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Examining the Impacts of the Wright State Model for Engineering Mathematics Education through Curricular Analytics

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Abstract

This complete evidence-based practice paper employs curricular analytics to help better understand the impacts of the Wright State Model for engineering mathematics education on student success in engineering. While previous studies have linked the impacts of the Wright State Model to increased student motivation and self-efficacy, none has attempted to fully quantify the impact of the associated restructuring of the curriculum. As a result, the current paper describes a detailed analysis of the Wright State Model using the Curricular Analytics platform (https://curricularanalytics.org/), which provides new and significant insight into the relative roles of curricular complexity and centrality on the success of the Wright State Model. In particular, results suggest that while the Wright State Model has had only a negligible impact on the overall complexity of the engineering curriculum, it has measurably reduced the complexity and dramatically reduced the centrality of the required calculus sequence. Moreover, the relative reduction in centrality of calculus is greater for students who are further behind in math, which helps explain the substantial impact of the Wright State approach on initially underprepared students.

Introduction

The inability of incoming students to advance past the traditional first-year calculus sequence is a primary cause of attrition in engineering programs nationwide. Similar curricular bottlenecks exist in other STEM disciplines, and in many ways, across all of higher education. This is of particular concern for members of underrepresented groups, as well as those who are initially underprepared for success in engineering. As a result, this study seeks to better understand the longitudinal impacts of an NSF funded curricular reform at Wright State University to redefine the way engineering mathematics is taught, with the goal of increasing student retention, motivation and success in engineering.

First implemented in 2004, the Wright State Model involves the introduction of a first-year engineering mathematics course, EGR 101 Introductory Mathematics for Engineering Applications (now running under semester course number EGR 1010) [1]. Taught by engineering faculty, the EGR 101 course includes lecture, laboratory and recitation components. Using an application-based, hands-on approach, the EGR 101 course addresses only the salient math topics actually used in the core first and second-year engineering courses. These include the traditional physics, engineering mechanics, electric circuits and computer programming sequences. All math topics are presented in the context of their engineering application, exactly as they are used in the above core courses. Perhaps more 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 first completing the required calculus sequence.* The result has shifted the traditional emphasis on math prerequisite requirements to an emphasis on engineering motivation for math, effectively uncorking the calculus bottleneck to the core engineering curriculum.

According to a prior longitudinal study [2], the Wright State Model has substantially mitigated the impact of incoming math preparation on student success in engineering over the full range of ACT math scores (Figure 1). As a result, the introduction of EGR 101 has more than doubled the overall graduation rate of students enrolled in the course, with the greatest impact on those from underrepresented groups in engineering (women and minorities). Moreover, it has done so without watering down the caliber of engineering graduates, who actually enjoyed a slight (but statistically significant) increase in graduation GPA. The subsequent introduction of EGR 199 Preparatory Mathematics for Engineering and Computer Science as a precursor to EGR 101 for initially underprepared students (now running under semester course number EGR 1980) has further strengthened the approach, making the core engineering curriculum accessible to students entering up to 3 classes behind in math [3].

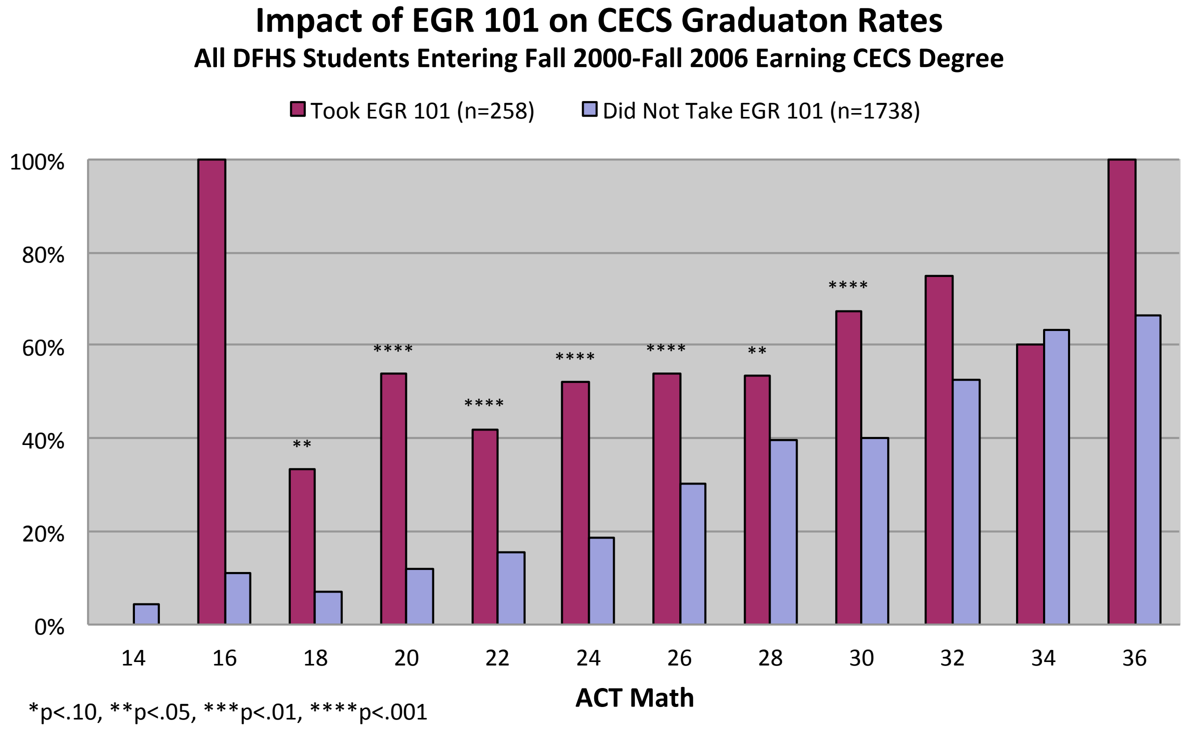


Figure 1: Impact of EGR 101 on College of Engineering and Computer Science (CECS) Graduation Rates Sorted by Incoming ACT Math Score [2]

Previous studies have linked the success of the Wright State Model to increased student motivation and self-efficacy resulting from the EGR 101 course itself [4,5]. In particular, longitudinal results of student perception surveys administered at the end of the course revealed that students who ultimately graduated had reported stronger increases in their motivation and chance of success in engineering, as compared to those who did not ultimately graduate [4]. These results were later shown to be consistent with direct measurement of changes in mathematics self-efficacy as a result of the course, which were highest for ‘support seekers’ – students with below average ACT math but above average high school GPA [5]. This particular group of students also exhibited the strongest increase in ultimate graduation rates as a result of the EGR 101 course, which certainly contributed to the results of Figure 1.

