

## **Math Placement Testing: Performance and Persistence in Civil Engineering**

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# **Math Placement Testing: Performance and Persistence in Civil Engineering**

## **Abstract**

The Virginia Military Institute (VMI) is an undergraduate college that provides fourteen different degrees, approximately half of which are awarded to STEM majors. The admissions process works on a rolling basis and allows students (called cadets) to choose any major once they are accepted. Many of the STEM majors require a calculus-based math course sequence. To start in Calculus I, VMI requires all entering cadets to pass a math placement test with a score of 21 or higher out of 30 problems. Although the test has changed slightly over the years, the requirement to pass with a 21 or higher has remained constant. Any student not receiving at least a 21 is required to take and pass Precalculus before registering for Calculus I. Precalculus has a high failure rate which causes many students to either fall behind, switch majors, or drop out of college. The math learning losses experienced during the COVID-19 pandemic have caused the engineering departments at VMI to reevaluate the appropriateness and effectiveness of the math placement test requirement. This paper presents results from a careful and objective analysis into the effectiveness of using the math placement test for Civil & Environmental Engineering (CEE) students over the past 15 years (matriculation classes 2010 to 2024). The challenges caused by the recent change in policy to no longer require SAT or ACT scores is discussed along with the resulting changes in community college policies. Results of the analysis have shown that student success can be defined in more than one way. The results also show that math skills for the students entering VMI are changing and that a new pathway to succeed in calculus-based math courses may be needed.

## **Keywords**

Math Preparation, Civil Engineering, Curriculum, Standardized Testing, SAT, Entrance Exam

## Background

All students that apply to attend the Virginia Military Institute (VMI) are required to take two placement tests before matriculating in August, one for language and one for mathematics. The placement test for mathematics has consisted of 30 questions for many years. To start in Calculus I students (called cadets at VMI) must score at least a 21 or higher on the Math Placement test. If a cadet scores less than 21, he or she must take and pass a Precalculus course before entering Calculus I. The Precalculus course is a pass/fail course that does not affect a cadet's grade if he or she fails it, and it does not count towards the total number of credits required for graduation. If passed, the three credits do count towards the minimum yearly hours required to remain in good standing. The requirement to obtain a 21 or higher to enter Calculus I is enforced even if a cadet has previously scored a five on the AP Calculus BC exam which would allow the cadet to receive 6 credits for Calculus I and Calculus II.

VMI required all applicants to submit either SAT or ACT scores prior to the pandemic but stopped requiring the standardized tests when most colleges went test optional. The standardized tests were used as part of the decision process for admissions but were not used for math placement. There were many studies done prior to the pandemic that considered the effectiveness of standardized tests and placement tests for math courses. Studies often concluded that placement tests were not the best predictors of success in math [1].

Most STEM majors at VMI, including Civil and Environmental Engineering (CEE), require calculus-based mathematics courses. In any given year, up to approximately 40% of cadets entering the CEE department fail to obtain a 21 or higher on the placement test and are required to start in Precalculus. The CEE curriculum has been designed to allow cadets to remain on track for graduation in eight semesters even if a cadet is required to start in Precalculus. However, since the pandemic, it has been increasingly difficult for students to catch up in math because of changes to the summer course offerings in the community college system. Prior to the pandemic, students could take both Precalculus and Calculus I over the summer to catch up in math if they were behind. Taking both courses in the summer is no longer an option in the community college system in Virginia. To remain on track for graduation within four years, CEE cadets must pass Calculus I with a "C" or better before returning for their sophomore year.

Enrollment in the STEM majors at VMI has declined since the pandemic. Throughout the Commonwealth of Virginia the enrollment in many of the smaller colleges has decreased since before the pandemic while enrollment in many of the larger colleges has increased.[2] From 2019 to 2023, enrollment at Virginia Tech has increased 5% while it has decreased 8% at VMI over the same period. In 2023, Virginia Tech enrolled approximately 25 students for every 1 student at VMI. Although the Commonwealth of Virginia has promoted the fact that overall enrollment has returned to approximately the pre-pandemic levels of 2019, the improvements are disproportionate with most of the improvements in Virginia occurring in the larger colleges. To compound the issue, the STEM majors at VMI have also noticed that the percentage of cadets electing to enroll in STEM majors that require calculus has decreased. This decrease in total enrollment and a decrease in the percentage of STEM majors has caused the CEE department to look closely at math performance as a possible reason for the decline.

