Figure 1. 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).
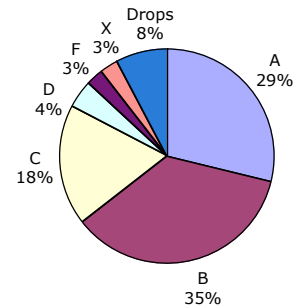

Fig. 1. Student Performance in EGR 101 First-Run

It should be noted that the first-run of EGR 101 included only those incoming students who were immediately eligible for the course, many of whom had prior exposure to calculus in high school. Of the students completing EGR 101, those who had at least some calculus in high school performed extremely well, with 80% earning at least a "B" and 94% earning a grade of "C" or better. Such results might be expected, since those students who take calculus in high school tend to be very good students. More notable, however, was the performance of those students completing EGR 101 without prior calculus in high school, of which 58% earned at least a "B", and 83% earned a grade of "C" or better. *Such results confirm that even incoming students with no prior calculus background can digest and apply mathematics concepts spanning calculus through differential equations, when presented in the context of their engineering application.*

In addition to student performance, a preliminary 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.

The results of the student survey, as sorted by high school math background (Calc or No Calc in high school), are shown in Fig. 2. On average, student perception of EGR 101 was extremely encouraging, with both groups of students reporting an increased motivation to study both math and engineering, as well as
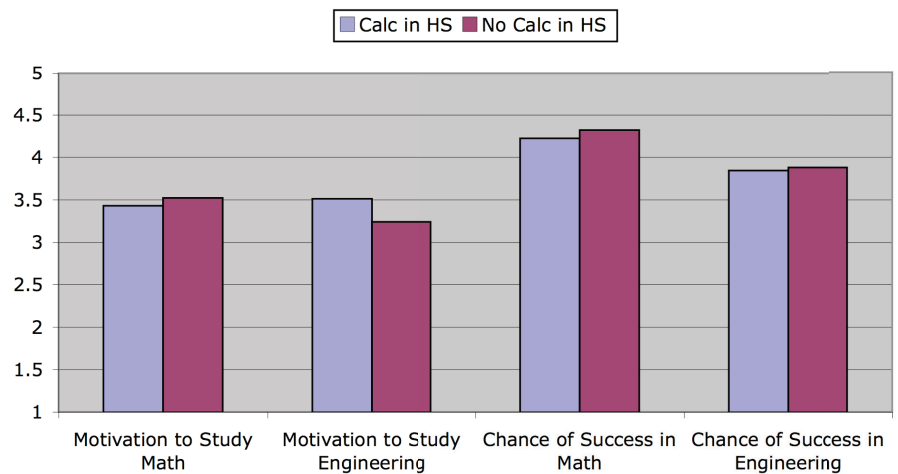

Fig. 2. Student Perception of EGR 101 Sorted by High School Math Background

an increased chance of success in future math and engineering courses. Interestingly, students without calculus in high school actually had a slightly stronger perception of EGR 101 in three of the four categories. The strongest perception reported by both groups of students was that EGR 101 had increased their chance of success in future math courses, which is expected to have a significant effect on student retention through the revised math sequence.

The EGR 101 course has run each quarter since Fall of 2004, with similar success. Since the enrollment in the following Winter and Spring quarters was composed largely of students not immediately eligible in the Fall, a decline in student performance was anticipated. However, student performance in subsequent quarters continued to surpass our expectations. During the 2004-2005 academic year, a total of 158 students were enrolled in EGR 101, with over 74% completing the course with a grade of "C" or better. *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.* 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.

