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Math Preparation and Progress of Undergraduate Students in Civil Engineering Programs in Virginia

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Math Preparation and Progress of Undergraduate Students in Civil Engineering Programs in Virginia

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Abstract

Math preparation and progress continue to be roadblocks for incoming undergraduate engineering students. Each college or university must address this issue in their own manner through their policies and procedures. At the Virginia Military Institute (VMI), the civil engineering faculty advisers consistently work with students so they can make progress in the math curriculum, maintain proper sequence with the civil engineering degree program, and ultimately graduate from the program on time. Students begin the math sequence in pre-calculus or a higher level of math if they score well on the math placement test and culminate the sequence in differential equations. The four-year graduation plan requires students to begin in Calculus I; however, almost half are only prepared for pre-calculus and are forced to start one class behind in the math sequence. Even with prerequisites in the curriculum and established math tutoring resources, math progress continues to be an issue and one of the main reasons students discontinue the program. This paper examines why math preparation and progress continue to be an issue at Virginia engineering programs and evaluates what solutions exist to overcome deficiencies. For schools in Virginia and West Virginia, this study focuses on 1) the math sequences for engineering students at undergraduate civil engineering or civil engineering technology programs, 2) the graduation requirements used by high schools and when students typically meet these standards, and 3) the programs in place that help students gain math skills to be successful at undergraduate engineering schools. Most engineering school programs expect students to enter the program prepared to start Calculus to complete a degree within four years. Many offer math resource centers with tutoring options for students struggling in math courses and opportunities to take lower-level math courses if they extend their graduation date beyond the four-year mark or make up courses in summer school. High schools in Virginia and West Virginia require students to complete three or four math courses, but those course selections can vary.

Keywords

Math, College Preparation, High School Diploma, Civil Engineering, Tutoring, Retention

Introduction

Civil engineering is built upon a core set of mathematics, science, and humanities topics. Incoming students are expected to have a level of base knowledge acquired prior to matriculating into a civil engineering program. How they obtain this knowledge is unique to every student due to the vast number of options to gain secondary education and prepare for college. In many cases, the depth of this knowledge varies greatly, especially in mathematics, science, and writing.

These discrepancies can lead to difficulties when the students' level of base knowledge is not equivalent to what professors in college programs expect, potentially leading to a difficult transition to college, additional years of study, and, worst case, attrition.

Math preparation has been largely viewed as one of the keys to success in engineering. The following paper reviews the program requirements of nine civil engineering and civil engineering technology programs in the Mid-Atlantic region and the current high school graduation requirements of the average incoming student. The expectations of programs, remediation options, and additional education options are reviewed to determine how different programs handle the various levels of math preparation of incoming students in civil engineering programs.

Background

The math requirements for a civil engineering program are typically created by the professors who run the program, but there are numerous influences on the program content.[1] Two influences are the program criteria from ABET, Inc. and the Civil Engineering Body of Knowledge.

Civil engineering programs are accredited by ABET, Inc. through their "Criteria for Accrediting Engineering Programs" (EAC-ABET). There is flexibility on how to meet the criteria, but there are some specific requirements. Included is the requirement that graduates master "College Level Mathematics that require a degree of mathematical sophistication at least equivalent to that of introductory calculus."[2] By this definition, any student that is not ready for calculus must take remediation math classes that would not count toward program or degree requirements.

Civil engineering technology programs are also accredited by ABET, Inc. through their "Criteria for Accrediting Engineering Technology Programs" (ETAC-ABET). For baccalaureate degree programs in civil engineering technology, students must be able to apply "integral and differential calculus, or other mathematics above the level of algebra and trigonometry, appropriate to the student outcomes and the discipline" to solve technical problems.[3] It is inferred that calculus level math classes should be included in the program, but other lower-level math courses may also be included.

