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The Wright State Model for Engineering Mathematics Education: Longitudinal Impact on Initially Underprepared Students

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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 summarizes 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. The 2007 introduction of EGR 199 as a precursor to EGR 101 for initially underprepared students (those placing 2-3 math classes below Calc I) has further strengthened the approach, and has made the core engineering curriculum accessible to incoming students across the entire range of ACT math scores. Prior work by the authors has included a longitudinal study of program impacts on the first three incoming classes of Fall 2004-2006, prior to the introduction of EGR 199. The current paper extends that analysis to the incoming classes of Fall 2007-2009, which included a significant increase in the number of initially unprepared students enrolled in EGR 101. The result could have substantial implications on both the recruitment and retention of engineering students at institutions across the country.

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.

Figure 1. The Derivative Lab

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.*

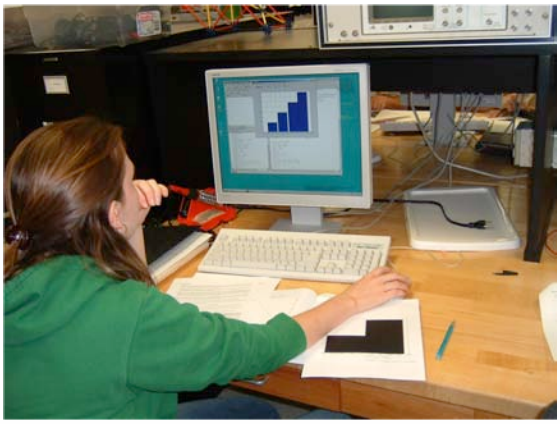

Figure 2. The Integral Lab

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 EGR 101 course was first implemented in Fall of 2004, and its effect on student retention, motivation and success in engineering has since been widely reported[13-29]. In particular, results of a longitudinal study have shown 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.[15,16] 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, including both women and minorities.

Introduction of EGR 199: An Intervention for Initially Underprepared Students

While the introduction of EGR 101 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 199 Preparatory Mathematics for Engineering and Computer Science, the inaugural offering of which enrolled over one hundred MPL 3 and 4 students in Fall 2007. These students are two or three classes behind Calc I (which requires an MPL 7) and are not immediately eligible for EGR 101. Assessment had 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 were retained in engineering and computer science through their first two years.

The EGR 199 content consisted 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. As such, the EGR 199 course served the following two purposes:

1) For majors requiring EGR 101, EGR 199 served as an alternative prerequisite requirement, which allowed 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 provided a comprehensive review of high school math topics, and culminated in a retest of the math placement exam at the end of the quarter. This provided an opportunity for initially underprepared students to avoid as many as 3 remedial math department courses before advancing in their chosen degree programs.

As discussed in a previous paper[20], 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. 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. Finally, the introduction of EGR 199 increased first-year student enrollment in EGR 101 by roughly 50%. Given this success, the course continued to run with little modification until Wright State's semester conversion in 2012, at which point it was converted to a semester course number.

Longitudinal Impact

The current paper seeks to investigate the extent to which the introduction of EGR 199 and associated increases in EGR 101 enrollments has affected the longitudinal analysis previously described[15,16], which was restricted to the incoming classes of Fall 2004-2006. That analysis is repeated here to include the incoming classes of Fall 2007-2009.

The populations of students entering Fall 2007-2009 who took EGR 199 and EGR 101 are shown in Figure 3. As shown in Figure 3a, a total of 227 students were enrolled in EGR 199, of which 116 subsequently enrolled in EGR 101 (Figure 3b). The students who took EGR 199 and did not subsequently enroll in EGR 101 included predominantly CS/CEG majors, for whom EGR 101 is not a required course. The population also included students who were not successful in EGR 199, or simply chose not to move forward in engineering by enrolling in EGR 101. Of the students who enrolled in EGR 101 (Figure 3b), the population previously enrolled in EGR 199 was predominantly composed of students with low ACT math scores. Likewise, the population not previously enrolled in EGR 199 was predominantly composed of students with higher ACT math scores. That said, the latter also included a measurable number of students with ACT math scores of 24 and below. Still, the net effect of EGR 199 was to substantially increase the number of initially underprepared students (and hence the total number of students) enrolled in EGR 101, which was a primary objective of the intervention.