As shown in Fig 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 is a primary focus of the current research.
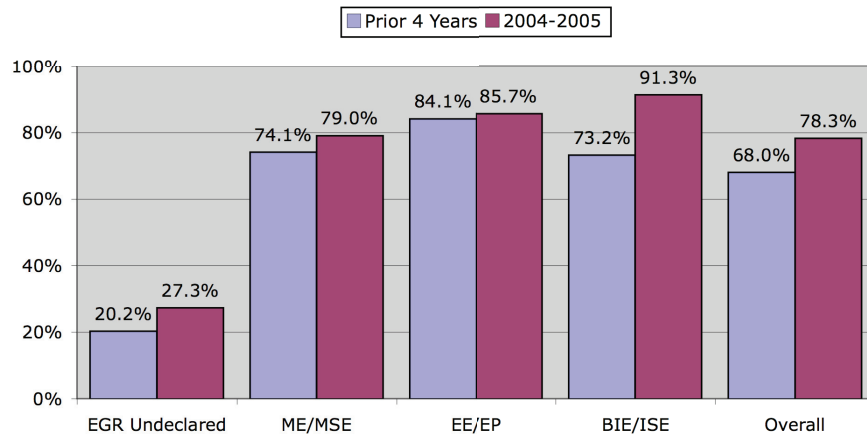

Fig. 3. First Year Fall-to-Fall Retention for Majors Requiring EGR 101

NSF CCLI Phase 2 Program

Initial NSF support has already resulted in the initial implementation of EGR 101 and associated large-scale curriculum reforms at Wright State University, where the feasibility of the approach has been demonstrated. *However, the realization of the WSU approach as a national model for engineering mathematics education will require a rigorous assessment and widespread dissemination of results, with demonstrated portability to other institutions.* Toward these goals, the current NSF CCLI Phase 2 program will focus on the following three tasks: 1) A multiyear implementation and assessment of the program at Wright State University; 2) The adoption and assessment of the WSU model at two other mid-size state universities; 3) A widespread dissemination of results.

Task 1: Multiyear Implementation and Assessment at WSU

As previously outlined, the primary goal of the WSU model is to increase student retention, motivation and success in engineering, much of which can be readily quantified. In addition, implementation of the WSU model is expected to have a significant impact on *student learning* in both math and engineering courses. It is well known that hands-on, problem-based learning can accommodate more learning styles than traditional classroom lecture alone. As such, it is expected that the application-oriented approach of the WSU model will make the material significantly more accessible to a wider range of students, including those of traditionally underrepresented groups. The extent to which this is accomplished must be rigorously evaluated. *Ultimately, a definitive assessment of the impact of the WSU model on student retention, motivation and success, as well as on student learning in subsequent math and engineering courses, will provide the pedagogical basis for its adoption nationwide.* To this end, the implementation of appropriate assessment methodologies will be a primary focus of the project.

Pedagogical Research Questions: During the course of the initial NSF planning grant, the PIs have worked with learning experts from the WSU Center for Teaching and Learning to formulate a number of fundamental pedagogical research questions associated with WSU model for engineering mathematics education. Among the key questions to be investigated are the following:

1. Have the introduction of EGR 101 and the restructuring of the engineering curriculum increased retention and ultimate graduation rates of engineering students?
2. How are retention and graduation rates related to student performance in high school, initial math preparation, student race/gender, and other factors?
3. How has the introduction of EGR 101 and the restructuring of the engineering curriculum affected student learning and performance in core engineering courses (PHY 240-244, ME 212-213, CEG 220, EGR 153, ME 313, EE 301)?
4. How has the application-oriented approach of EGR 101 and the just-in-time structuring of the new math sequence affected student learning and proficiency in mathematics?
5. Has the introduction of EGR 101 and the just-in-time structuring of the new math sequence enhanced student perception of math and engineering (e.g., are they more confident, motivated and excited about math and its engineering application)?
6. Is enhanced *student perception* ultimately related to enhanced *student learning* in subsequent math and engineering courses?

Over the course of the initial NSF planning grant, the PIs have worked with the WSU Center for Teaching and Learning, the Statistical Consulting Center, and the Institutional Research Office to develop an assessment plan to address the above research questions. The result of these efforts is a combination of quantitative and qualitative assessment methodologies, as summarized below.