While increased student motivation and self-efficacy have clearly played a role in the success of the Wright State Model, the extent to which the associated restructuring of the curriculum has also contributed has yet to be fully explored. To this end, the current study employs the Curricular Analytics platform (https://curricularanalytics.org/) [6] to quantify the impact of the Wright State Model on the complexity and centrality of the core engineering curriculum, as well as the required math sequence.

Curricular Analytics

The Curricular Analytics platform stems from the foundational work of Heileman et al. at the University of New Mexico, which sought to quantify the role that curricular structure plays on the ability of students to make progress toward their intended degrees [6-10]. To this end, a variety of metrics were developed to quantify curricular structure [6]. These include blocking factor, delay factor, complexity and centrality. These metrics can be determined for a particular course or group of courses, as well as for a particular term or for an entire degree program.

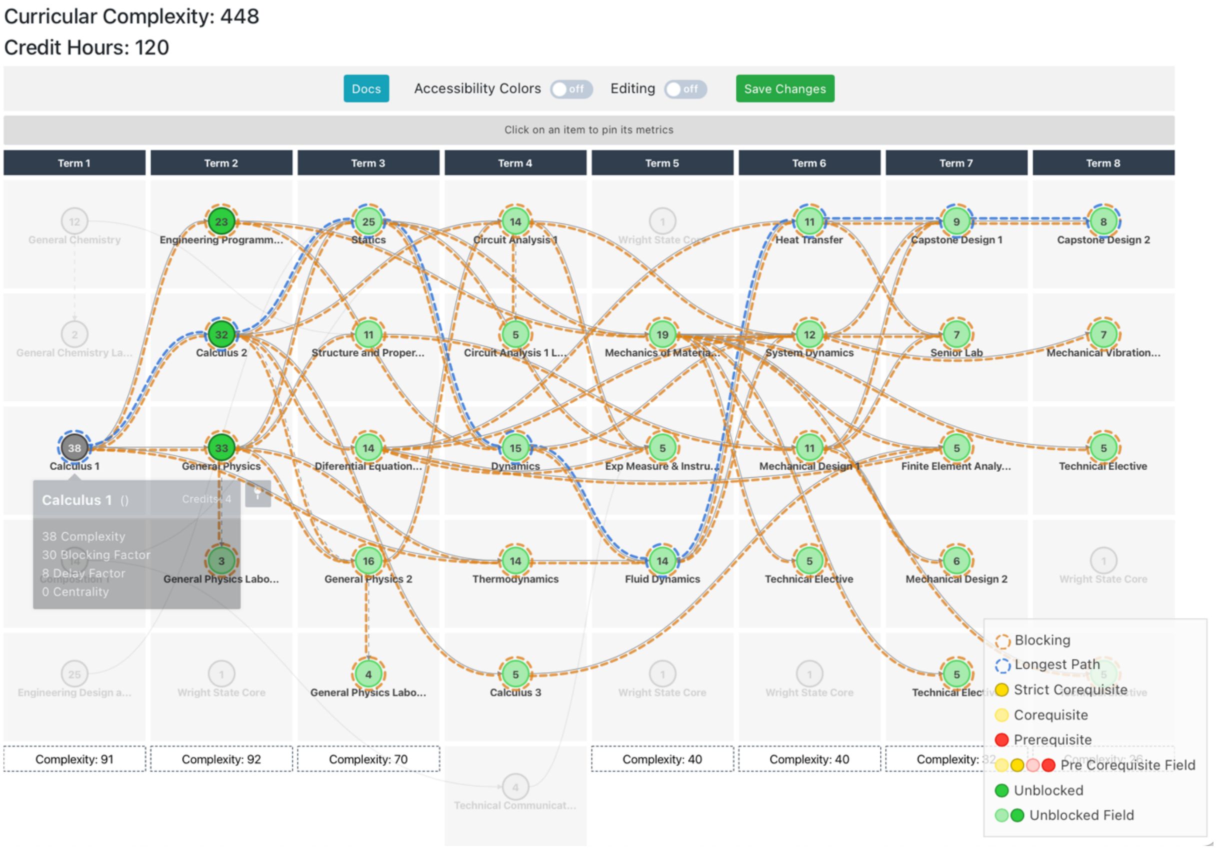
The *blocking factor* for a particular course is defined as the number of subsequent courses in the curriculum that require completion of that course. As such, it directly measures the extent to which a course blocks student progression in the degree program. For degree programs containing sequences of required courses, the *delay factor* is defined as the longest path (in terms of number of courses) for any sequence of courses that contains the current course. Thus, a course with a high delay factor represents a high stakes course for students, since failure to complete the course will delay progress toward degree. The *complexity* of a particular course is simply the sum of the delay and blocking factors for that course. Heileman et al. [9] have shown that increased complexity of a degree program can be correlated to decreased graduation rates. As such, the complexity of a curriculum represents a primary measure of "overall difficulty," at least in regard to student progression toward degree. Finally, the *centrality* of a particular course is defined as the sum of the number of courses in all possible pathways that must pass through that course. Thus, a course has high centrality if multiple courses must be completed prior to that course *and* if multiple subsequent courses also require prior completion of that course. By definition, if a course is the first or last course in a curricular pathway, then its centrality is zero.

Prior work by Heilman et al. [7] employed curricular analytics to investigate potential changes in pathways through engineering degree programs. In particular, this work was the first to quantify the impact of EGR 101 on the complexity of the pathways through a first course in Electric Circuits, which is required for most engineering degree programs and is the primary gateway to an Electrical Engineering degree. Moreover, the traditional pathway requires multiple required math courses before a student can enroll in Electric Circuits, which is then required for multiple subsequent engineering courses. As expected, the introduction of EGR 101 resulted in a substantial reduction in the complexity of the curricular pathways through Electric Circuits, as compared to the traditional calculus-based pathway.

The current study employs Curricular Analytics to provide a comprehensive comparison of the traditional calculus-based pathway and that associated with EGR 101, as a function of a student's starting point in math. While the prior longitudinal studies on the impact of EGR 101 were based on the quarter system in place prior to 2012, the current analysis is restricted to the current semester-based Mechanical Engineering degree program at Wright State University, which is more relevant to the semester-based degree programs at most other universities. As such, the semester course numbers EGR 1010 and EGR 1980 are used throughout the remainder of this paper.

Analysis

In order to provide a comparison between the EGR 1010-based pathway and the traditional calculus-based pathway in the Mechanical Engineering degree program, the first step is to reproduce the curricula within the Curricular Analytics platform (https://curricularanalytics.org/). The platform includes a graphical user interface (GUI) for generation of each course, including prerequisites, corequisites and credit hours. Alternatively, the entire curriculum can be uploaded to the website in .csv format, which is the method that was used in this study. Once uploaded, the curricula can be visualized to investigate pathways through various courses, as well as to evaluate the curricular complexity and centrality for each course, for a series of courses or for the entire curriculum. Moreover, the curricula can be organized into semester-by-semester degree plans, consistent with typical advising policy. The degree plans are particularly useful for visualizing delays in graduating that may be affected by incoming student math preparation.