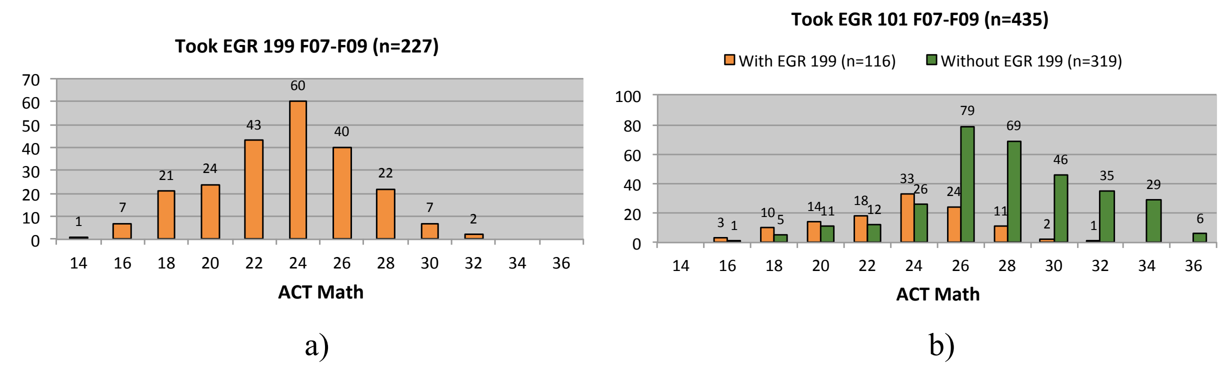

Figure 3. Populations of Students Entering Fall 2007-Fall 2009 who a) Took EGR 199 and b) Took EGR 101

The populations of students enrolled in EGR 101 before and after the introduction of EGR 199 is shown in Figure 4a, while the cumulative population of students who did not take EGR 101 is shown if Figure 4b.

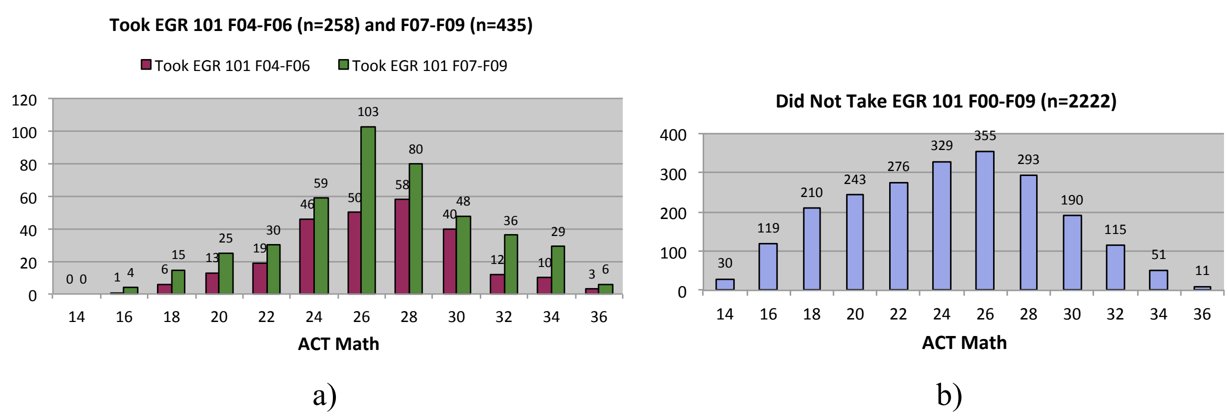

Figure 4. Populations of Students Entering Fall 2000-2009 who a) Took EGR 101 and b) Did Not Take EGR 101

