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A National Model for Engineering Mathematics Education: Longitudinal Impact at Wright State University

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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 summarize 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 approach involves the development of EGR 101 - a first-year engineering course replacing traditional math prerequisites for core sophomore engineering courses - along with a more just-in-time structuring of the required calculus sequence. Since its inception in Fall of 2004, the impact of the Wright State model on student retention, motivation and success has been widely reported. This paper includes results of a recent longitudinal study of program impacts at Wright State University, from student performance in math and engineering to ultimate graduation rates. Results show that the program has substantially mitigated the effect of incoming math preparation on student success in engineering across the entire range of incoming ACT math scores, which has more than doubled the average graduation rate of enrolled students. Moreover, it has done so without watering down the caliber of graduates, who have actually enjoyed a slight (but statistically significant) increase in graduation GPA. Finally, the approach has been shown to have the greatest impact on members of underrepresented groups, for many of whom the traditional engineering curriculum is simply not accessible. The paper concludes with a longitudinal examination of student perception data, which appears to establish a clear link between program impacts on student motivation and self-efficacy and ultimate graduate rates.

The Wright State Model

It is well known that student success in engineering is highly dependent on student success in math, and perhaps more importantly, on the ability to connect the math to the engineering[1-6]. However, first-year students typically arrive at the university with virtually no understanding of how their pre-college math background relates to their chosen degree programs, let alone their future careers. And despite the national call to increase the number of graduates in engineering and other STEM disciplines[7] , the inability of incoming students to successfully advance past the traditional freshman calculus sequence remains a primary cause of attrition in engineering programs across the country. 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 Wright State model begins with the development of a novel first-year engineering math 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 first completing a traditional first-year calculus sequence. The Wright State model concludes with a more just-in-time structuring of the required math sequence, 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.*

Figure 1. The Derivative Lab

The EGR 101 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[8-12]. Excerpts from the EGR 101 laboratory are shown in Figures 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 Wright State model was first implemented in Fall of 2004, and its effect on student retention, motivation and success in engineering has since been widely reported[13-25]. The 2007 introduction of EGR 199 as a precursor to EGR 101 for initially underprepared students has further strengthened the approach, and has made Wright State's core engineering curriculum accessible even to incoming students with math placement scores as low as 3 levels below Calc I. Results of the initial implementation are briefly summarized below.

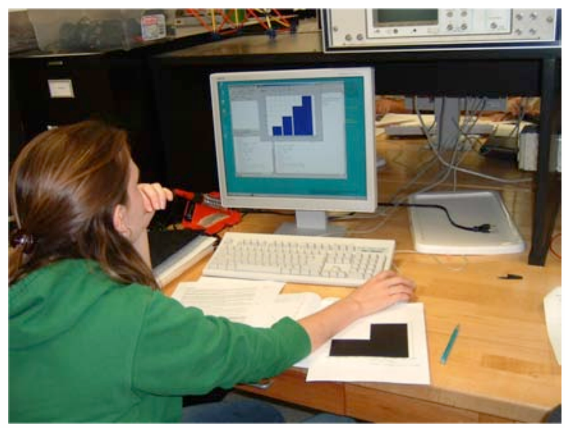


Figure 2. The Integral Lab

Results of Initial Implementation

The EGR 101 course ran for the first time in the Fall of 2004. All eligible incoming students in mechanical engineering, materials science and engineering, electrical engineering, engineering physics, biomedical engineering and industrial and systems engineering were enrolled in the course. Through its first year of implementation, a total of 158 students were enrolled in EGR 101, with over 74% completing the course with a grade of "C" or better.

The initial implementation of the program had an immediate and dramatic effect on student retention and success in engineering at Wright State. As shown in Fig. 3, 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%.

In addition to first-year retention, the introduction of EGR 101 and associated just-in-time structuring of the required math sequence had a significant impact on student performance in calculus. Of the 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 (Fig. 4). This undoubtedly contributed to significant increases in student persistence through the first two years of their programs. In particular, students who took EGR 101 at any time during their first two years were retained at a rate of 66.7%, compared to an alarming 23.5% for those who did not.