The American Society of Civil Engineers regularly publishes their Civil Engineering Body of Knowledge (CEBOK). The most recent addition includes an outcome, Mathematics, explaining the math needed for the civil engineering profession. Algebra, calculus, linear algebra, geometry and topology, differential equations, computation and numerical analysis, probability, set theory, statistics, and trigonometry are included. While there is no requirement that a student start at a certain point in this math sequence, it is expected to be mastered by graduation from an undergraduate program.[4] A student who enters with little to no math knowledge would not be able to complete the math requirements in a typical four-year program.

How a program deals with these recommendations and requirements will determine the curriculum of incoming students. Depending on their math preparation, these students may or may not be ready to enter a program. In some cases, students may need to start at a lower-level math class, receive additional instruction or help, or take additional time in college to complete

the requirements. Each university has different policies and requirements in place to address these challenges.

Research Questions

This study investigated what policies, requirements, and procedures are in place to ensure that incoming students in civil engineering programs in Virginia and West Virginia meet the math requirements. Three research questions were asked:

- What are the typical entry-level math requirements in an undergraduate civil engineering program in Virginia and West Virginia?
- What programs are in place at undergraduate institutions to help students gain the math skills necessary to be successful in undergraduate civil engineering programs?
- What are the typical mathematics graduation requirements in Virginia and West Virginia high schools, and when do students typically meet these requirements?

Methods

Data were collected using a two phased approach to address the research questions. The first step was to review requirements for engineering programs in the region to determine what methods and approaches are in place. The universities in the Virginias Section of the American Society of Civil Engineers (ASCE) student conference were used as a comparative group. Currently, this consists of seven EAC-ABET accredited civil engineering programs and two ETAC-ABET accredited civil engineering technology programs. These programs draw from a very similar and, in some cases, the same population of potential students in the region. It was determined that reviewing these university's math education for engineers would provide insight into how different universities deal with a set of students' math preparation and education.

Each university's website was reviewed to find data for incoming students. Students were broken down into categories to include first year students that have never attended college and first year transfer students. Information was gathered on required placement tests, incoming standardized test scores, high school GPA, and required first-year math curriculum. For transfer students, information was gathered on incoming minimum GPA, coursework that must be completed, and math requirements. Lastly, data on math resources was collected, such as tutoring opportunities, math resource centers, and peer study groups.

In the second phase of the project, the math skills of the incoming students were collected by reviewing the different high school diplomas offered in Virginia and West Virginia. Virginia has multiple tracks that students may take in public high schools, whereas West Virginia has one track. Most of the students that come to the nine universities are from these schools, therefore, it would be useful to gather what math courses they have completed. While this may not measure the quality of the math preparation, it does measure the expected content of that preparation.

Data Analysis

University Math Requirements

Table 1 summarizes the data found on university websites regarding entry requirements into engineering schools or programs. While placement test requirements are listed, all universities in Table 1 have waived the SAT/ACT requirements for the application cycle 2022-2023, continuing their optional requirements implemented during the COVID pandemic in the 2020-2021 application cycle. U1, U4, and U5 require admission to the School or College of Engineering, whereas U2, U3, U6, U8, and U9 require admission into the Civil Engineering program specifically. U7 requires completing the Civil Engineering Technology associates degree before admission into its Bachelor of Science program.

Only five universities indicate a math course prior to Calculus I is an option for engineers; however, two are technology programs, and the other three (U2, U9, U8) do not list pre-calculus as part of their curriculum. In essence, pre-calculus is not part of any EAC-ABET accredited program, even if they allow students to start in this course. Standardized tests are not required for admission, but taking them allows students to begin calculus directly if a threshold score is achieved at six different schools. Two schools (U4, U3) require a placement test to start in calculus regardless of standardized test scores, and only three schools use the ALEKS entrance test. Only one school does not require a placement test or entrance exam to start in Calculus I (U1). High school GPA is important for six of the schools. Typically, they required at least a 3.0 without an SAT/ACT score or 2.0 with an acceptable SAT/ACT score to begin their engineering program. Passing an AP-AB test in calculus with a score of 3 or higher will earn credit at six schools, and all will accept an AP-AB test score of 4 or higher. Clearly, the AP calculus test is universally recognized.