Quantitative Assessment Methodologies: Implementation of quantitative assessment methodologies will be used to address research questions 1-4. Fortunately, data will be readily

available on student retention, success in core courses, and graduation rates, and will be provided at no cost by the WSU Institutional Research Office.

The data provided by the Institutional Research Office will be sorted and analyzed to provide statistically meaningful answers to research questions 1-3. In addition to raw data on student retention and success in core courses, this will provide the *relationship* of such data to past performance in high school, initial math preparation (ACT and standard math placement scores), and race and gender. *Such results will provide substantial insight into how the WSU model impacts student learning for both traditional and high-risk students of significantly diverse backgrounds.* Research question 3 will be further addressed through established ABET assessment methodologies already in place throughout the College of Engineering and Computer Science. In particular, extensive examples of student work and their relation to ABET a-k outcomes are routinely collected in all core engineering courses, and have been recently assembled in preparation for the 2005-2006 accreditation cycle.   This will provide a clear datum for comparison with subsequent years' students advancing in the restructured curriculum. Finally, research question 4 will be addressed by tracking student performance through the revised math sequence.

Qualitative Assessment Methodologies: In addition to these quantitative measures, the PIs will develop student and faculty surveys to provide qualitative feedback on the success of the WSU model, with particular emphasis on *student perception* and its ultimate relationship to *student learning* (research questions 5 and 6).

First, student surveys will be administered to determine the impact of the WSU model on student perception of math and engineering. Of particular importance will be the students' *perceived* mathematics proficiency at each level of the program, which is expected to correlate with their motivation and success in both math and engineering courses. As previously outlined, such student surveys have already been administered during the initial implementation of EGR 101, with encouraging results.   Next, faculty in both Math and Engineering will be surveyed to assess the impact of the WSU model on *student learning* in their own courses. While the quantitative data (i.e., grade distributions and success rates) will provide a definitive assessment of *student performance*, the feedback of the faculty will be critical in making an ultimate assessment of *student learning* in subsequent math and engineering courses. When considered together, the student and faculty surveys will provide significant insight into the relationship between student perception and student learning. Moreover, they will reveal any key differences in perception and learning that may exist between traditional engineering students and those of underrepresented groups, and the extent to which the WSU model addresses those differences.

It should be noted that engineering students enrolled prior to Fall of 2004 are currently advancing in the traditional curriculum, which will provide a datum for the proposed research. *Hence, throughout the implementation of these quantitative and qualitative assessment methodologies, a real-time comparison between existing students advancing in the traditional curriculum and incoming students advancing in the restructured engineering curriculum will provide a definitive evaluation of program results.*

Task 2: Adoption and Assessment at Collaborating Institutions

As previously noted, the WSU model is designed to be readily adopted by any university employing a traditional engineering curriculum. *As such, a primary goal of the project is to illustrate the portability of the program, and to evaluate its performance at diverse institutions (including those on both quarter and semester systems).* To this end, initial dissemination of the WSU model has resulted in the addition of collaborating institutions from across the State of Ohio, including the University of Cincinnati and the University of Toledo. Each will adopt the WSU approach in a manner which expands the applicability of the model, with a focus on engineering programs not available at WSU (Civil Engineering and Chemical Engineering).

Adoption and Assessment at the University of Cincinnati: While the University of Cincinnati (UC) is considered one of the top engineering schools in the State of Ohio, faculty there still experience many of the same math problems encountered at WSU. As a result, they have enthusiastically agreed to consider the WSU model for adoption at their own institution.

To this end, the UC investigators will repackage the lectures and associated laboratories for the WSU EGR 101 course as *CEE 103 CEE Math*, which will focus on applications of the salient math topics in Civil Engineering. The course contents, and particularly the laboratory exercises, will be tailored to the scholastic activities and research facilities available at UC. The course CEE 103 will be taught every year during the first quarter of the freshmen year, followed by Calculus I, II and III, ODE and Matrix Methods. Calculus IV, which is in the current curriculum, will be dropped. Also, CEE 103 will be the prerequisite for Physics I, Engineering Fundamentals (statics and dynamics), CEE measurements, and engineering graphics, so that students can progress in the CEE program without having completed the traditional calculus sequence.