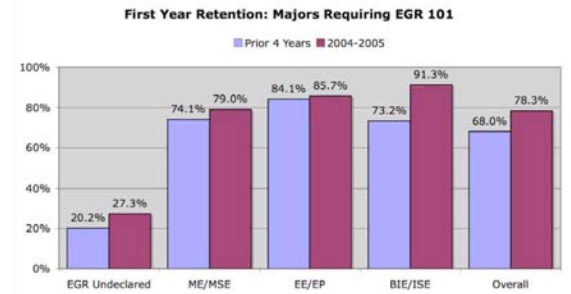


Figure 3. Initial Impact on First-Year Retention

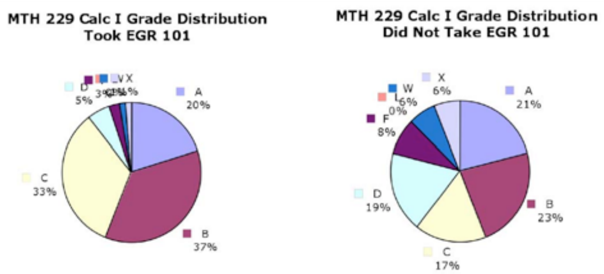


Figure 4. Initial Impact on Student Performance in Calculus

While the introduction of EGR 101 already had a dramatic effect on student retention and success in engineering, the course was only immediately accessible to incoming students with math placement in trigonometry, which corresponds to a WSU math placement level (MPL) of 5. Since our average incoming student has an MPL of around 4.3, our revised curriculum was still not immediately accessible to our AVERAGE incoming student. Moreover, roughly half of the college's incoming enrollment consists of computer science and engineering (CS/CEG) majors, for whom EGR 101 is not a required course. As a result, a multiyear assessment of the program revealed that only about 1/3 of our incoming students were ever taking EGR 101.

As a result of this finding, Wright State 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). These students are two or three classes behind Calc I (which requires an MPL 7) and are not immediately eligible for EGR 101. Assessment has shown that MPL 3 and 4 students make up about 1/3 of our college's incoming students, and that only about 30% of them are retained in engineering and computer science through their first two years. The EGR 199 content consists entirely of high school math, from algebra through trigonometry, with all topics presented in the context of their application in core engineering and computer science courses.

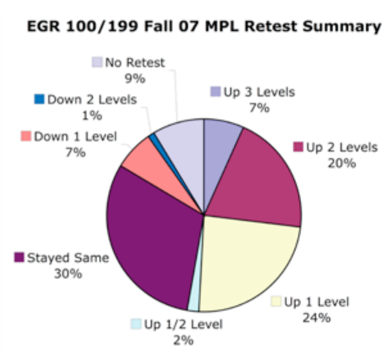


Figure 5. Results of Fall 2007 MPL Retest following EGR 199

The EGR 199 course serves the following two purposes:

1) For majors requiring EGR 101, EGR 199 serves as an alternative prerequisite requirement, which allows students who are 2-3 classes behind Calc I to enroll in EGR 101 and begin advancement in their chosen degree programs as early as their second quarter at WSU.

2) For all engineering and computer science majors, EGR 199 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.

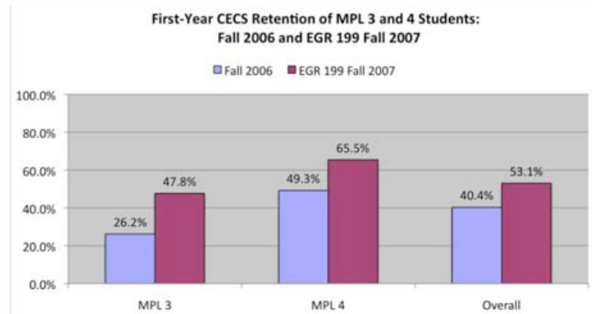


Figure 6. Impact of EGR 199 on First-Year Retention of Initially Underprepared Students

The initial Fall 2007 implementation of EGR 199 was enormously successful. Over half of the enrolled students increased their math placement level (MPL) scores at the end of the quarter, some by as many as 3 levels (Fig. 5). The resulting impact on first-year retention is shown in Figure 6. As compared to the prior year, the Fall 2007 implementation of EGR 199 nearly doubled the first-year retention rate of MPL 3 students, and had a significant impact on MPL 4 students as well. Overall, the first-year retention rate for MPL 3 and 4 students increased from 40.4% to 53.1%.

