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Applying Six Sigma to Precalculus Algebra

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Abstract

Mathematical preparedness among engineering and engineering technology students, particularly in calculus and pre-calculus sequences has persistently documented and are frequently associated with high failure rates, delayed progression through degree programs, and attrition from engineering pathways [10], [12]. Researchers have approached this problem from multiple perspectives, including curricular reform, student-centered pedagogy, preparatory interventions, and quality-management frameworks, like Six Sigma. This paper presents first, a literature of the challenges of student mathematical preparedness and solutions and second, the attempt to implement Six Sigma principles to improve the teaching of precalculus algebra. Preliminary results include reduced process variation and a modest decrease in DFW rates from 52% to 31% in five semesters. Finally, a discussion of the continued application of Six Sigma to precalculus and its anticipated future application to calculus is presented.

Literature Review

A substantial body of literature documents persistent challenges in mathematical preparedness among engineering and engineering technology students, particularly within precalculus and early calculus sequences. These challenges are consistently associated with high failure rates, delayed progression, and attrition from engineering pathways [10], [12]. Rather than isolated instructional shortcomings, scholars increasingly frame precalculus underperformance as a system-level problem requiring coordinated curricular, pedagogical, and institutional responses.

Early critiques of traditional calculus instruction anticipated this systems perspective. Hamming [3] argued that conventional mathematics courses prioritize abstraction and formalism at the expense of relevance, thereby diminishing student motivation and degrading overall engineering system performance. His assertion, that optimizing individual courses without regard to curricular integration harms the broader system, foreshadows later quality-improvement approaches grounded in systems thinking.

Subsequent research emphasizes student-centered, application-driven instructional models as a response to precalculus and calculus attrition. Studies of student-centered calculus reforms report improved conceptual understanding, persistence, and attitudes toward mathematics when active learning and engineering-contextualized problems are incorporated [10], [13]. Similarly, assertive precalculus interventions designed specifically for engineering students demonstrate positive effects on readiness and retention by narrowing curricular scope and emphasizing competencies aligned with downstream engineering coursework [15].

While these reforms show promise, the literature also notes a recurring limitation: many interventions lack systematic mechanisms for diagnosing root causes, coordinating changes across stakeholders, and sustaining improvements over time. This gap motivates the integration of continuous improvement frameworks into mathematics education.

Parallel to pedagogical reform efforts, scholars have explored the application of Total Quality Management (TQM), Lean, and Lean Six Sigma (LSS) in mathematics and engineering education. TQM-oriented studies emphasize continuous improvement, stakeholder engagement, and data-driven decision-making, while also identifying challenges related to faculty resistance and institutional culture [14]. These approaches shift attention from individual student deficiencies toward instructional and curricular processes as objects of improvement.

Systematic reviews [1], [9] confirm that Six Sigma based methodologies, particularly DMAIC, are most commonly applied in higher education, where standardized courses, measurable outcomes, and accreditation pressures create favorable conditions for structured improvement.

Furterer et al. [2] extend this line of inquiry through a Lean Six Sigma investigation of poor performance in a mathematics preparatory course for engineering technology students. Using Participatory Action Research embedded within DMAIC, the study identifies root causes including low student motivation, weak study skills, excessive course content, and limited understanding of mathematics' relevance to engineering applications. Notably, prior exposure to mathematics alone did not predict success reinforcing earlier critiques by [3] and findings from student-centered reform studies.

The proposed improvement strategies of online preparatory tools, reduced and refocused content, applied engineering examples, expanded tutoring, and academic coaching align closely with broader calculus reform literature. What distinguishes the Lean Six Sigma approach is its replicable diagnostic structure and control mechanisms, enabling sustained coordination of instructional reform rather than isolated innovation.

Kaizen-based instructional models represent the most direct translation of continuous improvement principles into pedagogy. The student-centered calculus case study by [4] demonstrates that frequent low-stakes assessment, immediate feedback, and structured repetition create a cybernetic learning system in which instructional adjustments occur in real time. Although implemented in calculus, the model is highly transferable to precalculus, where early disengagement and conceptual gaps often compound rapidly.