Curricular Complexity: 448

Credit Hours: 120

Calculus 1 () Credits: 4

38 Complexity

30 Blocking Factor

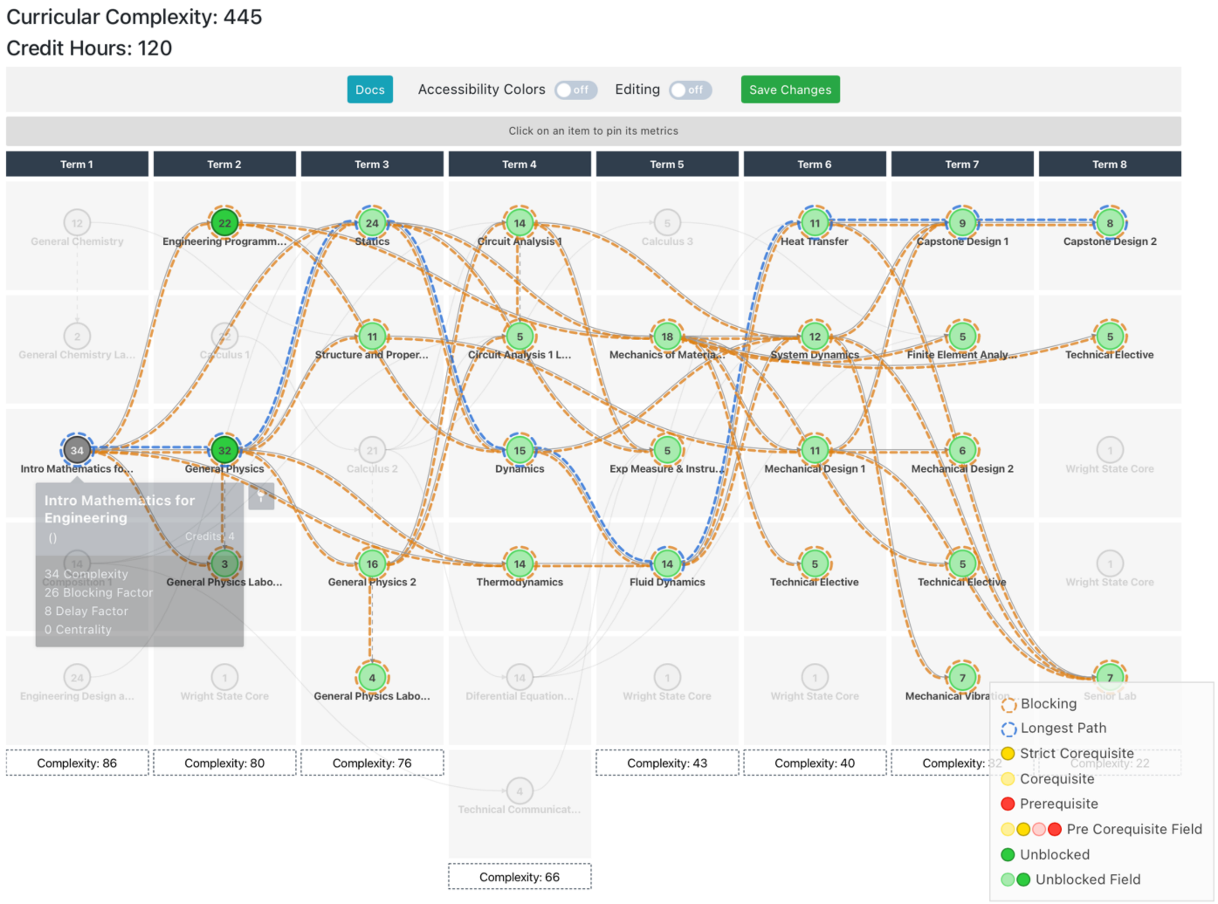
8 Delay Factor

0 Centrality

Figure 2: The traditional Mechanical Engineering degree plan (calculus-based)

A visualization of the 8-semester degree plan for a traditional calculus-based Mechanical Engineering curriculum is shown in Figure 2. Note that first-term Calculus 1 is the gateway to the core engineering curriculum, which begins in the second term with General Physics (calculus-based) and Engineering Programming and continues into the 3rd and 4th terms with Statics, Dynamics, Mechanics of Materials, Electric Circuits and Thermodynamics. Note that a number of these courses also require Calculus 2, with advancement to the 5th term requiring differential equations as well. Thus, the traditional required math sequence represents a significant bottleneck to the core engineering curriculum.

By contrast, a visualization of the degree plan for the EGR 1010-based curriculum is shown in Figure 3. Although the entire traditional calculus sequence is still required, the gateway to the core engineering curriculum is now EGR 1010, with Calculus 1 delayed until the 2nd term. Thus, students can advance through their sophomore-level engineering courses whether or not they have completed the required calculus sequence. This represents a substantial increase in flexibility for students, particularly if they find themselves struggling in calculus. Interestingly, the total curricular complexity is nearly unchanged at 445, compared to 448 in the traditional curriculum. Clearly, total curricular complexity would not seem to explain the dramatic increases in degree attainment shown in Figure 1.