The failure rate for Precalculus at VMI is high. CEE cadets that start in Calculus have a higher chance of passing Calculus I than those starting in Precalculus. The high failure rate in Precalculus has been discussed and debated for many years. Some have suggested that only cadets that are Calculus I ready their first semester should be allowed to enroll as engineering majors. The CEE department has maintained that, even though the failure rate is high in Precalculus, the number of cadets that persist to catch up in math is significant enough to justify this pathway. The following study was undertaken to provide an objective review of Math Placement test results for CEE associated cadets for fifteen years from 2010 to 2024.

## The Data

VMI uses Colleague Ellucian to maintain academic records. There are user interfaces that allow reports to be generated to obtain academic information. However, obtaining the information needed is not always simple for several reasons. First, VMI used to promote a motto “Don’t Do Ordinary” – and anyone familiar with VMI’s academic regulations would agree that it does not do ordinary. For example, most colleges allow 12 semesters for students to graduate if undertaking a four-year degree (8 semesters). This is consistent with the 150% time allowed for financial aid assistance. But VMI requires cadets to graduate within 10 semesters. This requires that the minimum required yearly hours be adjusted. Many of the standard Colleague Ellucian reports must be modified to meet this one VMI requirement. And there are many more.

It is also difficult to track cadets once they switch majors. The most reliable reports are based on a cadet’s status at the time of their graduation. At VMI, cadets can change majors at any time during the year, making tracking their status more challenging.

For this study the authors worked with the Information Technology department to create a search that would provide information for all cadets associated with Civil & Environmental Engineering. The data was considered for three groups of cadets: (1) cadets that graduated in Civil Engineering, (2) cadets that started in Civil Engineering but switched majors and graduated in a different major, and (3) cadets that started in Civil Engineering but eventually left VMI without graduating in any major. The breakdown is shown in Table 1.

Table 1 – Number of CEE Associated Cadets 2010 to 2024

Category	Number of Cadets
Graduated in CEE	709
Graduated in Other Major	144
Did Not Graduate	196
Total, n	1049

As shown in Table 1, there were 1049 cadets associated with CEE during the 15-year period. During this period, 81% of the cadets associated with CEE graduated from VMI with some degree, and 68% graduated with a degree in Civil Engineering. There was no sampling done; the data set includes all cadets associated with Civil Engineering over the 15-year period.

## Results

Cadets entering VMI are allowed to enter any major – there are no minimum math requirements to enter a major. This has resulted in some cadets that are unprepared in math in STEM majors that require calculus. In the past, cadets that found that they are unprepared during their first semester in math could catch up in the summer between their freshman and sophomore year before being required to switch to a non-STEM major. In previous years, more than fifty percentage of entering cadets would choose a STEM major at matriculation prior to the pandemic. The percentage of STEM majors would then decrease every year as cadets would switch from STEM to non-STEM majors. To keep the number of STEM vs non-STEM majors approximately equal, VMI instituted a right-sizing initiative to better manage the number of cadets in each major. This was done by implementing maximum capacities for each major. Maintaining the balance has become more challenging since the pandemic primarily because more cadets are choosing non-STEM majors at matriculation and cadets continue to primarily switch from STEM to non-STEM majors.

One concern has been that cadets that earn below a 21 on the math placement test, which is the minimum score to enter Calculus I, have a low probability of graduating in CEE, or even graduating from VMI. This was investigated by identifying all cadets associated with Civil Engineering and dividing them into the three categories listed in Table 1. For each category the number of cadets attaining each of the math placement scores was determined. The relative frequency of graduating was then calculated for each math placement score by simply dividing the number of cadets that graduated within each score by the total number of cadets that obtained the same score. The relative frequency, which comes from actual data, can be used to predict the probability of the event, in this case graduating [3]. This is shown in Figure 1 for both the cadets that graduated in CEE and the cadets that were once associated with CEE but switched majors and graduated in a different major.