Table 2 contains the requirements for transfer students into the nine engineering programs. GPA is the most common requirement. Six of the nine schools require a minimum 2.0 GPA, while one requires a 3.2 GPA, and two have no requirements. Calculus and physics courses were required at two schools, and one school required programming and chemistry. Two schools required applicants to not be on academic probation at their previous institution, and two required a minimum number of credits completed. All but one school had three or fewer requirements, and three only required a minimum GPA.

Tutoring resources for students are ubiquitous throughout the universities examined, although some of the opportunities offered are virtual or offsite. A specific math center is available at universities with EAC-ABET accredited programs (Table 3). Student-led group tutoring was only identified at two schools, but this was the most challenging category to identify online. Many of these resources may be on university-specific websites and apps or advertised in person.

High School Graduation Standards

The current Virginia Department of Education standards specify two high school graduation diplomas typical for career and college readiness.[5] The Standard diploma requires the completion of three math courses, where at least two are specified among a listing of approved courses shown in Table 4. In this table and discussion a math credit is equivalent to one academic year of math instruction (two semesters). An Advanced Studies diploma requires the completion of four math courses, where at least three are specified among a listing of approved courses. In each case, only one course credit is required to be verified by passing a Standards of Learning (SOL) test in addition to earning credit for completing the course. The current diploma standards apply to all students entering 9th grade starting in the 2018-2019 academic year and beyond. Similar

total course credits were required prior to the 2018-2019 academic year. However, previous standards indicate that students entering 9th grade in the 2011-2012 academic year through the 2017-2018 academic year were required to have two math credits verified by passing an SOL test to earn the Advanced Studies diploma. As mentioned, this requirement is now reduced to one verified course credit for the current standards.

The current West Virginia Board of Education standards specify one standard high school graduation diploma typical for career and college readiness.[6] Four credits are required for the completion of the diploma. Two credits are prescribed to include Math I or Algebra I and Math II or Geometry. The final two credits are personalized and may include courses among a list shown in Table 4. Mathematics III STEM and Mathematics – STEM Readiness are both courses meant to prepare students interested in STEM career fields and are included among this list.

In both states, students are likely to learn topics in algebra and geometry, while other topics may vary depending on their specific interests. With a Standard diploma in Virginia, some students could complete all math credits prior to their Senior year resulting in an entire year without math instruction. In both states, a problem could arise if they chose to take a computer science, quantitative reasoning or other non-traditional math-related course in place of a traditional math course their senior year. This gap year from traditional math (up to 15 months) could be detrimental to engineering students during their first year in college since they would likely be out-of-practice compared to peers with four years of continuous math instruction.

In both states, the majority of college-bound students will take algebra and geometry. However, these courses will likely be taken the first two years of high school or earlier. Much of the content in these classes is foundational for calculus and may need to be reviewed prior to matriculating into college. Students may not be selecting the most appropriate courses in the most appropriate order to thoroughly prepare themselves for college-level calculus courses. The problem may not be that the high schools didn't offer proper preparation, but rather that students did not select the right math courses in their last two years of high school even though they are on the college-bound track.

Discussion of Results

The following observations were discovered when reviewing the data:

1. Universities do not currently require standardized tests for admissions, but many still trust them to place students in their first math course in engineering.
2. All universities but one require either an entrance exam or standardized test score to start in calculus.
3. Arriving Calculus I ready is the standard for entering a civil engineering program. Starting in a lower-level math will require additional credits beyond the engineering program requirements; four universities do not advertise a direct path for students not ready for calculus.
4. The AP Calculus AB and BC tests are universally recognized as a standard to test out of college-level calculus.
5. For transfer students, GPA is the most common requirement. Only three universities required the completion of specific courses to transfer.