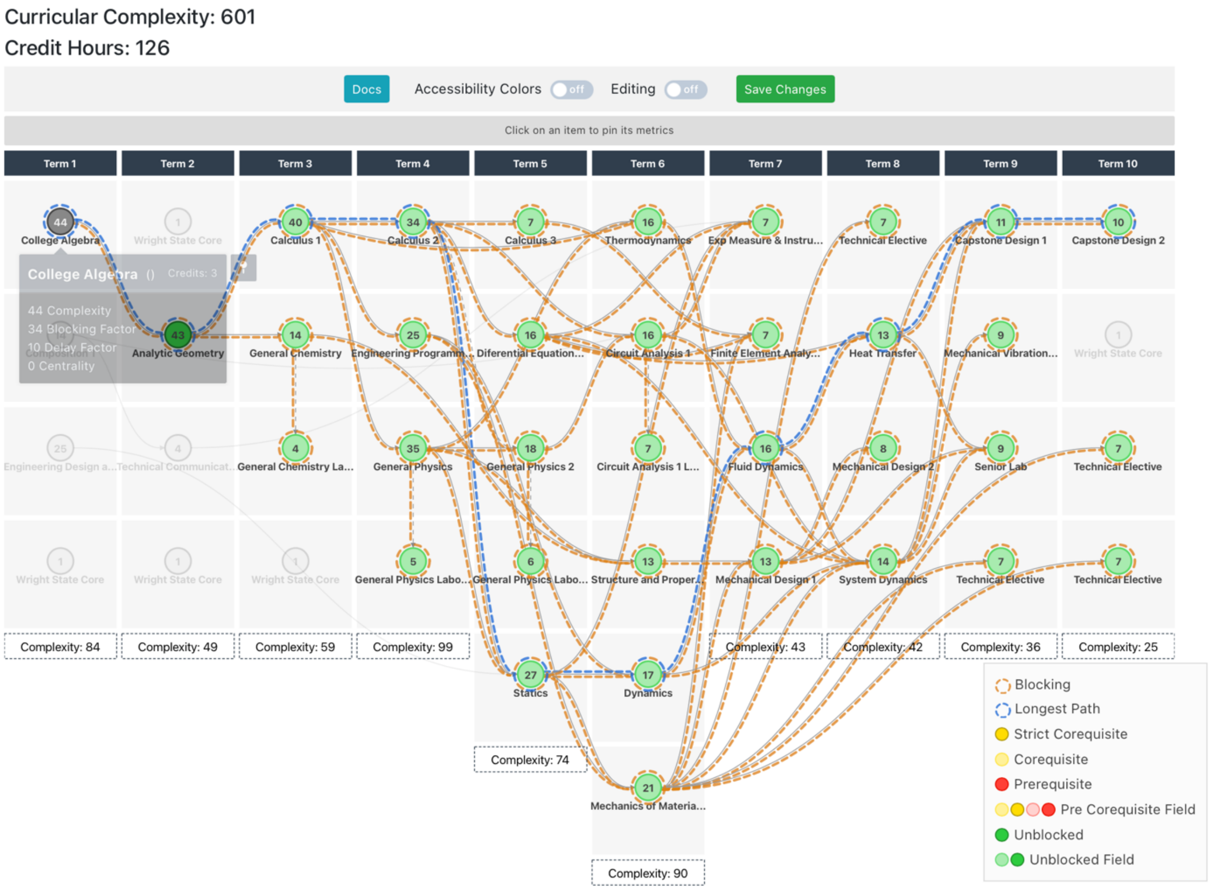

Curricular Complexity: 445
Credit Hours: 120

Intro Mathematics for Engineering
()
Credits: 4
34 Complexity
26 Blocking Factor
8 Delay Factor
0 Centrality

Figure 3: The Mechanical Engineering degree plan with EGR 1010

It is important to note that the 8-semester degree plans shown in Figs. 2 and 3 are applicable only for incoming students who are calculus-ready, which corresponds to an ACT math score of 27 or higher. However, the primary difficulty with successfully graduating engineering students at a regional comprehensive university like Wright State is that the average incoming student is not calculus-ready, with an incoming ACT math score around 24. This corresponds to math placement at the College Algebra level, a full 2 semesters behind Calculus 1.

A visualization of the degree plan for a student beginning at College Algebra in the traditional calculus-based Mechanical Engineering degree program is shown in Figure 4. An immediate consequence of this new math starting point is that the degree plan is now 10 terms long instead of 8. Moreover, a 3-course math sequence (College Algebra, Analytic Geometry and Calculus 1) becomes the new gateway into the core engineering curriculum, even though only Calculus 1 counts within the 120 hours of the required degree program. To make matters worse, the prior two math courses have notoriously poor success rates at most state universities. It is no wonder that an ACT math 24 (i.e., average) incoming student advancing in the traditional curriculum had only a 20% chance of earning an engineering degree (see Figure 1). Finally, it should be noted that starting two courses behind in math increases the overall complexity of the Mechanical Engineering degree program by 34% (from 448 to 601). For students starting three courses behind (developmental math), the degree plan increases in length to 11 terms, while the curricular complexity increases by 52% (from 448 to 682).



Curricular Complexity: 601

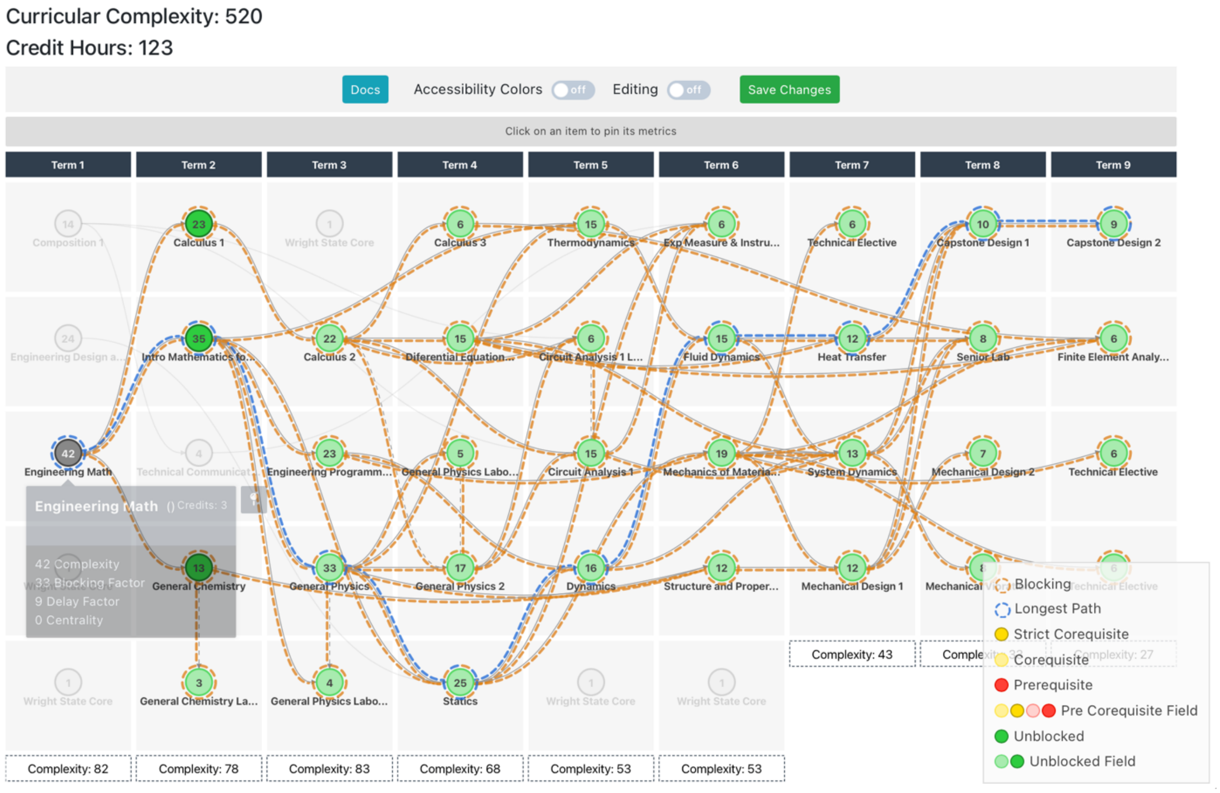
Credit Hours: 126

Figure 4: The traditional calculus-based Mechanical Engineering degree plan for incoming students starting in College Algebra