In Figure 4a, the population of students who took EGR 101 from Fall 2004-2006 (i.e., prior to the introduction of EGR 199) is the same as that from the longitudinal study previously described[15,16], while the population who took EGR 101 from Fall 2007-2009 includes all 435 students from Figure 3b (i.e., both with and without EGR 199). In Figure 4b, the population of students who did not take EGR 101 includes all students from the incoming classes of Fall 2000-2003 (i.e., prior to the introduction of EGR 101), as well as all students who did not take EGR 101 from Fall 2004-2009. The latter population includes a significant number of CS/CEG majors, for whom EGR 101 is not a required course, as well as students who dropped out of engineering before ever taking EGR 101.

The cumulative impact of EGR 101 on ultimate graduation rates in engineering is shown by demographic group in Figure 5.

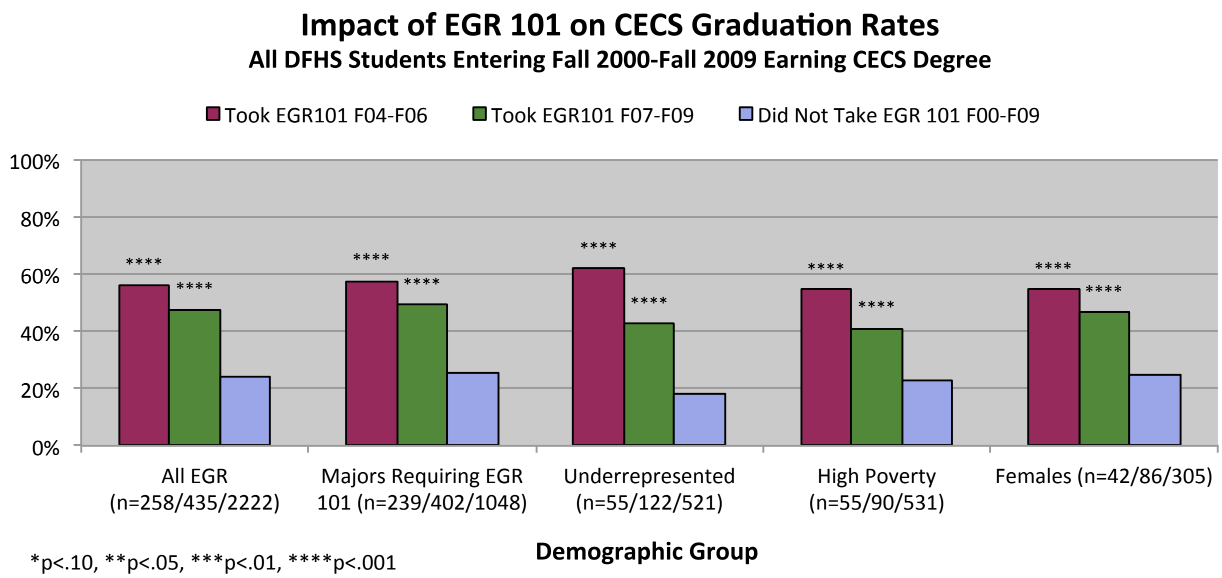

Figure 5. Cumulative Impact of EGR 101 on CECS Graduation Rates

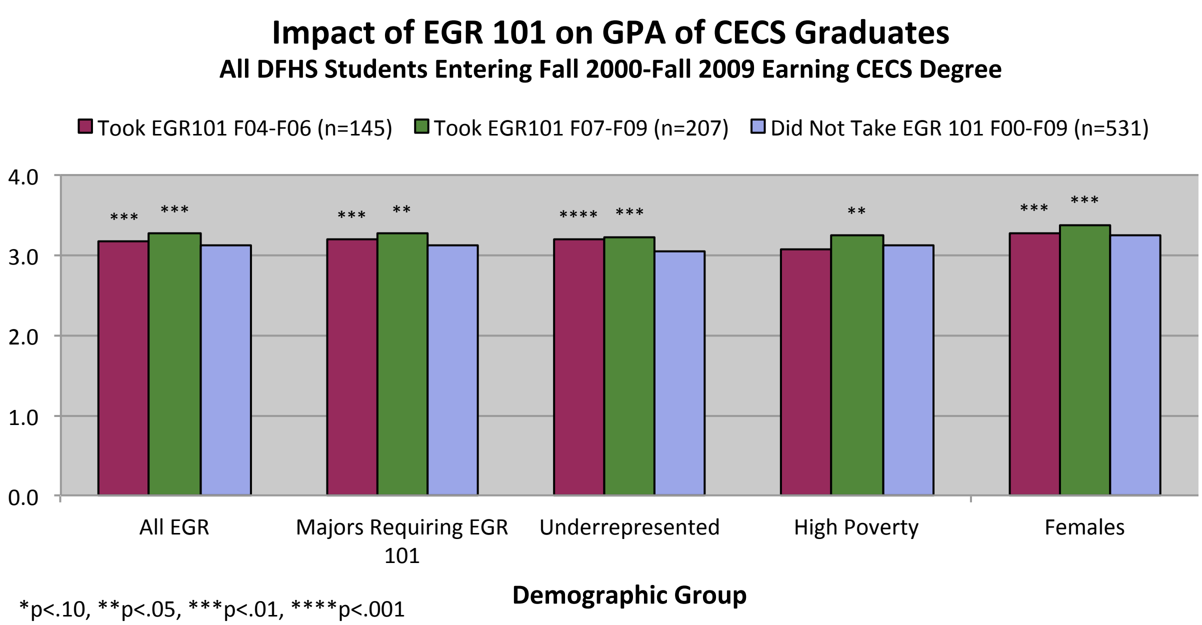

Figure 6. Cumulative Impact of EGR 101 on Graduation GPA

Of students who took EGR 101, there was a measurable decrease in the average graduation rate of students from the incoming cohorts of Fall 2007-2009, as compared to those of Fall 2004-2006, although this decrease was somewhat less pronounced for majors requiring EGR 101 (i.e., no CS/CEG). This might be expected based on the increased numbers of initially underprepared students enrolled in the course. That said, the decrease in graduation rate pales in comparison to the increase in total number of students enrolled in EGR 101, and hence the actual number of degrees awarded. Based on the graduation rates and populations indicated in the figure, the total number of degrees awarded from students enrolled in EGR 101 increased from 145 for the incoming cohorts of Fall 2004-2006 to 207 for those of Fall 2007-2009, or an additional 62 degrees awarded. Even after the introduction of EGR 199, the greatest impact of EGR 101 remained on members of underrepresented groups.

A primary concern about opening pathways for underprepared students is whether or not it might water down the caliber of engineering graduates. As shown in Figure 6, this appears not to be the case. In fact, students who took EGR 101 from the incoming cohorts of Fall 2007-2009 had the highest graduation GPA across all demographic groups, despite the increased number of initially underprepared students successfully earning their degrees. This can be attributed (at least in part) to the ability of initially underprepared students who took EGR 199 to progress in their intended degree programs without first completing an entire sequence of remedial math courses, which all too often damage the GPA's of incoming engineering students who are already at very high risk.