The impact on student learning will be assessed by comparing the student grades attained by the CE students in the Calculus, Physics and Engineering Fundamentals courses with other College of Engineering students who did not take the CEE 103. To assess to what extent the goals of the WSU course model were satisfied in the CEE 103 implementation, specific questions will be added to the standard course evaluation form used by the College of Engineering, and a Likert scale will be used to evaluate student feedback. This feedback will be used for course improvement, as well as to assess the impact on student learning. In the end, the positive results expected in Civil and Environmental Engineering will serve as a model for college-wide adoption at the University of Cincinnati.

Adoption and Assessment at the University of Toledo: Students who leave the UT engineering program overwhelmingly remark that the required math is too difficult and, although they enjoy the field, they seek a more hands-on approach to the material. Hence, the faculty at UT have enthusiastically agreed to consider the WSU model for adoption at their own institution. The objectives of the UT adoption are two-fold:

1) To demonstrate the applicability of the WSU model on a semester system, as opposed to the quarter system used by WSU and UC.

2) To expand the EGR 101 course modules to include applications in Chemical Engineering. This supplements the work at WSU, which has no Chemical Engineering program.

Toward these objectives, the UT investigators will coordinate the introduction of WSU EGR 101 modules into a modified course on a semester basis, with additional modules developed for chemical engineering applications. Students who do not test directly into Calculus I will comprise the pilot enrollment in the semester version of EGR 101. A control group will proceed without EGR 101, allowing comparisons of student learning to be made. Students who directly enter the Calculus sequence will also be compared. As part of the UT adoption of EGR 101, the investigators will implement team-based design experiences that demonstrate mathematics principles via student learning communities called Freshman Interest Groups (FIG), which have been employed at UT for nearly 11 years. This will enhance learning in the first year and demonstrate the connections between fundamental mathematics and engineering practice. A weekly recitation/lab in the course will be devoted to presentation and hands-on application of the WSU EGR 101 lab modules. The approach will include planned assessment throughout the pilot course, with immediate adaptation to students needs, as they present themselves. The result of the UT implementation will be a demonstrated application of the WSU model on a semester basis, with definitive results for initially underprepared students.

Task 3: Dissemination of Results

Since the WSU approach is intended to serve as a national model for engineering mathematics education, dissemination of results is a primary focus of the project. The planned and ongoing dissemination activities include the following:

Development of a Textbook for EGR 101: The broadest dissemination of the WSU model will be effected through the publication of a textbook for the EGR 101 course. The textbook will be developed from the original EGR 101 course materials developed at WSU, but will also include examples and homework problems from the Civil Engineering and Chemical Engineering modules developed at University of Cincinnati and University of Toledo. As such, the book will be designed for broad applicability to engineering programs nationwide, spanning all engineering disciplines.

Publication and Presentation in Engineering Education Venues: Throughout the project duration, results will be aggressively disseminated in local, regional and national engineering education venues. Results of the initial implementation have already been published and presented at multiple ASEE conferences[18-21], and the WSU model has been further disseminated through invited talks at a variety of academic institutions.

Implementation of a Web Site for the WSU Model: All materials associated with the WSU model for engineering mathematics education are now available at http://www.cs.wright.edu/engmath/. In addition to restructured program guides for each engineering discipline, this includes all materials associated with EGR 101 - course notes, homework assignments, laboratory assignments and past exams - with full access provided to interested faculty from any institution.

