Calculus 1 (MATH 1220) Course Redesign at Western Michigan University

Instructor Collaboration in Calculus 1 to Improve Student Retention and Progression

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At Western Michigan University, Calculus 1 (MATH 1220) had low student success rates. After issues were identified, a team of instructors was assigned to collaboratively coordinate the course. In this case study, we describe the evolution of the coordination, effects on instructors of this course, effects on student success in this course, and effects on other courses. Changes implemented make access to calculus education more equitable.

STATEMENT OF THE PROBLEM

In MATH 1220 at Western Michigan University (WMU), local data revealed a steady decline in student success rates from 67% in 2005 to 48% in 2014. Since many of the MATH 1220 students use this course for the calculus requirement in their STEM major, success rates affect majors in multiple departments. In a cross-disciplinary committee, multiple areas of opportunity were identified. In this case study, we discuss how implementing a coordinated approach to teaching calculus addressed the following issues.

Issue 1: Students are not equally prepared for calculus. Students could place into the course by ACT/SAT score, by departmental placement test score, or by completing a prerequisite course at WMU or elsewhere. In addition, some students had weaker preparation because they had longer time between satisfying the prerequisite and taking calculus. Some students needed remediation.

Issue 2: The course could better prepare students for subsequent courses. Anecdotal evidence from partner disciplines suggested that some students struggled to use their calculus knowledge in subsequent courses.

Issue 3: Student success rates (nearly 50% of students who started the class) were discouragingly low.

Issue 4: When disaggregated by instructor, data showed high variability in success rates. Some aspects of the course were uniform (text, topics list, contact hours); however, instructors had great flexibility in the course they delivered. Instructor choices impacted the student skills and the nature of student understanding; what the students had mastered in turn influenced the effectiveness of the course as a prerequisite for subsequent math and science courses. Variations resulted in different learning environments which could unintentionally create inequities for students both in MATH 1220 and in subsequent courses.

METHODS

A team of instructors was assigned to coordinate elements of the course to address these issues. This instructional team began planning collaboratively the semester prior to implementing the course coordination. The following common elements were developed by the team:

- Common student learning outcomes
- Common grading scale and grading scheme
- Inclusion of low-stakes assessments in grading scheme
- Pacing
- Order of topics
- Two common midterm exams and one common final with common rubrics
- Two mastery tests to assess and improve computational skills, one for prerequisites and another for limits and derivatives
- Similar lesson plans for the first few days of class to ease student transitions between sections
- Self-remediation of algebra and precalculus content using ALEKS

To address issue 1 (unequal preparation), the initial team incorporated the online program ALEKS. During the first few weeks of the semester students were required to use ALEKS to complete an initial assessment on prerequisite skills to determine opportunities for improvement. The implementation of ALEKS allowed instructors to focus on calculus concepts while students could use the tool to self-remediate prior content. To motivate the students to remediate, a first mastery test was given in ALEKS on prerequisite material. In subsequent semesters, students were also provided with "just-in-time" remediation of their algebra and trigonometry skills in ALEKS.

To address issue 2 (student preparation for subsequent courses), issue 3 (student success rates) and issue 4 (high variability of success across sections), the teaching team has been meeting at least once per week to discuss instructional issues and instructional methods, exams, and rubrics during the semester. For example, two mastery tests were developed. The instructional team discussed the skills most important for the calculus sequence, both from precalculus and calculus 1. The first mastery test was designed to ensure that students remediated algebra and trigonometry skills, and the second mastery test was designed to ensure that students became proficient with limits and derivatives. For each mastery test a score of at least 75% was required for passing, with a maximum of three attempts allowed. In addition, the team created and incorporated active learning materials to introduce key concepts (first day activity on functions, E-δ definition of limit, limit definition of derivative, Riemann sum approximation of integral).