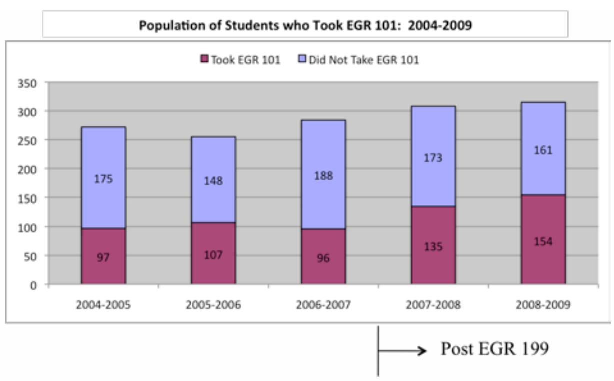


Figure 7. Impact of EGR 199 on Student Enrollment in EGR 101

As shown in Figure 7, the introduction of EGR 199 increased first-year student enrollment in EGR 101 by roughly 50%, which amounts to some 50 more students per year enrolled in the course.

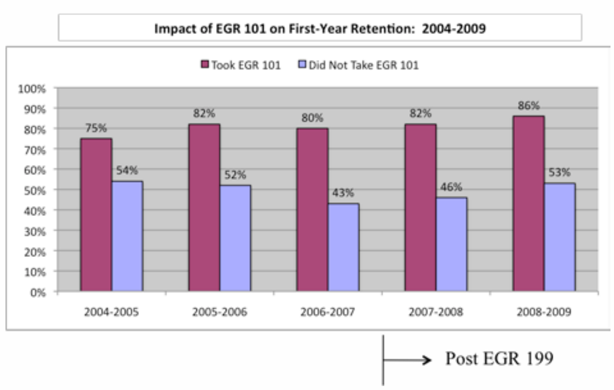


Figure 8. Impact of EGR 101 on First-Year Retention Post EGR 199

While flooding EGR 101 with initially underprepared students might be expected to decrease first-year retention, this has not been the case. As shown in Figure 8, first-year retention for students who took EGR 101 reached an all-time high of 86% in 2008-2009. For an incoming class of roughly 300 students, it is estimated that the combination of EGR 101 and EGR 199 has resulted in at least 30 additional sophomores per year in the Wright State engineering programs.

In addition to first-year retention, the introduction of EGR 101 had a significant impact on college-wide 4-year graduation rates for the initial cohorts, which were more than 4 percentage points higher than those of prior years. This despite the fact that only about 1/3 of the college enrollment ever took EGR 101. For the incoming class of 2004, the impact of EGR 101 on 6-year graduation rates is overwhelming (Fig. 9). Of the students who took EGR 101, 71% completed a bachelor's degree from Wright State University, and 52% completed their degrees in an engineering field. This compared to rates of 40% and 15% for students who did not take EGR 101. Based on tuition revenue associated with increased enrollment and graduation rates, the Wright State model is now fully sustainable.