6. Every university had at least one form of math help, and all but one had multiple opportunities to get math help clearly advertised online.
7. Students entering with a diploma from a Virginia or West Virginia high school may not have had math courses in all four years of high school. In some cases, they may not have had a math class for over 15 months upon entering college.
8. Most college-bound students take algebra and geometry classes during their first and second years of high school, over two years before matriculation into college.

Conclusion

All schools recognize the importance of math based on the methods used to assign students to an initial math class and the widespread use of math centers and tutoring. Prerequisites exist for engineering and math courses at every university in some format, indicating the importance of math preparation prior to entering college. In many cases, students are not ready for a calculus-level math class and must either start in a lower-level math or delay entrance into college until these math courses are complete. An examination of high school requirements near these universities demonstrates that students have numerous paths that, while considered college-bound, are not ideal preparation for students wanting to major in engineering. Preparation for entering an engineering program ready for calculus-level math upon entry requires thorough planning in high school. In the future, better coordination between engineering schools and high schools may help alleviate the math preparation problems that currently exist for matriculating students. In most cases, the opportunities likely exist to take college-bound math for four years in high school. Still, students may not clearly understand the importance of this preparation for an engineering program.

Table 1: Summary of Entry Requirements for Students Entering College for the First Time into Civil Engineering

School[a]	Placement Tests								High School	
	ALEKS[d]		SAT-Math		ACT		AP CALC		GPA	
	Min.	Required for	Min.	Required for	Min.	Required for	Replace-ment for Calc I or II		Min.	Typical
U1	None		None		None		4	AB or BC	None	
U2	78	Calc I	620	Calc I	27	Calc I	3	AB or BC	None	Middle 50% 3.15-3.38
	68	Pre-Calc	570	Pre-Calc	25	Pre-Calc				
U3	Other[c]	Calc I	None		None		4	AB	None	
U4	80	Calc I	None		None		4	AB	None	3.0 guarantees acceptance to engi-neering dept
							3	BC		
U5	75	Calc I	510	Calc I	19	Calc I	3	AB or BC	3.5 if no SAT	
U6	Other[b]	Applied Tech Math	510	Applied Tech Math	19	Applied Tech Math	3	AB or BC	3.0 if no SAT, 2.0 if SAT/ACT	
U7	Other[b]		NA	NA	19	Algebra/ Trig	3	AB or BC	3.0 if no SAT, 2.0 if SAT	
U8	Other[b]	None	560	Calc I	24	Pre-Calc	3	AB or BC	2.0 or 3.0 dependent on SAT/ACT scores	2.00/3.00
U9	No score men-tioned	Pre-Calc or Calc 1	510	Calc I	19	Calc I	3	AB or BC	3.0 or 2.0 based on SAT	2.00/3.00

[a]No shading indicates a EAC program, shading indicates an ETAC program
[b]Accuplacer is the alternate placement test
[c]Internal test requires a 21 out of 30 to start in Calculus I
[d]ALEKS is a standardized Math preparation and placement program.

Table 2: Summary of Transfer Requirements for Students Entering an Engineering Program

School[a]	Min. GPA	Math	Physics	Chemistry	Program-ming	Other
U1	2.0	Calculus II & III	Physics I	Chemistry I	Intro to Program-ming	GPA 3.0 and coursework highly recommended, but not required
U2	None	None	None	None	None	Must not be on aca-demic probation
U3	3.2	None	None	None	None	None
U4	None	Calculus I & II	Physics I & II	None	None	None
U5	2.0	None	None	None	None	None
U6	2.0	None	None	None	None	None
U7	2.0	None	None	None	None	Must be eligible to return to previous institution
U8	2.0	College Algebra / Pre-Calc	None	None	None	More than 30 credits completed
U9	2.0	None	None	None	None	More than 24 credits completed

[a]No shading indicates a EAC program, shading indicates an ETAC program

Table 3: Summary of Math-Related Resources for Undergraduate Students in Civil Engineering Departments