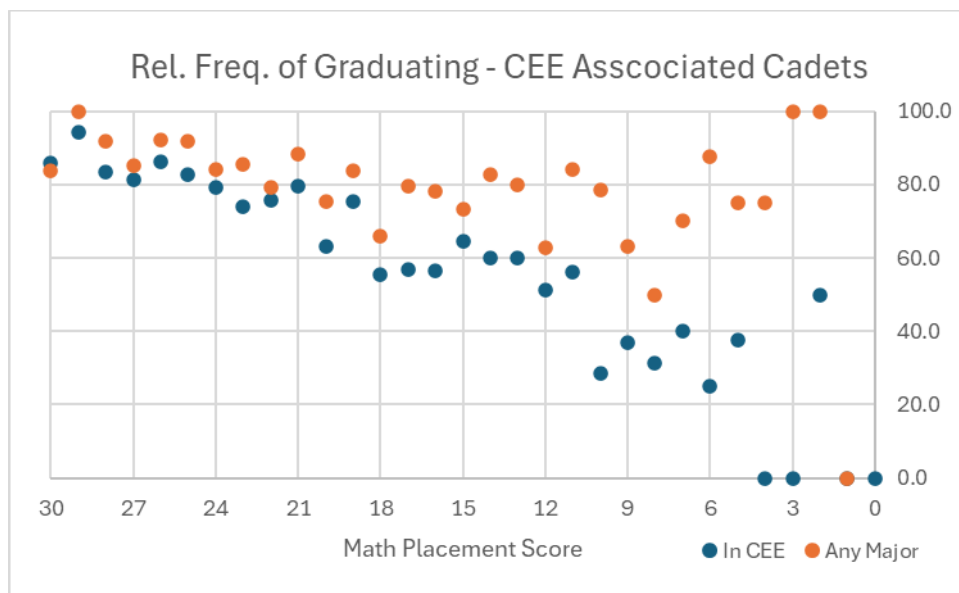


Figure 1 – Relative Frequency of Graduating

The results show two natural breaks. First, cadets scoring approximately 19 and above on the math placement test had a high probability of graduating either in CEE or a different major. This supports the use of the minimum score of 21 as a metric to determine who should be allowed to start in Calculus I. Another natural break occurs for cadets scoring approximately 10 or below. At this break the probability of graduating from CEE decreased substantially but the probability of graduating from a different major remained high. Some of the points that are zero or 100 percent indicated situations where no cadets, or possibly only one or two, obtained that math placement score. These data points were left for completion.

A second way to consider the same data is shown in Figure 2. This shows the actual number of cadets that graduated at each math placement score value. It is interesting to note that the two natural breaks indicated in Figure 1 also appear in Figure 2. It is also interesting that the number of cadets graduating in different majors is relatively level throughout all math placement score values, only once does the value go above a ceiling of 10. As indicated earlier, there have been discussions to not allow any cadets that received below a 21 on the math placement test to enter Civil Engineering. As shown in Figures 1 and 2, this restriction would eliminate a significant number of successful CEE graduates.