The current study has considered Mechanical Engineering curricula and degree plans corresponding to every level of incoming student math preparation, from developmental math to calculus-ready. As an additional piece to the analysis, EGR 1980 was also included as a precursor to EGR 1010 for initially underprepared students. The current EGR 1980 course at Wright State University is an ALEKS-based intervention (https://www.aleks.com) taught by engineering faculty that provides an *opportunity* for underprepared students (those entering at

College Algebra or below) to increase their math placement by as many as three levels [11]. Thus, EGR 1980 represents a one-semester path to both EGR 1010 and Calculus 1. It should be noted that incoming students placing in Analytic Geometry (only one course behind in math) already have a one-semester path to Calculus 1 and are enrolled in EGR 1010 immediately in their first term.

In order to demonstrate the advantages of a one-term path to both EGR 1010 and Calculus 1 for initially underprepared students, a visualization of the Mechanical Engineering degree plan is shown in Figure 5 for students beginning in EGR 1980 and successfully placing into both EGR 1010 and Calculus 1 by the end of their first term. As compared to students starting in College Algebra or Developmental Math, the degree plan is now only 9 semesters, as opposed to 10 or 11. Moreover, the curricular complexity is only 520, as opposed to 601 or 682, respectively. With the inclusion of EGR 1010, the EGR 1980 pathway for students entering 2-3 courses behind in math represents only a 16% increase in curricular complexity, as compared to that for calculus-ready students advancing in the traditional curriculum.



Curricular Complexity: 520

Credit Hours: 123

Click on an item to pin its metrics

Engineering Math () Credits: 3

42 Complexity

33 Blocking Factor

9 Delay Factor

0 Centrality

Figure 5: The Mechanical Engineering degree plan for underprepared students starting in EGR 1980 and subsequently placing into both EGR 1010 and Calculus 1

As previously noted, EGR 1010 provides only a slight decrease in overall curricular complexity for calculus-ready students. However, the effect is substantially amplified for students who are underprepared in math, particularly with the inclusion of EGR 1980. In order to fully understand this effect, the term-by-term complexity of the Mechanical Degree program was extracted as a function of incoming math preparation (i.e., starting point), for both the traditional calculus-based curriculum and that based on EGR 1010. The results of this analysis are shown in Table 1. The results clearly indicate that starting behind in math increases both time to degree and curricular complexity, which is consistent with traditionally low graduation rates for initially underprepared students. The extent to which EGR 1010 mitigates this effect is measurable and increases with the number of math classes behind; however, the impact of EGR 1010 on curricular complexity is still less than one might expect based on the results of Figure 1.

Table 1: Complexity of the Mechanical Engineering Program by Math Starting Point

Complexity of the Mechanical Engineering Degree Program by Math Starting Point															
Program	Variation	Starting Point	Complexity by Term												Total
			1	2	3	4	5	6	7	8	9	10	11	
ME	**EGR 1010**	Calculus-Ready	86	80	76	66	43	40	32	22				**445**
ME		Analytic Geometry and Trig.	102	96	83	71	40	40	28	25				485
ME		EGR 1980 to Calculus-Ready	82	78	83	68	53	53	43	33	27			520
ME		College Algebra	83	37	77	83	72	73	46	43	25	23		562
ME		DEV (Full Supplemental Path)	60	50	57	81	87	77	80	52	47	28	26	**645**
ME	**Calc-based**	Calculus-Ready	91	92	70	57	40	40	32	26				**448**
ME		Analytic Geometry and Trig.	83	60	96	81	72	45	44	27	15			523
ME		EGR 1980 to Calculus-Ready	83	60	95	69	72	39	49	37	19			523
ME		College Algebra	84	49	59	99	74	90	43	42	36	25		601
ME		DEV (Full Supplemental Path)	86	51	46	61	103	93	82	63	54	32	11	**682**

In order to better understand this result, an in-depth analysis was conducted of only the portion of the curriculum most affected by the introduction of EGR 1010. This includes both the required math sequence (Calc 1-3 and Differential Equations, termed "Calculus Portion") as well as the core engineering courses (General Physics, Computer Programming, Statics, Dynamics, Mechanics of Materials and Thermodynamics). In addition to the impacts of EGR 1010 on curricular complexity, its effects on the *centrality* of both the required math sequence and the core engineering courses was also considered. A summary of the results as a function of initial math starting point is shown in Table 2, where "Total" refers to the sum for all courses considered (core engineering courses plus calculus portion).

Table 2: Complexity and Centrality of Core Courses

	Math Starting Point	**Core Complexity**		**Core Centrality**	
		Total	Calculus Portion	Total	Calculus Portion
Calculus-Based	DEV (Full Supplemental Path)	400	236	4776	2994
	College Algebra	341	184	3479	1873
	Analytic Geometry and Trig.	285	135	2386	956
	EGR 1980 – College Algebra	400	236	4776	2994
	EGR 1980 – Analytic Geometry	341	184	3479	1873
	EGR 1980 – Calculus	285	135	2386	956
	Calculus-Ready	232	89	1512	258
EGR 1010	**Math Starting Point**	**Core Complexity**		**Core Centrality**	
		Total	Calculus Portion	Total	Calculus Portion
	DEV (Full Supplemental Path)	384	194	3405	1305
	College Algebra	325	143	2335	480
	Analytic Geometry and Trig.	282	108	1829	295
	EGR 1980 – College Algebra	384	194	3405	1305
	EGR 1980 – Analytic Geometry	325	143	2335	480
	EGR 1980 – Calculus	289	108	2161	295
	Calculus-Ready	235	62	1322	142

In Table 2, the starting points associated with EGR 1980 include the possible math placement levels at the end of the course. For example, EGR 1980 – College Algebra refers to a student who places into College Algebra by the end of the course, while EGR 1980 – Calculus refers to a student who places into calculus by the end of the course.

Results and Discussion

In this section, the results of Table 2 are visually represented to further examine the impacts of EGR 1010 on the total complexity and centrality of the core first and second-year engineering courses, as well as those associated with the required math sequence (i.e., the calculus portion). All results are presented as a function of math starting point, for both the traditional calculus-based curriculum (green) and the EGR 1010-based curriculum (yellow).

A comparison of total core complexity (including both the math and engineering courses) is shown in Figure 6. As might be expected, the total core complexity increases with decreasing math placement level, reaching a maximum for students beginning with developmental math (DEV). However, as compared to the traditional calculus-based curriculum, the introduction of EGR 1010 has only a minimal impact on the total core complexity, regardless of incoming math placement level.