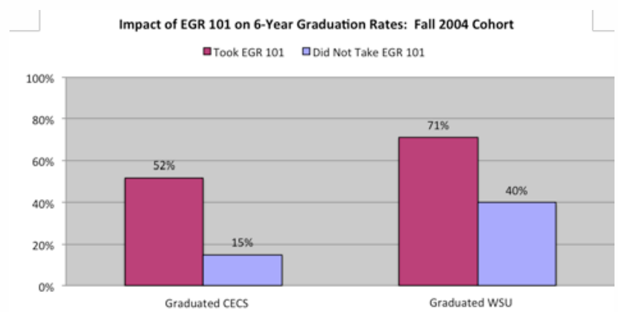


Figure 9. Impact of EGR 101 on 6-Year Graduation Rates

Longitudinal Study of Program Impacts

This section summarizes the results of a recent longitudinal study of program impacts at Wright State University. The population considered includes all incoming direct-from-high-school (DFHS) students entering the College of Engineering and Computer Science (CECS) from Fall 2000-Fall 2006. At the time of this study, the incoming class of Fall 2006 is the latest cohort having at least 6 academic years to graduate. In addition, it is the latest cohort which pre-dates the implementation of EGR 199 and associated expansion of EGR 101 enrollments.

Throughout this longitudinal study, the data are sorted in two categories: Took EGR 101 and Did Not Take EGR 101. The EGR 101 course was instituted in Fall 2004 as a mandatory degree program requirement for the ME, MSE, EE, EP, BME and ISE programs. The course is not required for CS/CEG majors, although it can be counted as an elective (the data includes 19 CS/CEG majors who took the course). The Did Not Take EGR 101 category includes ALL incoming CECS students from Fall 2000-Spring 2003 (i.e, before EGR 101), as well as CECS students entering Fall 2004-Fall 2006 who did not take the course. In comparing the two categories, statistical significance testing was conducted for all results presented herein using the JMP software package.

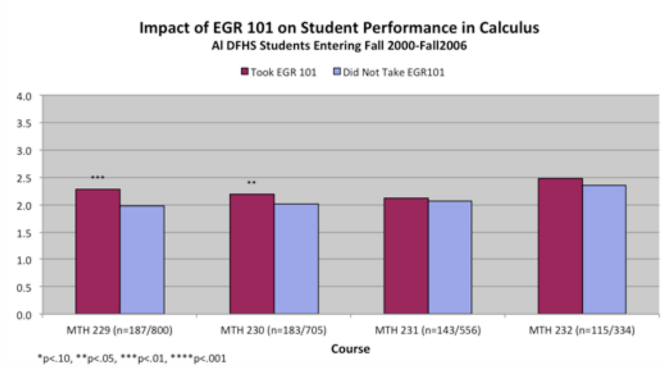


Figure 10. Impact of EGR 101 on Student Performance in Calculus

The impact of EGR 101 on student performance in calculus (MTH 229-232) is shown in Fig 10. As might be expected, students who took EGR 101 had a significant advantage in MTH 229 Calc

I over those who did not. While the advantage was less in Calc II, it was still statistically significant. There was no statistically significant difference in student performance in Calc III or Calc IV.

The impact of EGR 101 on student performance in core first and second-year engineering courses is shown in Figure 11. While there was no statistically significant difference in student performance in either General Physics I (PHY 240) or Statics (ME 212), students who took EGR 101 enjoyed statistically stronger performance in ME 213 Dynamics, ME 313 Strength of Materials and EE 301 Circuits I. This may seem counterintuitive, as the latter three courses occur somewhat later in the curriculum. However, the content of these courses is also somewhat more mathematical, and aligns well with the treatment of derivatives, integrals and differential equations in EGR 101.