School[a]	Group Tutoring	Individual Tutoring	Specific Math Center	Student Led Group Tutoring
U1	Peer led learning for math classes bi-weekly	Free on demand, student led, 2 weeks' notice to find a tutor	Yes	Eta Kappa Nu lead Math/Engineering sessions that vary by semester
U2	Yes, for high demand classes	Yes, for more than 50 subjects	Yes	None
U3	Group Study Sessions for specific courses led by peer tutors	Open Math Lab for individual appointments and a web-based tutoring service available	Yes	Yes
U4	Peer led tutoring meets weekly for math classes	Appointments available upon request	Math Department offers tutoring services	None
U5	Weekly drop-in hours for math classes	Yes, by appointment at the tutoring center or private tutors for hire	Yes, drop-in hours in person or online	None
U6	Yes, peer-led group tutoring	Yes, by appointment for math assistance	None	None
U7	None	Peer tutoring in most classes, tutor.com for up to 10 hours per semester for free	None	None
U8	Drop-in tutoring for 100 and 200 level math courses	Yes	Yes, offered by the Math department, virtual or in person drop-in appts held weekly	None
U9	Yes, weekly math specific review sessions	Peer tutoring available	Yes, offered by TRIO Student Support Services (federally funded by US Dept of Education)	None

[a]No shading indicates a EAC program, shading indicates an ETAC program

Table 4: Summary of High School Mathematics Graduation Requirements for Virginia and West Virginia

<table>
<tr><th></th><th colspan="2">Virginia[5]</th><th colspan="2">West Virginia[6]</th></tr>
<tr><th>Diploma</th><th>Standard</th><th>Advanced Studies</th><th colspan="2">Standard</th></tr>
<tr><td>Math Credits</td><td>3</td><td>4</td><td colspan="2">4</td></tr>
<tr><td>Verified Credits</td><td>1</td><td>1</td><td colspan="2">-</td></tr>
<tr><td rowspan="2">Required Courses</td><td rowspan="2">NA</td><td rowspan="2">NA</td><td colspan="2">Math I or Algebra I</td></tr>
<tr><td colspan="2">Math II or Geometry</td></tr>
<tr><td rowspan="20">Course Options</td><td>At least two among:</td><td>At least three among:</td><td colspan="2">Two Among:</td></tr>
<tr><td>Algebra I</td><td>Algebra I</td><td rowspan="4">Recommended for College and Career Readiness</td><td>Math III STEM / Math III LA / Algebra II</td></tr>
<tr><td>Geometry</td><td>Geometry</td><td>Math IV - Trigonometry / Pre-calculus</td></tr>
<tr><td rowspan="2">Algebra, Functions & Data Analysis</td><td>Algebra II</td><td>Applied Statistics</td></tr>
<tr><td rowspan="2">Other courses above Algebra II</td><td>Transition Mathematics for Seniors</td></tr>
<tr><td>Algebra II</td><td rowspan="16">Additional Course Options</td><td>Math I Lab / Algebra I Support</td></tr>
<tr><td>An approved Computer Science course</td><td>An approved Computer Science course</td><td>AP Computer Science</td></tr>
<tr><td colspan="2">Other Course Options with SOLs:</td><td>Advanced Mathematical Modeling</td></tr>
<tr><td colspan="2">Trigonometry</td><td>Calculus</td></tr>
<tr><td colspan="2">Computer Mathematics</td><td>Statistics</td></tr>
<tr><td colspan="2">Probability & Statistics</td><td>Financial Algebra</td></tr>
<tr><td colspan="2">Discrete Mathematics</td><td>County-created and approved math courses above Math II or Algebra II</td></tr>
<tr><td colspan="2">Mathematical Analysis</td><td>STEM Readiness Math</td></tr>
<tr><td colspan="2">Data Science</td><td>Math III TR / Math IV TR</td></tr>
<tr><td colspan="2" rowspan="5"></td><td>Quantitative Reasoning</td></tr>
<tr><td>College Math Courses</td></tr>
<tr><td>Computer Science & Math</td></tr>
<tr><td>Technical Transition Math</td></tr>
</table>

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