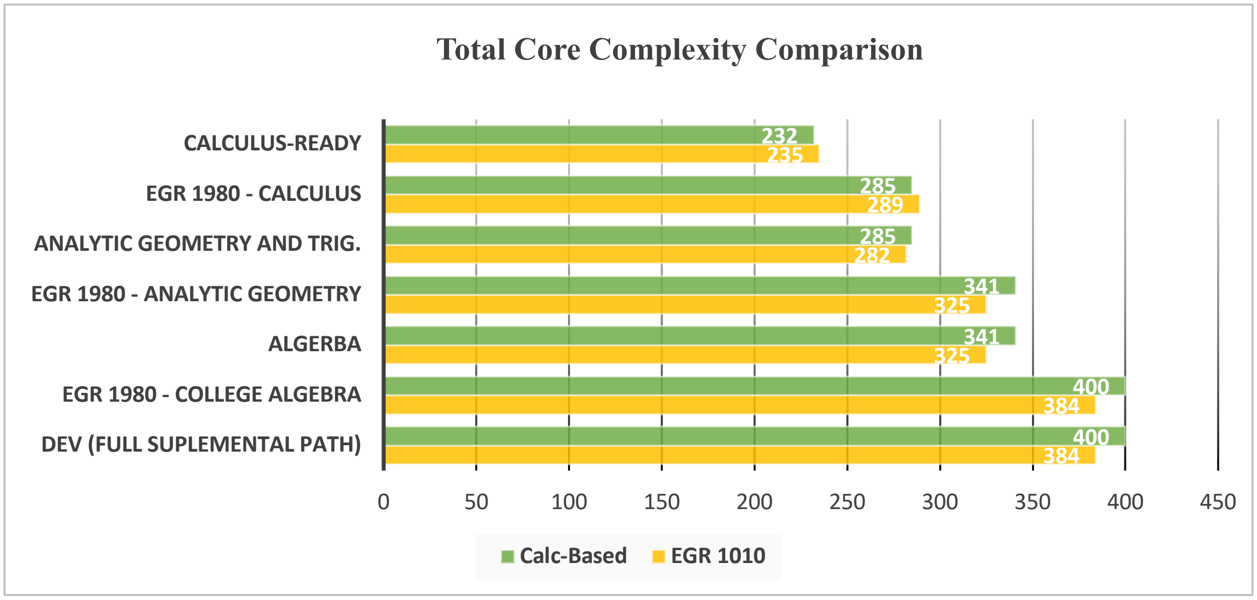


Figure 6. Comparison of total core complexity as a function of math starting point

A comparison of curricular complexity for the calculus portion only is shown in Figure 7. In contrast to its minimal effect on total core complexity, the introduction of EGR 1010 results in a measurable decrease in complexity of the required math sequence for all incoming math placement levels. Coupled with the reported increases in student motivation and self-efficacy, this might suggest that a decrease in the curricular complexity of the required math sequence had a measurable impact on student persistence in their intended engineering degree programs.

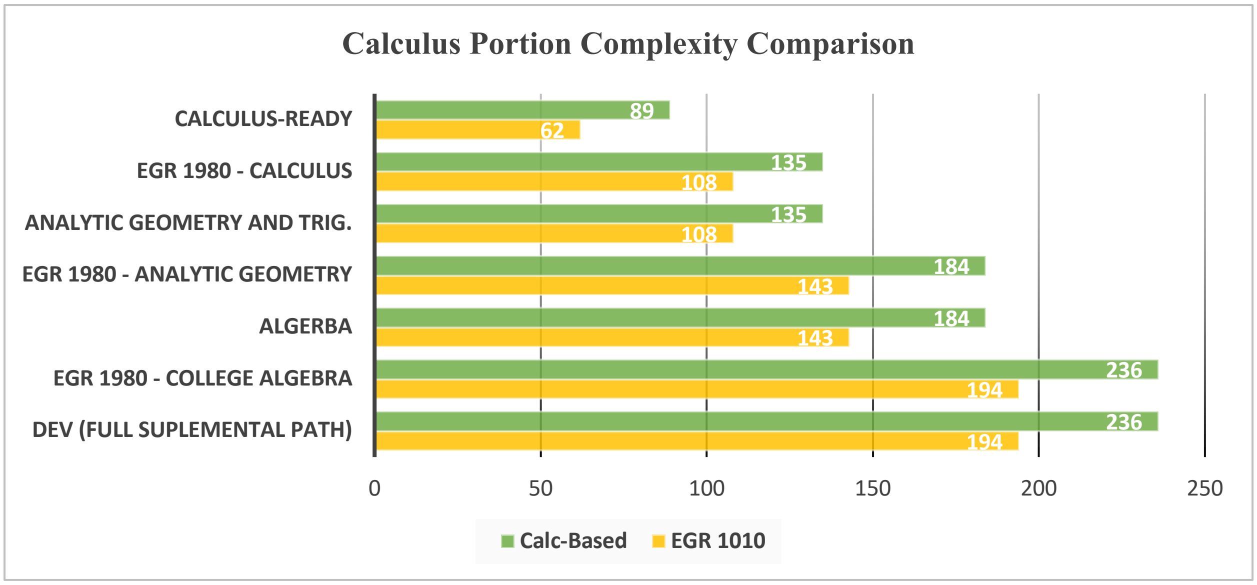


Figure 7. Comparison of calculus portion complexity as a function of math starting point

A comparison of total core centrality is shown in Figure 8. As observed for total core complexity, the total core centrality increases with decreasing math placement level. For all math starting points, the introduction of EGR 1010 results in a substantial reduction in total core centrality, as compared to the traditional calculus-based curriculum. In light of the results of Figure 1, this might suggest that the centrality of particular *portions* of a curriculum may play an important role in student persistence.