Across studies, learning continuity and not short-term exam preparation emerges as the strongest predictor of success, reinforcing the importance of embedded feedback loops in gateway mathematics courses.

Collectively, the literature suggests that improving precalculus outcomes requires integrated solutions combining curricular relevance, student-centered pedagogy, preparatory support, and continuous process improvement. Hybrid improvement architectures—DMAIC for structural alignment and Kaizen/PDSA cycles for instructional refinement—offer a scalable pathway for addressing persistent variability in student preparedness while maintaining pedagogical integrity.

Introduction of the Precalculus Algebra Problem

At one time or another every university has discussed high failure rates, delayed progression, and attrition of students. The moniker attached to many of the courses with these characteristics is "gateway". Precalculus algebra, at many engineering schools, is one of those "gateways". This paper is a presentation of the beginning of the rebranding of precalculus algebra from a "gateway" to a "pathway" to success.

Between three to six sections of pre-calculus are offered every fall and spring semester with a total enrollment of about 600 in the fall and 250 in the spring. The prerequisite for this course is a math ACT score of 19 or its equivalent which could be a placement test or some other remediation. Failure rates, described as DFW percentage rates in this paper, have been as high as an average of 52% for all sections taught in one semester, with some instructors having had DFW percentages as high as 65%.

Beginning in fall 2023, the basic methods of Six Sigma were applied for three years or, more precisely, five semesters to the teaching of a multi-section pre-calculus algebra course.

By incorporating Six Sigma, process variation has been reduced with a modest decrease in DFW rates from the high of 52% to a low of 31% in five semesters. The application of Six Sigma to this and other courses will be discussed along with the anticipated future results of its application to calculus in the conclusion of this paper.

Methodology and Results

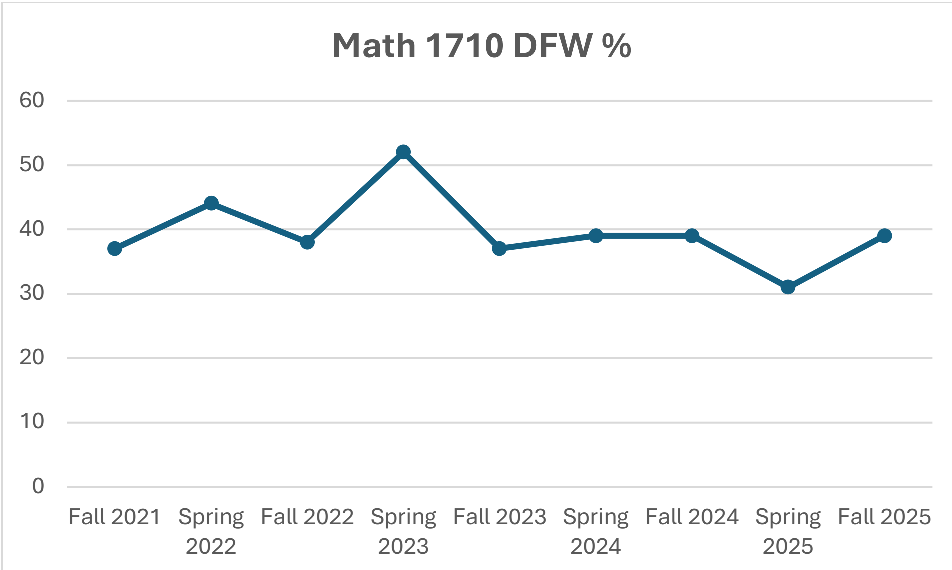
The Six Sigma method consists of these five steps: Define, Measure, Analyze, Improve, and Control (DMAIC). This method was introduced to the precalculus algebra committee in fall 2023 with the challenge of reducing the DFW rate. A brief definition for each step is given below with an example and discussion of how that step was applied to precalculus reform.

Define – From the problem at hand, decide on clear, obtainable goals to achieve.