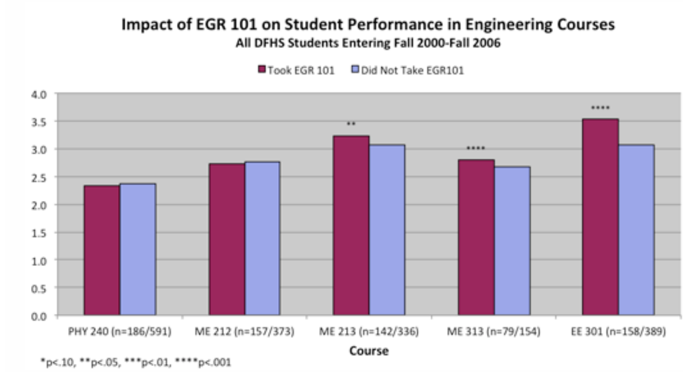


Figure 11. Impact of EGR 101 on Student Performance in Core Engineering Courses

While increased student performance is certainly important, the ultimate goal of this program is to graduate more engineers. Given the increased accessibility of the curriculum, one might also expect to graduate more diverse engineers. As such, the impact of EGR 101 on ultimate graduation rates is shown in Figure 12 for a variety of demographic groups. These include the entire population (All EGR), Majors Requiring EGR 101 (all engineering degree programs except CS/CEG), Underrepresented (Female, Black or Hispanic), High Poverty (classified by school district of origin) and Female. For all groups, students who took EGR 101 had an overwhelming advantage over those who did not. Overall, 56.2% of students who took EGR 101 earned CECS degrees, compared to only 25.7% of those who did not.

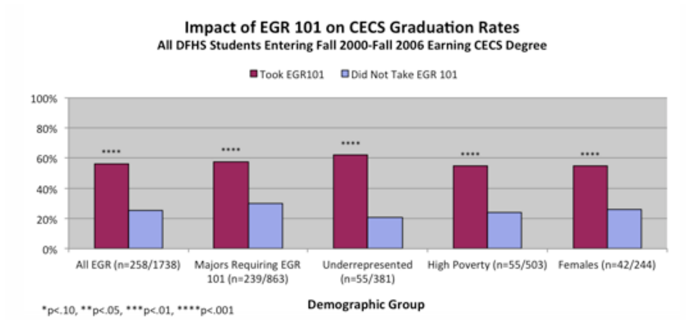
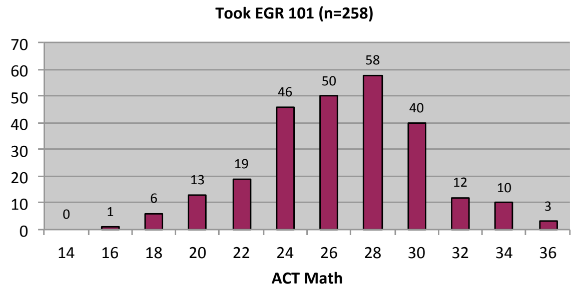


Figure 12. Impact of EGR 101 on CECS Graduation Rates

At this point one might start to wonder whether the two populations (Took EGR 101 and Did Not Take EGR 101) are even comparable. A comparison of the two populations sorted by incoming ACT math score is shown in Fig. 13. As might be expected, the Took EGR 101 population was somewhat more prepared, since it pre-dated the inception of EGR 199. Hence, initially underprepared students who dropped out of engineering before ever taking EGR 101 are necessarily in the Did Not Take EGR 101 category. The mean and standard deviation $(\bar{x}, s_x)$ of the incoming ACT math scores for the two populations were as follows: Took EGR 101 (26.1, 3.67), Did Not Take EGR 101 (23.9, 4.70). On average, neither population was calculus ready (ACT Math 27) upon entering WSU.



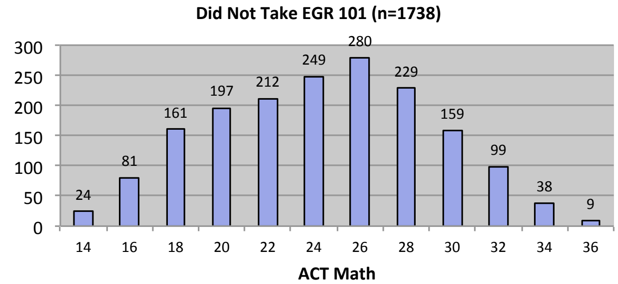


Figure 13. Populations of Students Sorted by ACT Math

Given that the population of students who took EGR 101 was slightly better prepared, it is useful to sort the most compelling data (impact of EGR 101 on CECS graduation rates) by incoming ACT math score. The result is shown in Figure 14, and appears equally compelling. The introduction of EGR 101 and associated prerequisite changes have effectively mitigated the impact of incoming math preparation on student success in engineering over the full range of incoming ACT math scores.