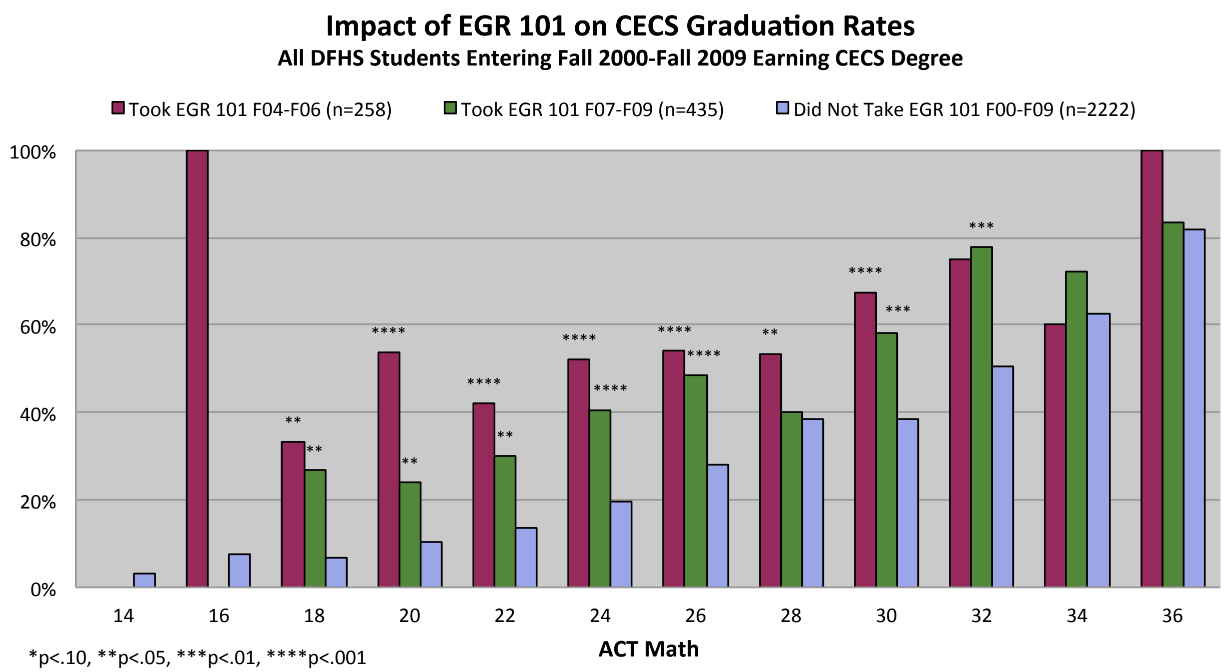

Figure 7. Cumulative Impact of EGR 101 on Graduation Rates in Engineering Sorted by ACT Math

One of the primary conclusions from the prior longitudinal study was that EGR 101 appears to have mitigated the impact of incoming ACT math score on student success in engineering[15,16]. As such, the extent to which that observation still holds for the incoming cohorts of Fall 2007-2009 is of interest. The cumulative impact of EGR 101 on graduation rates in engineering sorted by incoming ACT math score is shown in Figure 7 for the same total population considered in

Figure 5. Despite the significant increase in total degrees awarded, it is clear that the increased enrollment in EGR 101 associated with the F07-F09 cohorts has limited the extent to which ACT is mitigated.