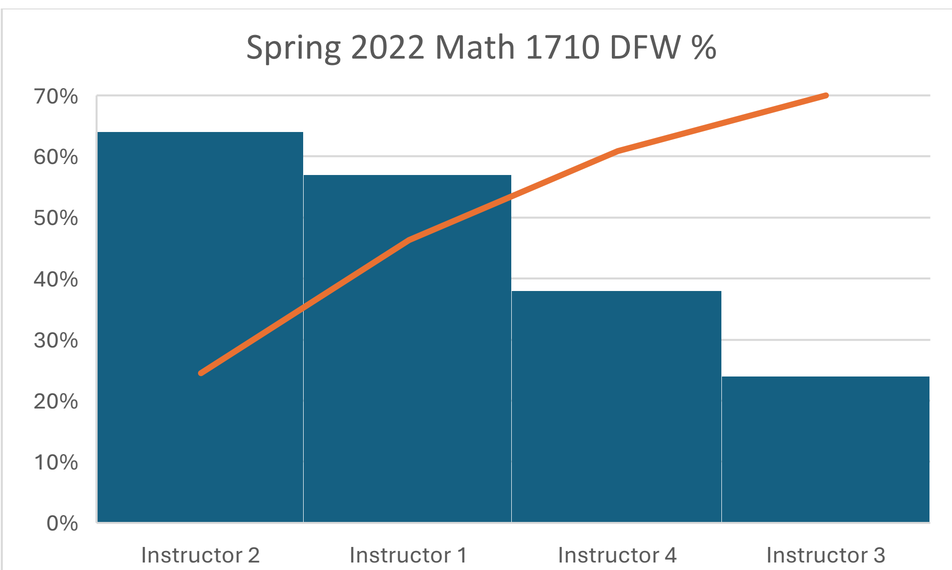
For precalculus, the goal was very clear, reduce the DFW rate, i.e., increase the success rate of precalculus students. Based on the results from the previous spring 2023 semester, with a DFW rate of over 50%, it became apparent the overall course structure, grade rubric, teaching and assessment methods must be analyzed, monitored, and adjusted.

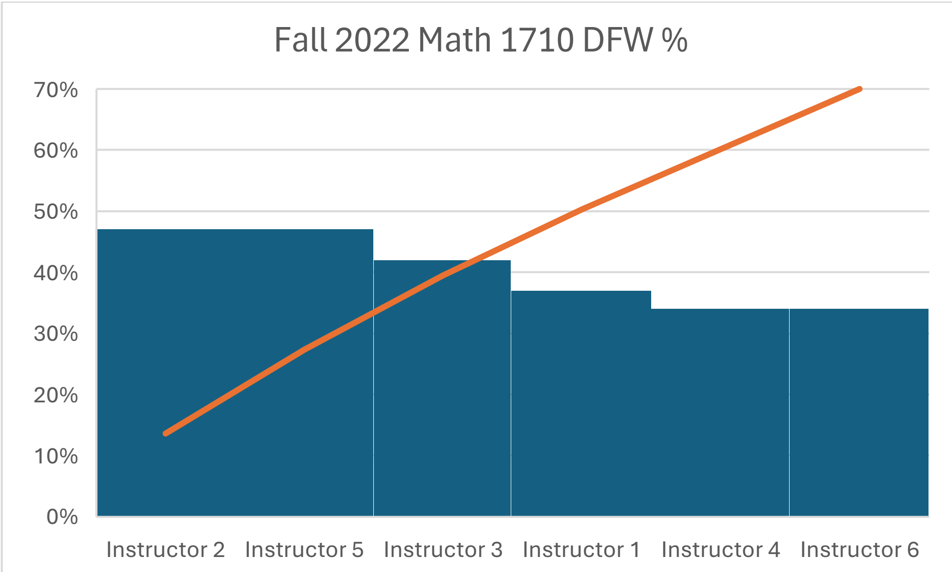
Analyze – Using statistical tools and methods, determine the root causes of the defects or inefficiencies.