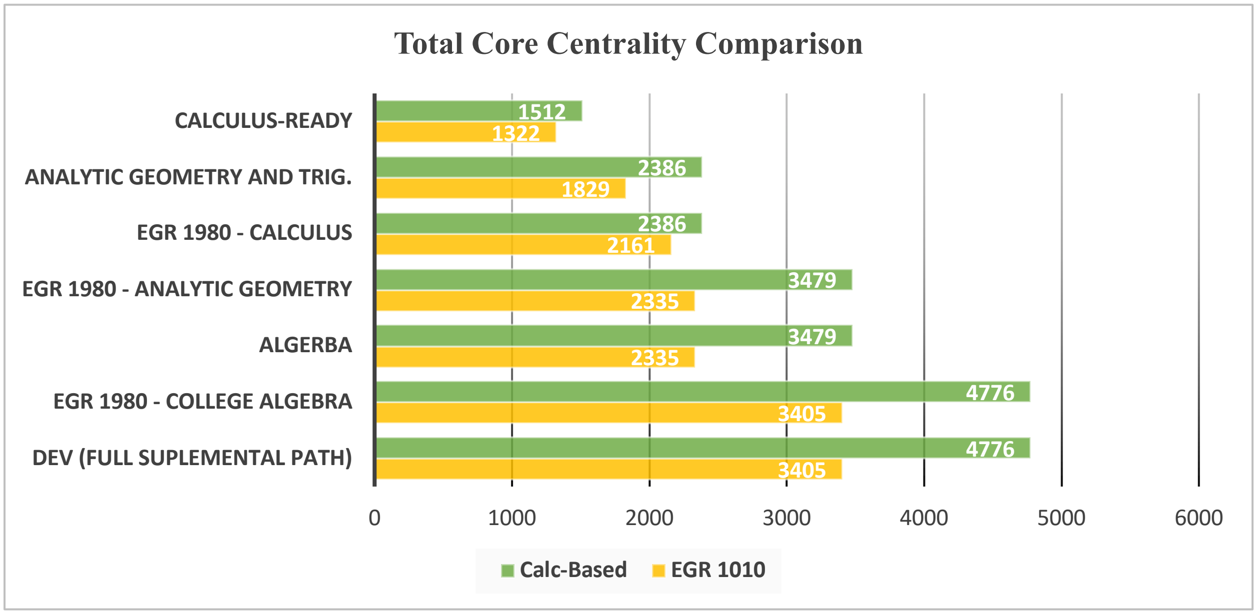


Figure 8. Comparison of total core centrality as a function of math starting point

Finally, a comparison of the calculus portion centrality is shown in Figure 9. For all math placement levels, the introduction of EGR 1010 results in a dramatic reduction in the centrality of the required math sequence. In fact, a comparison of Figures 7-9 reveals that a reduction in centrality of the required math sequence may be the greatest curricular impact of EGR 1010. Conversely, the traditional calculus-based curriculum sends a quantifiable curricular message to students: If you would like to be an engineer, then calculus is the most central part of your chosen degree program. For students who start out behind in math, that message makes the engineering degree program seem almost completely inaccessible. It seems reasonable that changing that message to students may have been a significant contributor to the increases in self-efficacy previously reported, as well as the observed increases in student success and degree attainment shown in Figure 1.

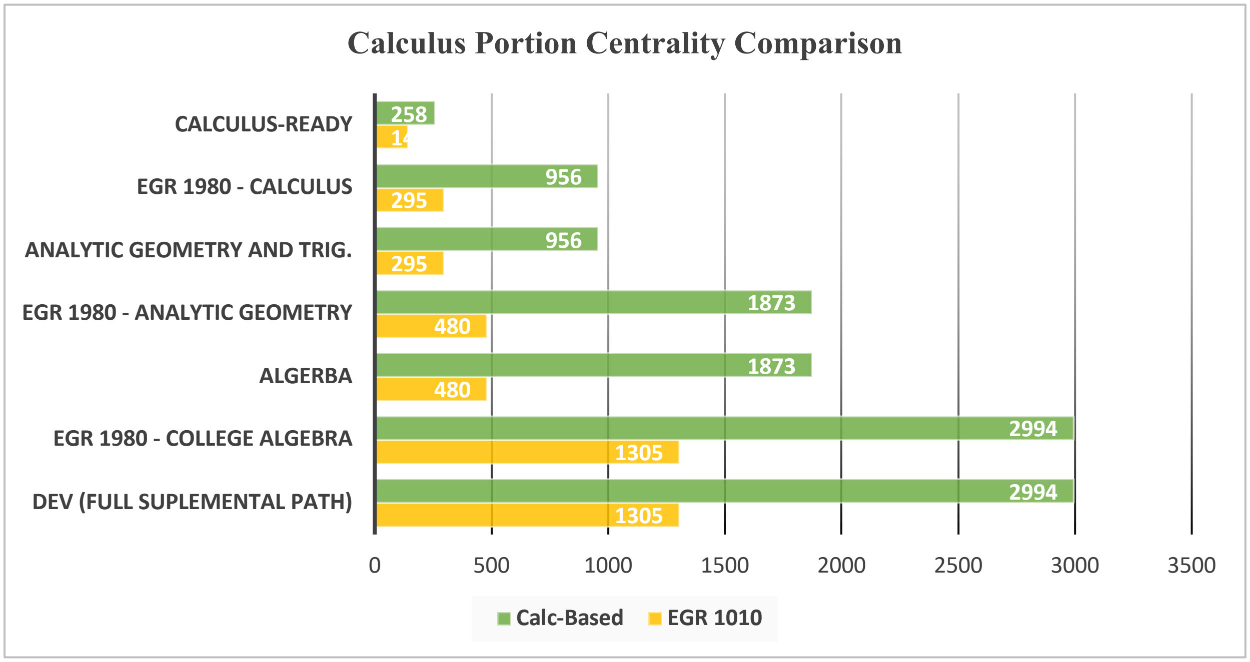


Figure 9. Comparison of calculus portion centrality as a function of math starting point

A final look at the impact of incoming math preparation is provided in Figures 10 and 11, which depict the *relative* complexity and centrality of the calculus portion as a percentage of the total core engineering curriculum.

As shown in Figure 10, the percent of total core complexity associated with the calculus portion increases with the number of math classes behind. This is true for both the traditional calculus-based curriculum and the EGR 1010-based curriculum. However, EGR 1010 results in a measurable reduction in the relative complexity of the calculus portion, which is relatively constant for all math starting points.

As shown in Figure 11, the percentage of total core centrality associated with the calculus portion also increases with number of math classes behind. However, this increase is far more dramatic for the traditional calculus-based curriculum than for the EGR 1010-based curriculum, which increases far less sharply. Interestingly, the greatest difference between the two curves is for students beginning 2 classes behind in math, which corresponds to College Algebra. This also corresponds to the starting point for the average incoming engineering student at Wright State University and comparable state universities nationwide. Overall, these results suggest that a reduction in the relative centrality of the required calculus sequence may have been a significant contributor to success of the Wright State Model on student success and degree attainment.