Annual Faculty Workshops: The current NSF CCLI Phase 2 program includes funding for annual faculty workshops on the WSU model for engineering mathematics education, which will be hosted by WSU and its collaborating institutions. In addition to all senior personnel directly associated with the project, the workshops will include other interested faculty from institutions

across the country. Based on the initial dissemination effort, faculty at dozens of institutions have already expressed a strong interest in the model. The annual agenda will include updates on the implementation and assessment at WSU and its collaborating institutions, and will establish new pedagogical research directions based on lessons learned.

Interaction with Regional High Schools: Interaction with regional high schools will be continued throughout the project duration. A primary goal of this interaction will be to educate high school faculty on the WSU approach, and how applications of math in engineering could potentially be integrated into the senior high school curriculum. Such integration could ultimately result in a significant increase in recruitment to engineering programs at WSU and nationwide.

Interaction with Industrial Advisory Board: As part of a continuous effort to provide engineering graduates which meet or exceed the expectations of industry, feedback on the WSU model has already been sought from industrial members of the College's External Advisory Board, and will continue to be sought throughout the project duration. *The industrial feedback to date suggests that in addition to increasing the pool of engineering graduates, the WSU approach will improve the quality and preparedness of graduating engineers.* Hence, the program has the potential to have a significant impact on both academia and industry.

Broader Impacts

Integration of Research and Education: The hands-on laboratory component of the EGR 101 course provides an opportunity to infuse modern scientific tools and research methods into the undergraduate curriculum at the freshman level. *More importantly, the restructuring of the engineering curriculum allows student exposure to engineering research activities prior to the completion of a traditional math sequence.* This provides students with an opportunity to get "hooked" on the excitement of research and discovery in engineering, regardless of whether they have successfully advanced through a traditional calculus sequence. It should also be noted that the engineering PIs all have active research programs, several of which are supported by NSF. As such, the graduate assistants supported are expected to complete masters or Ph.D. thesis research in the PIs' respective research areas. Moreover, the unique combination of teaching and research experience afforded to these graduate students is helping to groom the next generation of outstanding faculty members.

Integration of Diversity: Low retention is of particular concern for members of traditionally underrepresented groups. As such, the introduction of EGR 101 and large-scale restructuring of the engineering curriculum are expected to have a significant effect on retention rates for traditionally high-risk students, including both women and minorities. The proposed assessment methodologies will provide a definitive evaluation of the impact of the WSU model on retention, motivation and success of underrepresented groups, as well as key differences in perception and learning specific to those groups.   It should finally be noted that the EGR 101 GTA positions have proven a valuable tool for recruiting underrepresented groups to the graduate program. In particular, the majority of the EGR 101 GTAs have been women, who are grossly underrepresented among engineering faculty.

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. Expected long-term impacts include significant increases in engineering retention and graduation rates not only at WSU and its collaborating institutions, but at universities across the country.

Acknowledgments

Bibliography

1. Klingbeil, N.W., Mercer, R.E., Rattan, K.S., Raymer, M.L. and Reynolds, D.B., 2004, "Rethinking Engineering Mathematics Education: A Model for Increased Retention, Motivation and Success in Engineering." *Proceedings 2004 ASEE Annual Conference & Exposition*, Salt Lake City, Utah, June 2004.

2. Klingbeil, N.W., Mercer, R.E., Rattan, K.S., Raymer, M.L. and Reynolds, D.B., 2005, "The WSU Model for Engineering Mathematics Education," *Proceedings 2005 ASEE Annual Conference & Exposition*, Portland, Oregon, June 2005.

3. Klingbeil, N.W., Mercer, R.E., Rattan, K.S., Raymer M.L. and Reynolds, D.B., 2006, "Redefining Engineering Mathematics Education at Wright State University," *Proceedings 2006 ASEE Annual Conference & Exposition*, Chicago, IL, June 2006.

4. Klingbeil, N.W., Mercer, R.E., Rattan, K.S., Raymer, M.L. and Reynolds, D.B., 2006, "The WSU Model for Engineering Mathematics Education: Student Performance, Perception and Retention in Year One," *Proceedings 2006 ASEE Illinois-Indiana and North Central Conference,* Fort Wayne, IN, April 2006.