Two faculty members agreed to serve as co-coordinators and to teach the course every semester for three years. The co-coordinators have been leading the teaching teams. The teams use the Deming Cycle (Plan-Do-Study-Act) to improve the outcomes of the course (Bryk, Gomez, & Grunow, 2010). At the start of each semester, the team discusses common elements. During the semester, the team enacts these elements, writes additional materials, and examines student progress. At the end of the semester, the team discusses the effectiveness of the approach. For the following semester, the next team incorporates effective elements and designs (or revises) elements to address known issues.

The chair prioritizes selection of instructors for the course: each semester, team members are chosen to maintain instructional consistency and to bring new skills to the team. With every introduction of a new member, careful communication and negotiation of common elements allowed for the continuation of a coordinated approach. The development of common examinations and rubrics by the entire team provided key insights into instructor beliefs and behaviors and helped provide a more equitable learning environment for students.

In addition, most sections are assigned an undergraduate learning assistant. A learning assistant is a student who excelled in the course and demonstrated potential for co-learning. Throughout the semester, these students are provided with pedagogical training by the Student Success Services and their section's instructor. The learning assistant attends class daily and assists students in group-work activities. Outside of class, the learning assistant works with the course instructor to identify gaps in students' conceptual understanding and skill-based procedures. Together instructor and learning assistant develop strategies and activities to implement in the learning assistant's out-of-class help sessions and weekly email reminders/summaries.