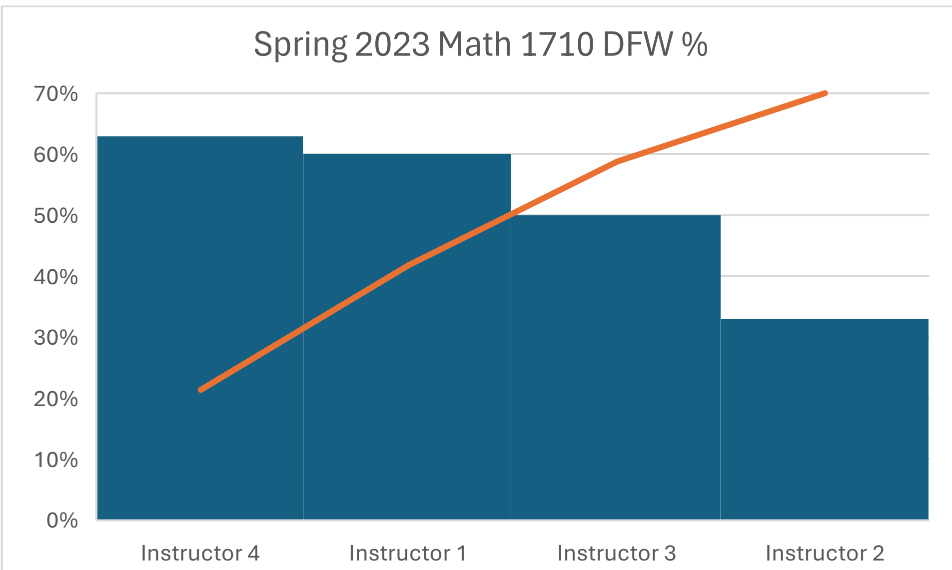
Individual precalculus section's grade distributions were compared as well as the number and types of assessments given and the various teaching methods. There were obvious differences in all factors. DFW rates for fall and spring semesters were plotted in a control chart like method. A true control chart could not be implemented yet because of the lack of known parametric values, like the process standard deviation. Summer enrollment was relatively negligible compared to the fall and spring enrollments and hence was not included.



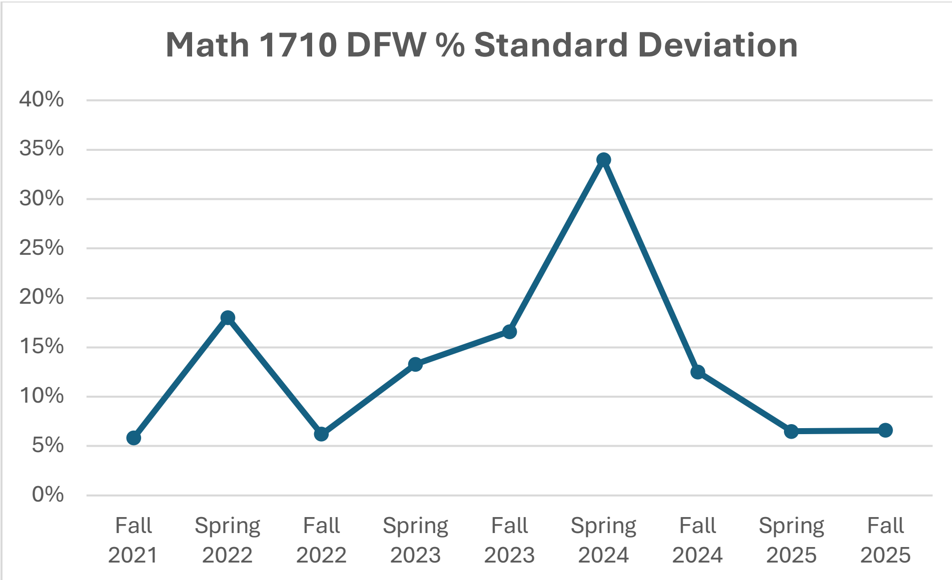
Pareto charts of the DFW rates for instructors per semester were created and a small set of them presented here.