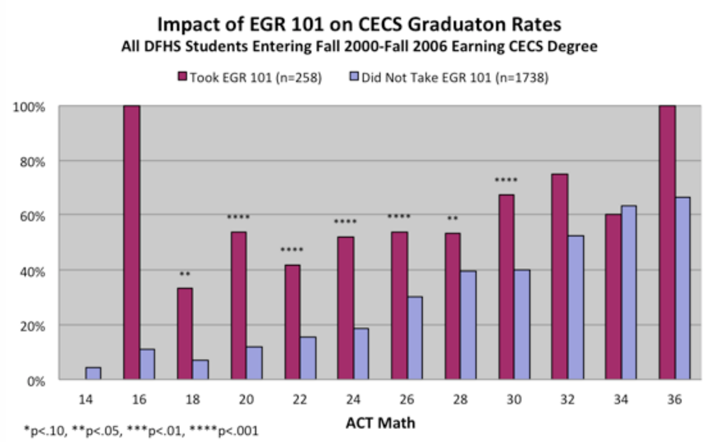


Figure 14. Impact of EGR 101 on CECS Graduation Rates Sorted by Incoming ACT Math Score

Clearly, the Wright State approach has made engineering accessible to an extremely broad range of American high school graduates. That said, a legitimate concern with increasing the accessibility of the curriculum is whether it waters down the caliber of engineering graduates.

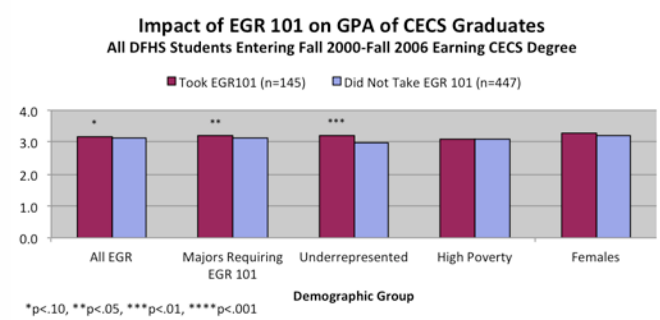


Figure 15. Impact of EGR 101 on GPA of CECS Graduates

As shown in Figure 15, this seems not to be the case. On the contrary, students who took EGR 101 enjoyed a slight (but statistically significant) increase in graduation GPA. The strongest effect was for members of underrepresented groups. For that particular demographic, taking EGR 101 was the difference between graduating with a 2.9 or graduating with a 3.0 – the interview cutoff for many prospective employers.

It should finally be noted that EGR 101 has increased not only student success in engineering, but also student success in college. Of the students who took EGR 101, 69.7% earned a Wright State degree, compared to only 50.6% of those who did not.

The Role of Student Motivation and Self-Efficacy

While EGR 101 was designed to increase student motivation and perceived chance of success (i.e., self-efficacy) in both math and engineering, insight into their relative roles can be gained by a longitudinal analysis of end-of-course student survey data for the 2004-2006 cohorts considered herein (Figure 16). 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 compared to those who did not, students who graduated with degrees in engineering felt more strongly that EGR 101 increased their motivation to study both math and engineering, and that it increased their perceived chance of success (i.e., self-efficacy) in engineering. While both groups felt strongly that the course also increased their perceived chance of success in future math courses, there was not a statistically significant difference between the two groups.

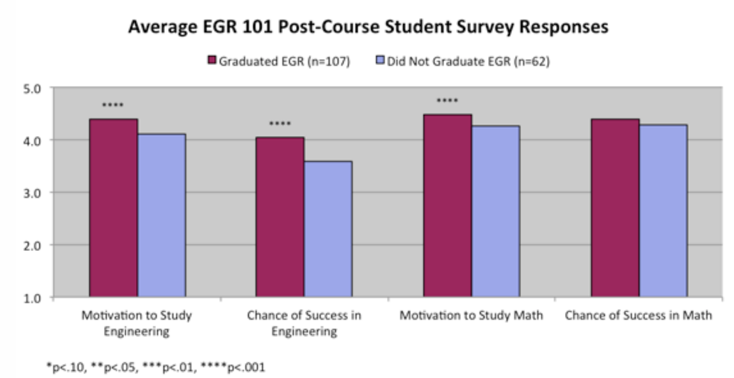


Figure 16. Impact of EGR 101 on Student Motivation and Self-Efficacy

The relationship between the ACT scores of these students and their average answer for question 2 (this course has increased my chances of success in engineering) is also noteworthy. As shown in Figure 17, students with ACT math scores in the range 26-32 who subsequently graduated with a degree in engineering felt more strongly that the course increased their chance of success in engineering than those who ultimately did not graduate.