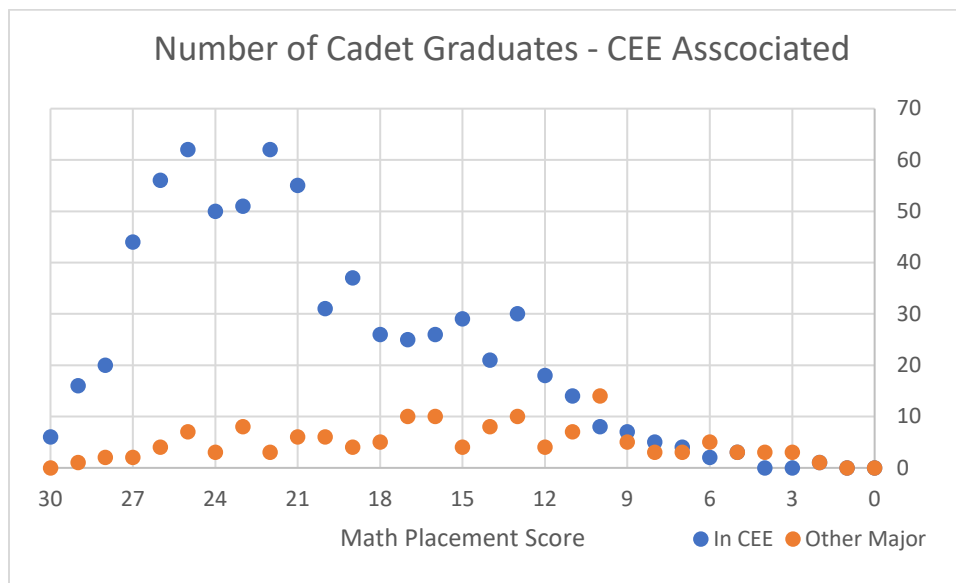


Figure 2 – Number of Cadet Graduates per Math Placement Scores

Cadets leave VMI for many reasons. For some, the military environment is simply not a good fit. Figure 3 shows the math placement score for all the cadets that were at one time associated with Civil Engineering that left VMI. The natural breaks that appeared in the data in Figures 1 and 2 are not quite as pronounced in Figure 3. The data appears somewhat normally distributed, indicating that leaving VMI may not be associate with the math placement score.

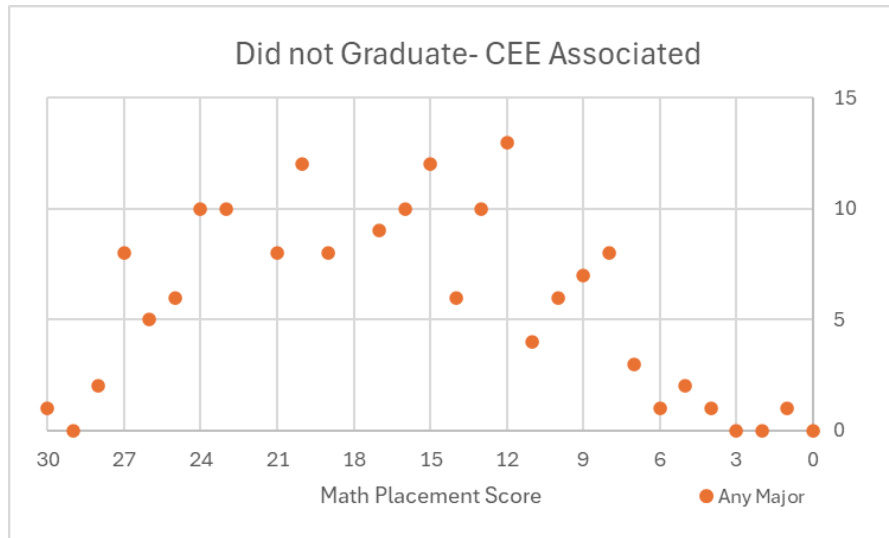


Figure 3 – Math Placement Score for cadets that did Not Graduate

Many faculty members in the CEE department believed, anecdotally, that math skills have been slowly declining over the past fifteen years. However, an objective review of the data does not necessarily support this observation. In fact, both the math placement scores and the SAT scores have slightly increased for those cadets that graduated in CEE. Figures 4 and 5 show these results. The average math placement score and SAT for each year is shown with a linear trendline.