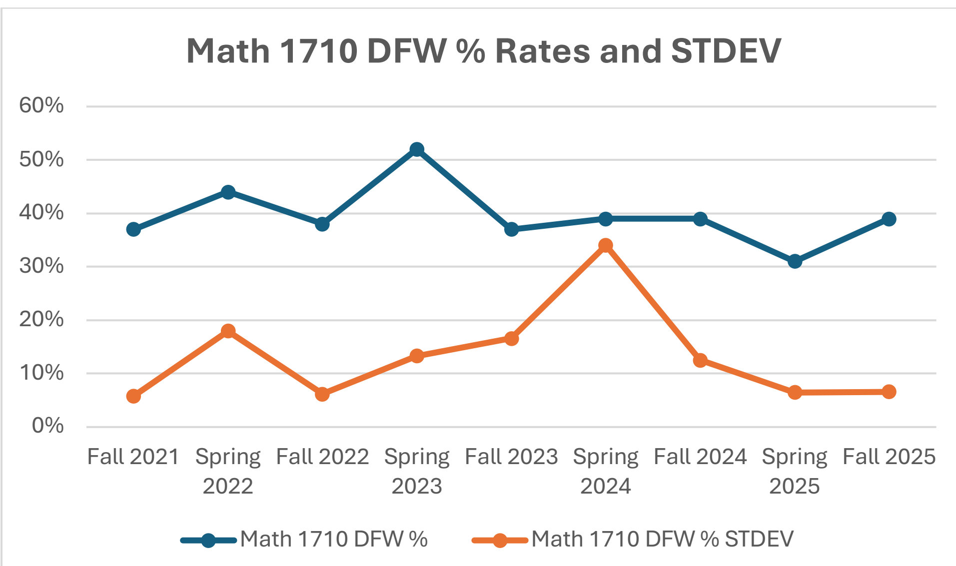




To continue and enhance the investigation, the standard deviation of DFW rates between instructors for each semester was also plotted.



When plotted together, a slight trend can be noticed between the mean DFW rates and the standard deviations of the rates between instructors per semester.



Although not an aggressively strong correlation here, there appears to be a subtle connection between the average DFW rate and its standard deviation. By lowering the standard deviation of the DFW rate, could the DFW rate also be reduced and a baseline be achieved?

The goal of the project had morphed. Reducing variability between sections was now an additional goal.

Improve – Implement changes that make positive, significant improvements.

Because of the variability found in multiple areas ranging from the number of homework problems assigned to the final exam grading rubric, steps were taken to reduce this variability. At the beginning of each semester, discussions on where variability still lies between sections were had and changes were made. The first year of precalculus reform included a request of faculty to follow the departmental syllabus to the letter along with common, pertinent questions on final exams. Previous and current DFW rates were tracked. In the second and third years faculty moved to online homework and assessments with common question pools. DFW variability was reduced.

Control – This step involves incorporating measures to sustain and maintain the improvements already obtained.

For precalculus algebra, this step is the hardest because of the turnover of instructors, either through scheduling, retirements, or job changes. In the past the precalculus algebra course committee might have met once a semester to discuss adopting a new book or possibly updating the syllabus. Now, meetings began before the semester starts with discussions including what common assessment questions to give and common grading rubrics. Consistency of the product, i.e., teaching and assessment of precalculus, is the committee's number one goal.

Conclusion and Future Work

The application of Six Sigma as a process control method has been successful, to a point. Obviously, the DFW rate has not been reduced but the variability between sections has. Making the course "instructor agnostic" has helped with such reduction.

By implementing Six Sigma, the faculty are now more trusting of the methodology and are willing to apply it to continue to improve course success. As the faculty grew to understand the Six Sigma methods, the objective of reducing DFW rates now included reducing the variability of DFW rates to get a baseline DFW rate. Other course committees are starting to apply Six Sigma. The calculus committee has likewise resolved to reduce variability between sections, with DFW rates recorded from 15% to 70% in one semester, to get a baseline DFW rate to understand further how to reduce it.

As mentioned in the literature review, faculty resistance and institutional culture can be a barrier to change. But when the resistance is reduced and a cultural shift is made through the introduction of a successful quality enhancement method like Six Sigma, curricular and instructional processes can be adjusted to exact a positive change.

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