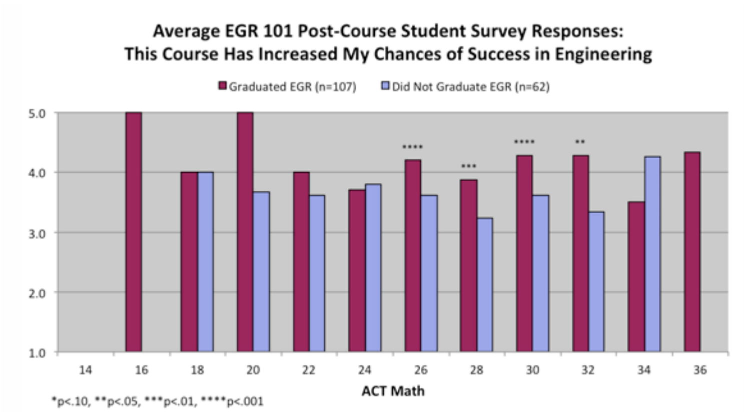


Figure 17. Impact of EGR 101 on Self-Efficacy Sorted by ACT Math

Overall, the above results suggest the impact of EGR 101 on student motivation and self-efficacy in engineering has played a significant role in the success of the Wright State model in graduating more engineers. That said, establishing *causality* between improved self-efficacy and subsequent graduation is a difficult task. To this end, a paired test designed to remove confounding variables from the longitudinal data is currently being conducted, and the analysis of that test will be the subject of future research.

Expansion to Collaborating Institutions

The success of the Wright State model has led to its expansion to collaborating institutions in Ohio and beyond. As part of an NSF CCLI Phase 2 initiative, aspects of the Wright State model were adopted by both the University of Cincinnati and the University of Toledo. The University of Cincinnati has adapted the Wright State approach specifically for civil and environmental engineering, which is not offered at Wright State. 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 Wright State). As part of an NSF STEP Type 1 program, the Wright State 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.

The success of these programs has led to a more widespread expansion of the Wright State model, which has been funded through an NSF CCLI Phase 3 award. 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 goal of this Phase 3 initiative is to effect a transformative and nationwide change in the way engineering mathematics is taught, which would ultimately translate into increased student retention and success in engineering programs across the country. The dissemination component of the project has resulted in the addition of numerous unfunded collaborators, and the approach is now under consideration by at least two dozen institutions across the country. The recent publication of a nationally marketed EGR 101 textbook[26] is intended to encourage an even more widespread adoption of the approach.

Conclusion

This paper has summarized an NSF funded curriculum reform initiative at Wright State University to increase student success in engineering by removing the first-year bottleneck associated with the traditional freshman calculus sequence. The approach involves the introduction of EGR 101, a first-year engineering math course replacing traditional math prerequisites for core sophomore engineering courses, along with a more just-in-time structuring of the required calculus sequence. Since its inception in Fall of 2004, the program has had an overwhelming impact on engineering student retention, motivation and success at Wright State University. The approach is designed to be readily adopted by any institution employing a traditional engineering curriculum, and is under consideration by at least two dozen institutions across the country. Should it be sufficiently scaled, results of the longitudinal study presented herein suggest that the Wright State approach has the potential to *double* the number of our nation's engineering graduates, while both maintaining their quality and increasing their diversity.

Program Information

More information on the Wright State model (including all course materials for EGR 101) can be found at www.cecs.wright.edu/engmath/. Textbook information is available at www.wiley.com/college/rattan.

Acknowledgment

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