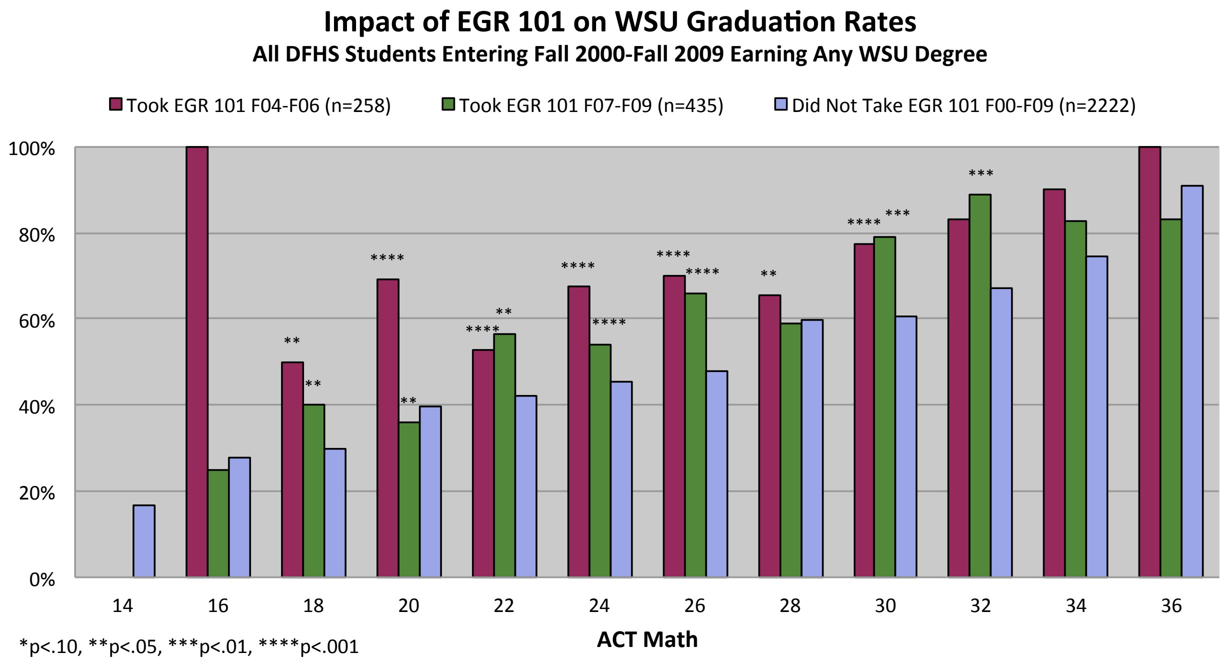

Figure 8. Cumulative Impact of EGR 101 on Graduation Rates (Any WSU Degree) Sorted by ACT Math

This result can best be explained in the context of the Academic Performance Commitment Matrix (APCM) described in a prior publication by the authors[13]. In short, ACT score alone is insufficient to describe the likelihood of a student's persistence in engineering. A two-dimensional analysis including a student's cumulative high school GPA was shown to be a much better predictor of student success in the Wright State engineering programs. Moreover, it was shown that EGR 101 had the greatest effect on the group termed 'Support Seekers', composed of students with below median ACT math scores but above median high school GPA's. The latter indicates greater work ethic and ability to persevere in engineering, while the former may arguably indicate below median 'ability'. Thus, the mitigation of ACT math score associated with the F04-F06 cohorts was due to the fact that the low ACT math students who enrolled in EGR 101 were predominantly 'support seekers', who had the work ethic and perseverance required to progress through the remedial math sequence before enrolling in EGR 101. On the contrary, low ACT math students from the incoming cohorts of Fall 2007-2009 were given a direct path to EGR 101 via EGR 199. As such, significant numbers of students with below median high school GPA's were enrolled in EGR 101, even at the higher ACT levels. This also explains the somewhat anomalous result in the ACT 28 bin, where students who took EGR 101 graduated at roughly the same rates as those who did not.

It should finally be noted that EGR 101 has continued to have a significant impact on graduation rates even for students who switched out of engineering after taking the course. The cumulative impact of EGR 101 on graduation rates for students earning any WSU degree is shown in Figure

8. For nearly all ACT bins, students who took EGR 101 earned WSU degrees at significantly higher rates than those who did not. While the effect of ACT math score was again somewhat less mitigated for the F07-F09 cohorts, students who took EGR 101 still earned WSU degrees at an overall rate of 64.1%, as compared to only 47.1% for those who did not. While this is a reduction from the 69.8% graduation rate for the F04-F06 cohorts, it again pales in comparison to the increase in number of students enrolled in EGR 101, and hence the total number of degrees awarded. Based on the populations and associated graduation rates, the ultimate number of WSU graduates from students who took EGR 101 increased from 180 for F04-F06 to 279 for F07-F09, for a whopping 99 additional WSU degrees awarded. For institutions considering a similar approach, it should be noted that the associated tuition revenues outweigh the instructional costs by more than an order of magnitude.

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. The current study has extended a prior longitudinal analysis of program impacts to include the effect of EGR 199 as a precursor for initially underprepared students, which significantly increased the number of initially underprepared students taking EGR 101. Despite the expected decrease in overall graduation rates for students enrolled in the course, the net impact of driving up the population of students taking EGR 101 was a significant increase in the number of engineering degrees awarded, without any negative impact on graduation GPA. Overall, the greatest impact of the program remains on students near the median of incoming ACT math scores (i.e., the fat part of the population), as well as on students from underrepresented groups.

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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