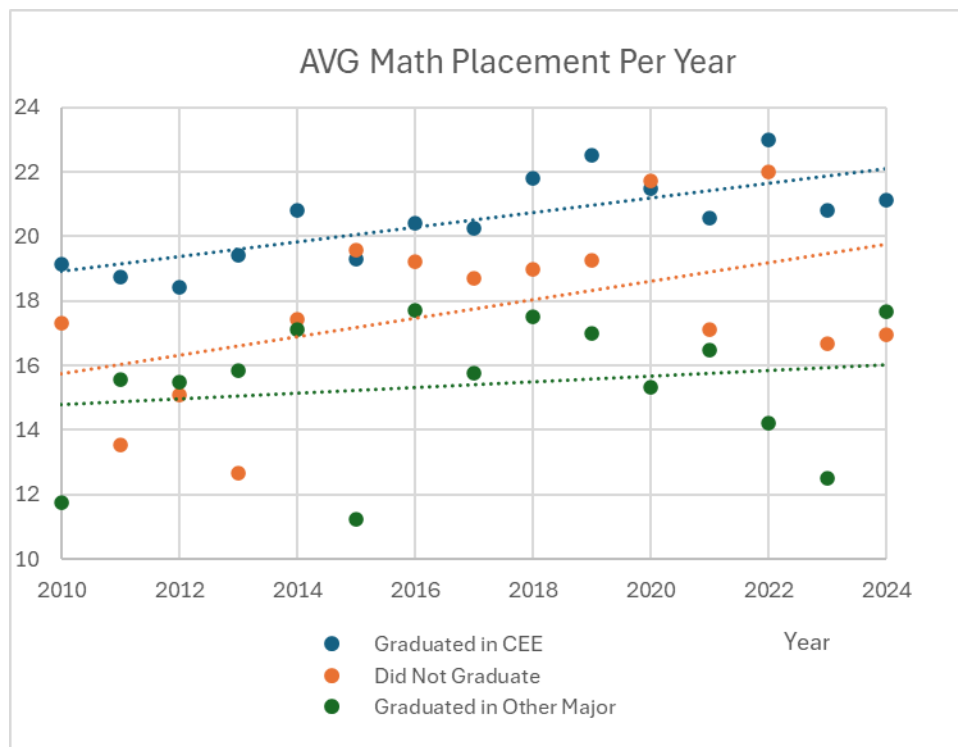


Figure 4 – Average Math Placement Score for 15 Years

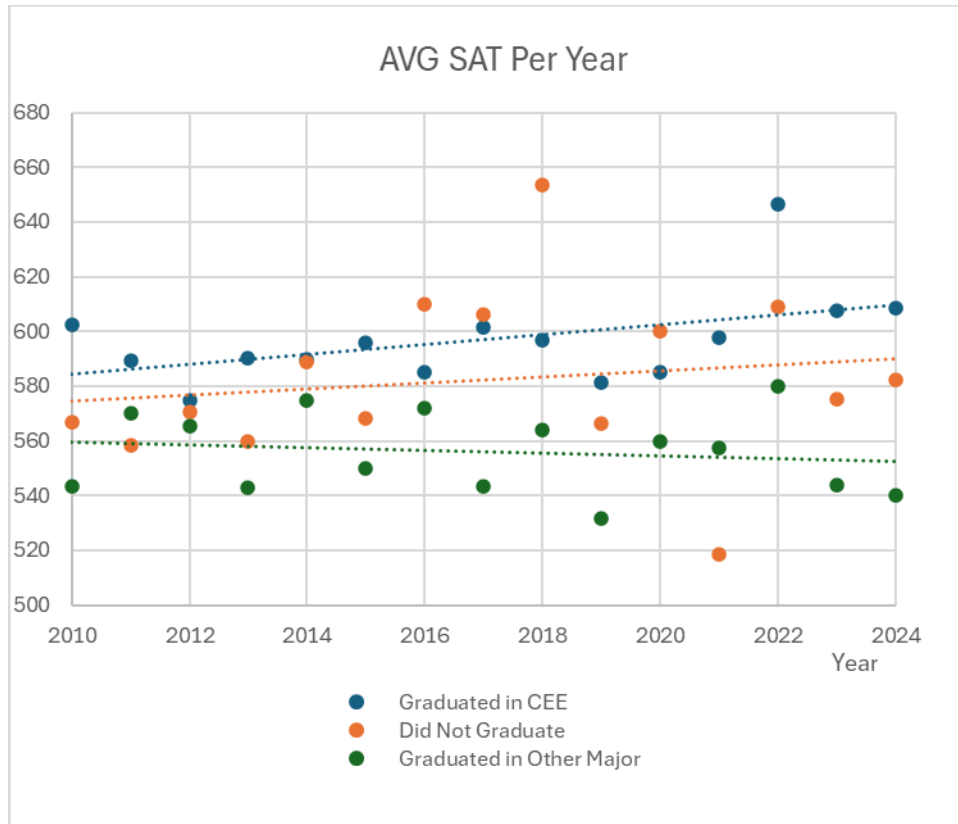


Figure 5 – Average SAT Score for 15 Years

The data was closely considered to determine whether the average values presented were consistent with a normal distribution. The concern was prompted again by anecdotal evidence that, during the current 2024-2025 academic year, academic performance in many engineering courses has been bimodally distributed. It seems as if there is a group of students doing very well, performing at the “A” and high “B” range, and a group of students performing poorly, in the “D” and “F” range. Plotting the grades for some current courses confirms this. However, the math placement and SAT scores observed do not support this, but instead appear normally distributed. To confirm this, both the skewness and kurtosis were determined for each year for the cadets that graduated in CEE. The results are shown in Figure 6. MP means Math Placement in the figure.