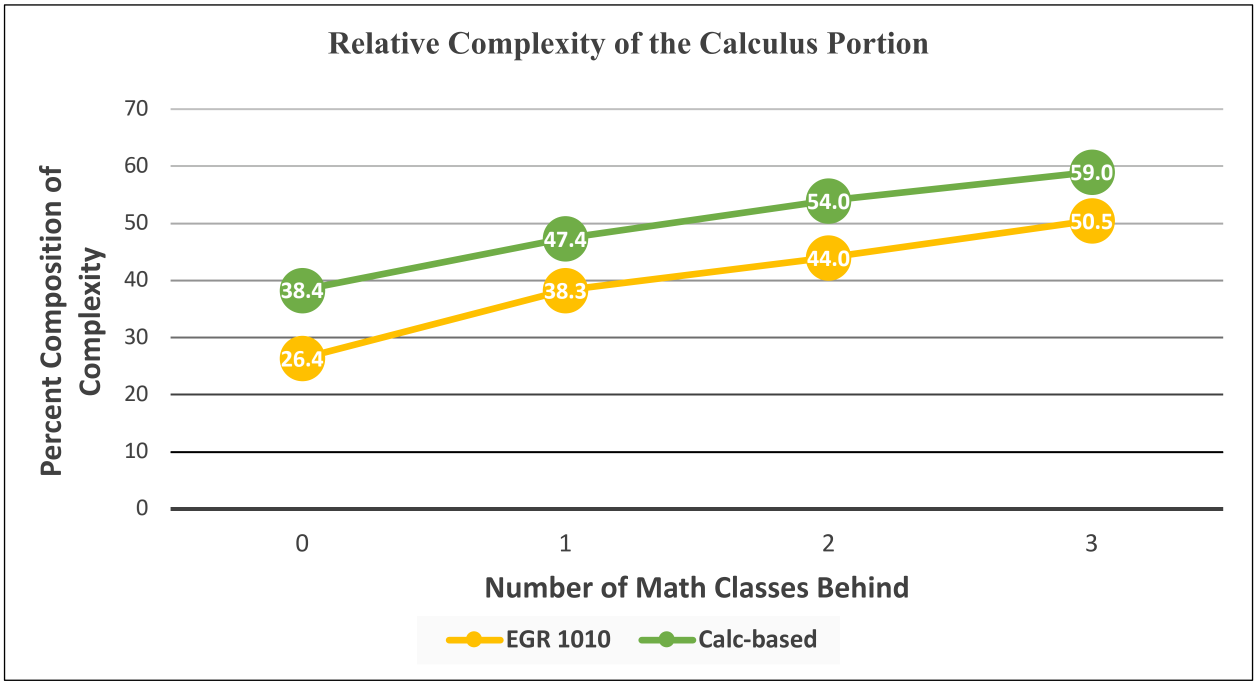


Figure 10. Relative complexity of the calculus portion as a function of math starting point

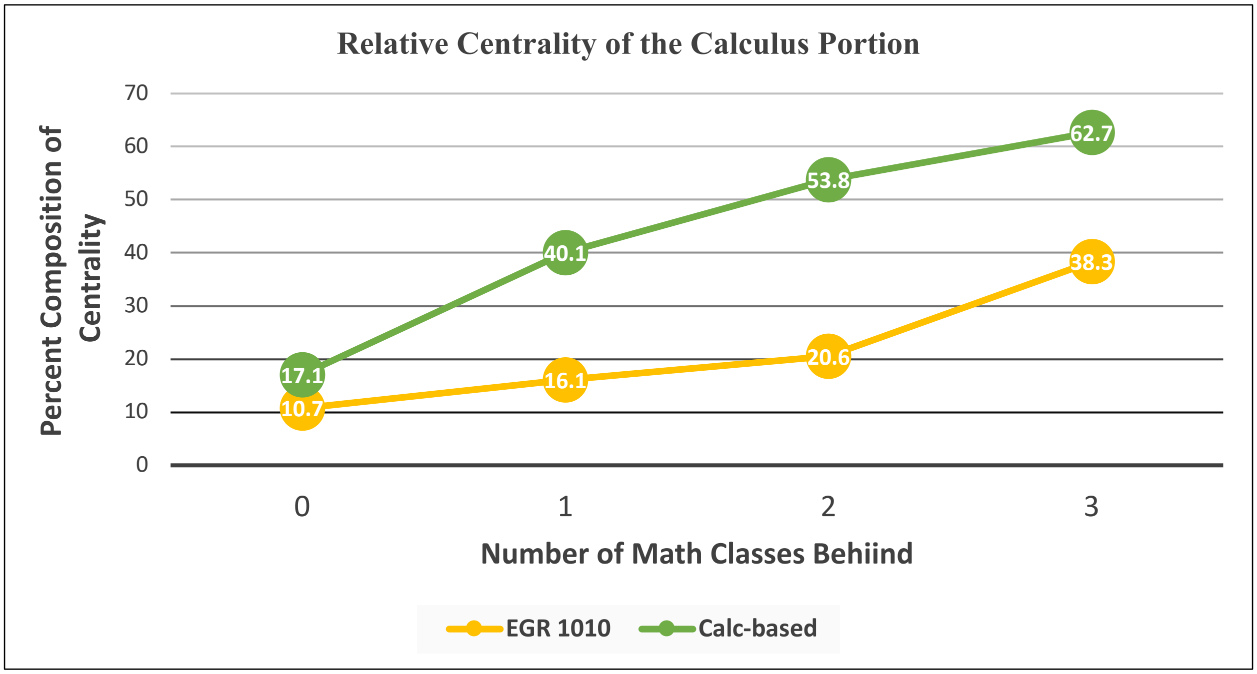


Figure 11. Relative centrality of the calculus portion as a function of math starting point

Conclusions

This study has employed the Curricular Analytics platform (https://curricularanalytics.org/) to better understand the longitudinal impacts of the Wright State Model for engineering mathematics education. While previous work has linked the observed increases on student success and degree attainment to increased student motivation and self-efficacy, the relative impact of the associated restructuring of the engineering curriculum had not been fully explored. To this end, comprehensive results for curricular complexity and centrality have been presented as a function of incoming student math preparation, for both the traditional calculus-based pathway and the EGR 1010-based pathway in the Mechanical Engineering degree program. Overall, the introduction of EGR 1010 has been shown to have only a minimal impact on the overall complexity of the curriculum, which increases with a decreasing levels of incoming student math preparation. However, the introduction of EGR 1010 has been shown to have a measurable impact on the curricular complexity of the required math sequence. While reduced curricular complexity has been the curricular analytics metric typically associated with increased graduation rates, the Wright State Model has actually had a greater impact on the *centrality* of the core engineering and math courses, which occur in the first two years of a student's degree program. In particular, the introduction of EGR 1010 results in a measurable reduction in total core centrality and a dramatic reduction in the centrality of the required math sequence, as compared to the traditional calculus-based pathway. Moreover, the relative reduction in centrality of the required math sequence increases with a student's number of math classes behind, with the greatest difference for students entering at the College Algebra level (i.e., the average incoming engineering student at Wright State University and comparable institutions nationwide). As such, it can be concluded that the Wright State Model has substantially reduced both the complexity and centrality of the required math sequence, which may have been a significant contributor to its longitudinal impact on student success and degree attainment.

Acknowledgment

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