5. Adelman, Clifford, 1998, "Women and Men of the Engineering Path: A Model for Analyses of Undergraduate Careers," U.S. Department of Education Report, May, 1998.

6. Pomalaza-Raez, C. and Henry Groff, B., 2003, "Retention 101: Where Robots Go... Students Follow," *Journal of Engineering Education*, Vol. 92, No. 1, 85-90.

7. Arenaz, P., Fisher, W., Della-Piana, C. K., 1999, "CircLES: A Retention Program for Entering Students in Engineering, Mathematics and Science," *Proceedings - Frontiers in Education Conference*, Vol. 3, 13d8-2.

8. Richardson, J., Dantzler, J, 2002, "Effect of a Freshman Engineering Program on Retention and Academic Performance," *Proceedings - Frontiers in Education Conference*, Vol. 3, S2C/16-S2C/22.

9. Kellar, J.J., Hovey, W., Langerman, M., Howard, S., Simonson, L., Kjerengtroen, L., Stetler, L., Heilhecker, H., Arneson-Meyer, L., Kellogg, S. D., 2000, "Problem Based Learning Approach for Freshman Engineering," *Proceedings - Frontiers in Education Conference*, Vol. 2, F2G-7-F2G-10.

10. Howard, B., 1999, "Enough of This Science and Mathematics, Let's Do Some Engineering," *Proceedings - Frontiers in Education Conference*, Vol. 3, 13d2-8.

11. Clausing, A.M., 1998, "Successful Freshman Engineering Course: An Active Learning Experience," *ASEE Annual Conference Proceedings*, 1998.

12. Corradini, M.; Farrell, P.; Mitchell, J.; Marleau, R.; Moskwa, J.; Sanders, K.; Webster, J., 1995, "Team-Based Design Course for Freshmen," *ASEE Annual Conference Proceedings*, Vol. 2, 2044-2053.

13. Dally, J. W. and Zhang, G. M., 1993, "Freshman Engineering Design Course," *Journal of Engineering Education,* Vol. 82, No. 2, 83-91.

14. Guzdial, M., Ludovice, P., Realff, M., Morley, T., Carroll, K., Ladak, A., 2001, "The Challenge of Collaborative Learning in Engineering and Math," *Proceedings - Frontiers in Education Conference*, Vol. 1, T3B/24-T3B/29.

15. McKenna, A., McMartin, F. and Agogino, A., 2000, "What Students Say About Learning Physics, Math and Engineering," *Proceedings - Frontiers in Education Conference*, Vol. 1, T1F-9.

16. Sathianathan, D., Tavener, S., Voss, K. Armentrout, S. Yaeger, P. and Marra, R., 1999, "Using Applied Engineering Problems in Calculus Classes to Promote Learning in Context and Teamwork," *Proceedings - Frontiers in Education Conference*, Vol. 2, 12d5-14.

17. Barrow, D.L. and Fulling, S.A., 1998, "Using an Integrated Engineering Curriculum to Improve Freshman Calculus," *Proceedings of the 1998 ASEE Conference*, Seattle, WA.

18. Hansen, E.W., 1998, "Integrated Mathematics and Physical Science (IMPS): A New Approach for First Year Students at Dartmouth College," *Proceedings - Frontiers in Education Conference*, Vol. 2, 579.

19. Kumar, S. and Jalkio, J., 1998, "Teaching Mathematics from an Applications Perspective," *Proceedings of the 1998 ASEE Conference*, Seattle, WA.

20. Whiteacre, M.M. and Malave, C.O., 1998, "Integrated Freshman Engineering Curriculum for Pre-Calculus Students," *Proceedings - Frontiers in Education Conference*, Vol. 2, 820-823.

21. Gabriele, G., 2005, "Future of NSF Engineering Education Programs," *NSF Engineering and Computing Education Grantee Meeting*, Washington, DC, February 2005.