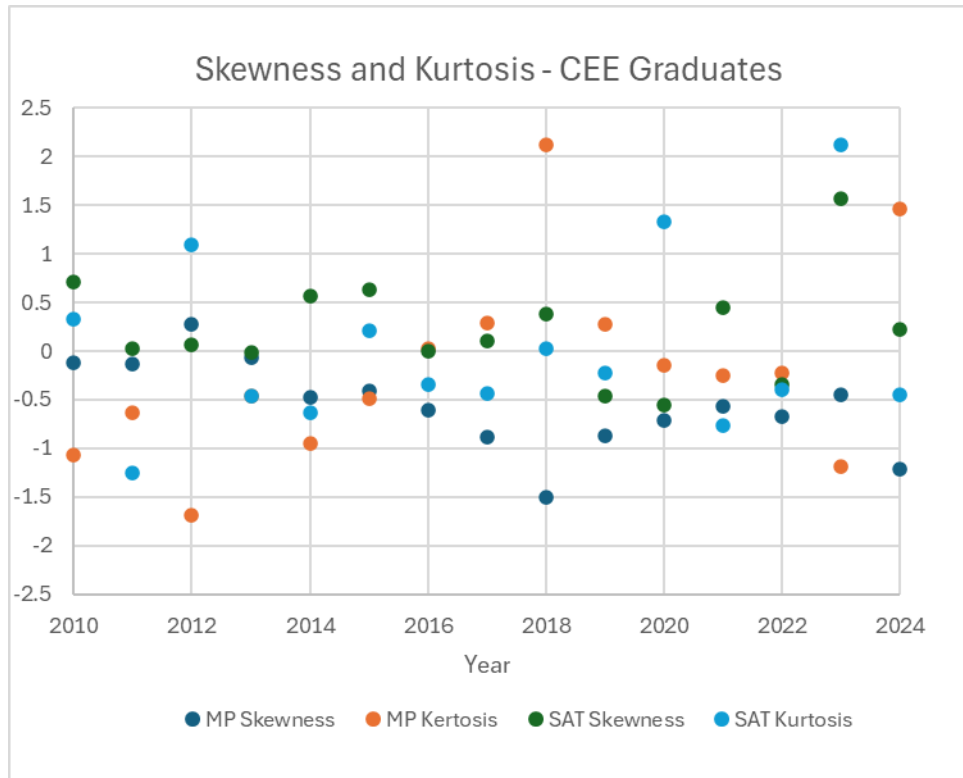


Figure 6 – Skewness and Kurtosis for CEE Graduates

As shown in Figure 6, nearly all the data points for both the skewness and kurtosis are within a plus or minus 2 range. This indicates that the data can be considered normally distributed. It does not appear that the math placement and SAT values over the past 15 years have become bimodally distributed even though performance in the current academic year shows this trend.

The class of 2025, which has not graduated, was also considered. Although it is impossible to predict with 100 percent certainty who will graduate in CEE in this class, a best guess was made and the math placement scores were considered. Of the 29 cadets that are anticipated to graduate in May 2025, only 7 submitted their SAT scores. VMI went test optional during the pandemic. The average math placement score was determined to be 21.8 with skewness and kurtosis values of -1.3 and 1.8 respectively. The slightly negative skewness value indicates that the distribution is slightly skewed to the lower math placement scores, and the positive kurtosis value means that the data is more singly peaked and does not demonstrate two separate peaks or flatness.

The last relationship considered was the relationship between math placement score and SAT. Figure 7 shows this relationship for 635 of the 709 cadets that graduated in CEE. The 74 missing cadets most likely submitted ACT scores only. As shown in Figure 7, there is considerable variability in the relationship between the two producing a low R-squared value (0.25). The bubble sizes indicate how many scored the same combination on the math placement and SAT tests. There were 298 unique combinations. The largest bubble shows the nine that scored a 22 on the math placement test and 570 on the SAT test. A linear trend line for the best fit linear prediction using the 298 unique combinations of scores predicts a combination of 22 and 600 when the data is considered as shown. When all 635 data points are considered, the line

is shifted slightly higher, predicting a combination of 21 and 600. Interestingly, the R-squared values are nearly identical, both at 0.25, regardless of whether the 298 unique combinations or all 635 combinations are considered.

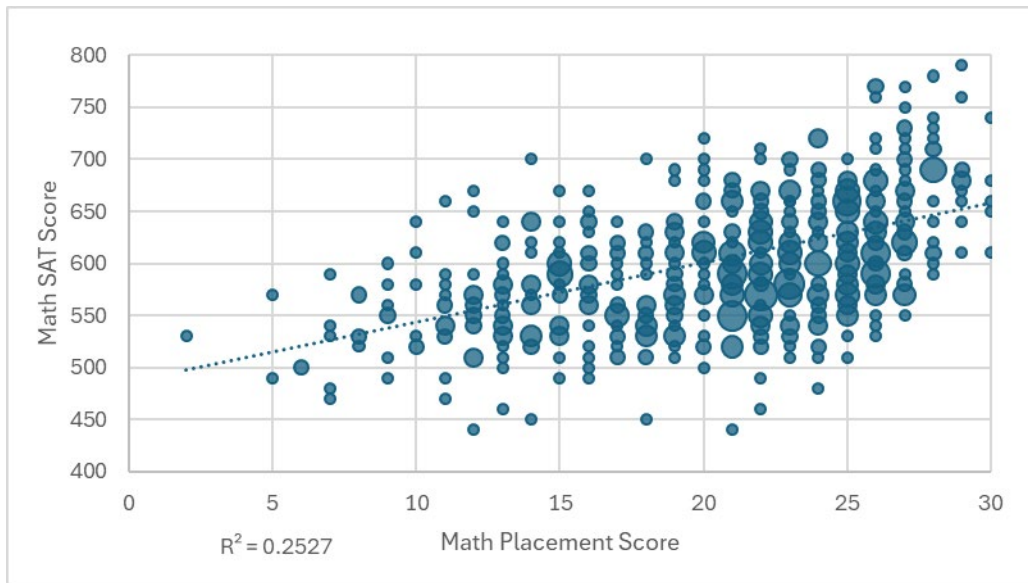


Figure 7 – SAT vs Math Placement

## Conclusions

The results of the objective consideration of the data for the cadets associated with the CEE department over the past 15 years (up to the graduating class of 2024) are surprising to many of the faculty in the CEE department. Anecdotally, the faculty members have been experiencing bimodal performance in many courses since the pandemic and have blamed decreasing math skills for the loss of the “C” students. The data does not support this.

The use of a minimum score of 21 to determine whether a cadet should be allowed to take Calculus I was partly supported by the data. The CEE department will consider the following conclusions as it continues to investigate the issues:

1. The number of cadets that score below a 21 on the math placement test and are ultimately able to graduate with a Civil Engineering degree is significant. This group of cadets should not be restricted from attempting CEE as a major. Since the community college system has recently made it nearly impossible to take both Precalculus and Calculus I in the same summer (since both are now offered in the same longer summer semester), VMI and the CEE department will need to investigate ways to provide a path for students that receive below a 21 on the math placement test and fail Precalculus on their first attempt.
2. The data does suggest that there are two natural breaks that should be considered in the future. A different path may be needed for cadets that score less than 10 on the math placement test. These cadets most likely need a developmental math course prior to attempting Precalculus if they elect to choose a STEM major.

3. As overall enrollment numbers drop, combined with the drop in the percentage of cadets wanting to undertake a more difficult STEM major, the number of cadets that will be able to pass Precalculus will continue to drop simply because there are fewer cadets with the math skills needed during their first semester. The problem is more associated with fewer numbers than with less ability. The best way to improve the situation will be targeted admissions efforts.
4. The CEE department must look to other reasons for the bimodal academic performance. It is possible that some of the problems are associated with certain teaching techniques, both in the K-12 years, and at VMI. And it is also possible that the transition from high school to college has fundamentally changed since the pandemic.
5. The math placement test score is a relatively good indicator of performance in some areas, but not all areas. Additional indicators such as high school GPA and/or standardized tests (SAT or ACT) may improve the ability to predict success (defined as obtaining the CE degree). The low R-squared value of 0.25 indicates that either the math placement test or the SAT or both are not able to accurately predict a certain level of math ability. It is also possible that more students are cheating on the math placement test. The test is taken after a student is admitted but prior to introduction to the honor code.

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