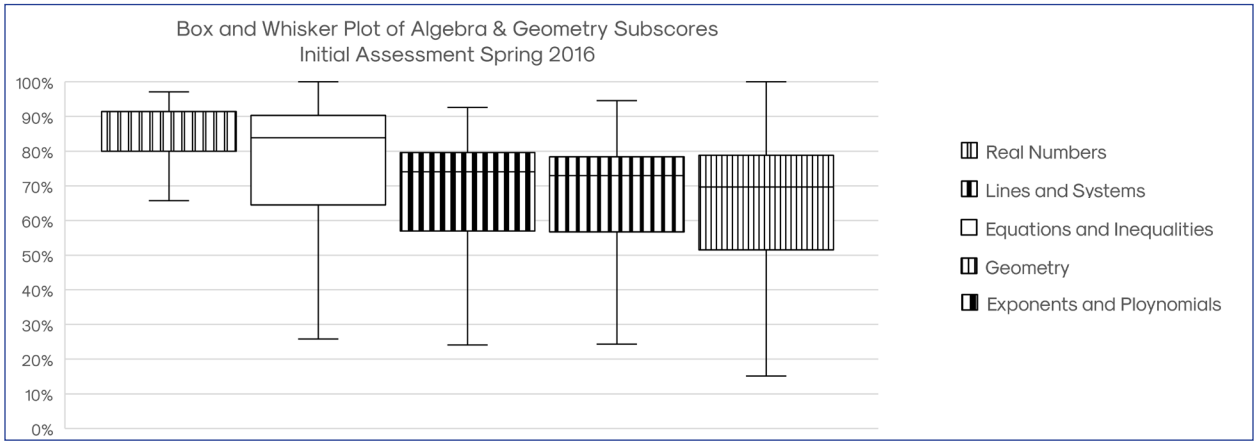
OUTCOMES

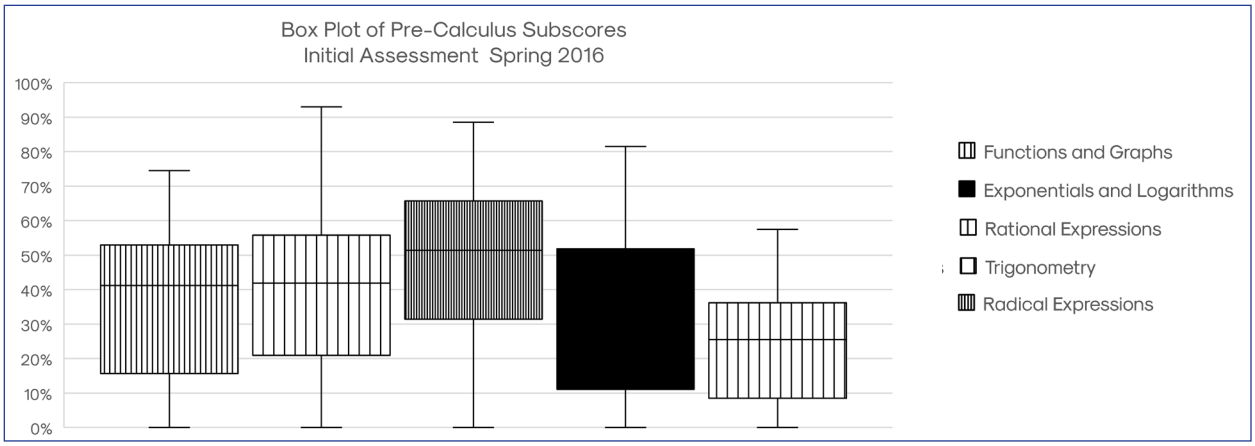
Student Prerequisite Preparation

The initial team verified the lack of student readiness. Student readiness in each of ten subject areas is shown in Figure 1. The ten areas can be roughly separated into two categories: "algebra & geometry" and "precalculus." The student scores in the precalculus category were noticeably lower and more varied than those in the algebra & geometry category. In all precalculus areas, the median score is below 52%.

Figure 1

Box Plots of Prerequisite Content Area Scores By Student





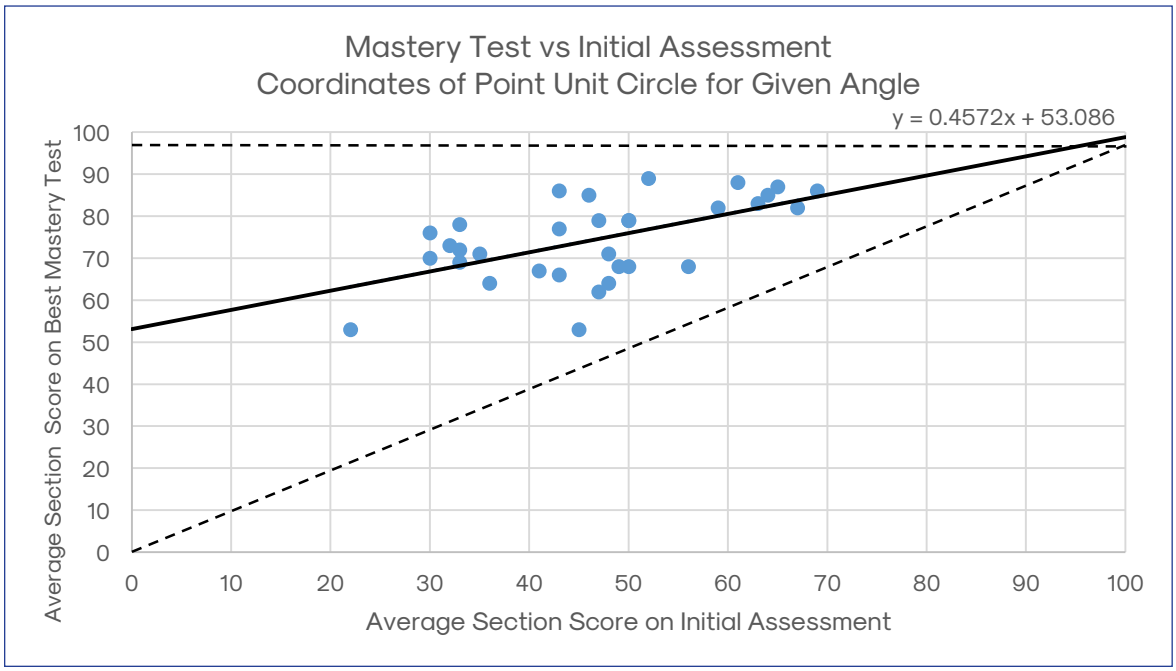
Student scores in algebra and geometry (left) are higher than in precalculus (right). In all areas, many students are underprepared, and there is high variability among students.

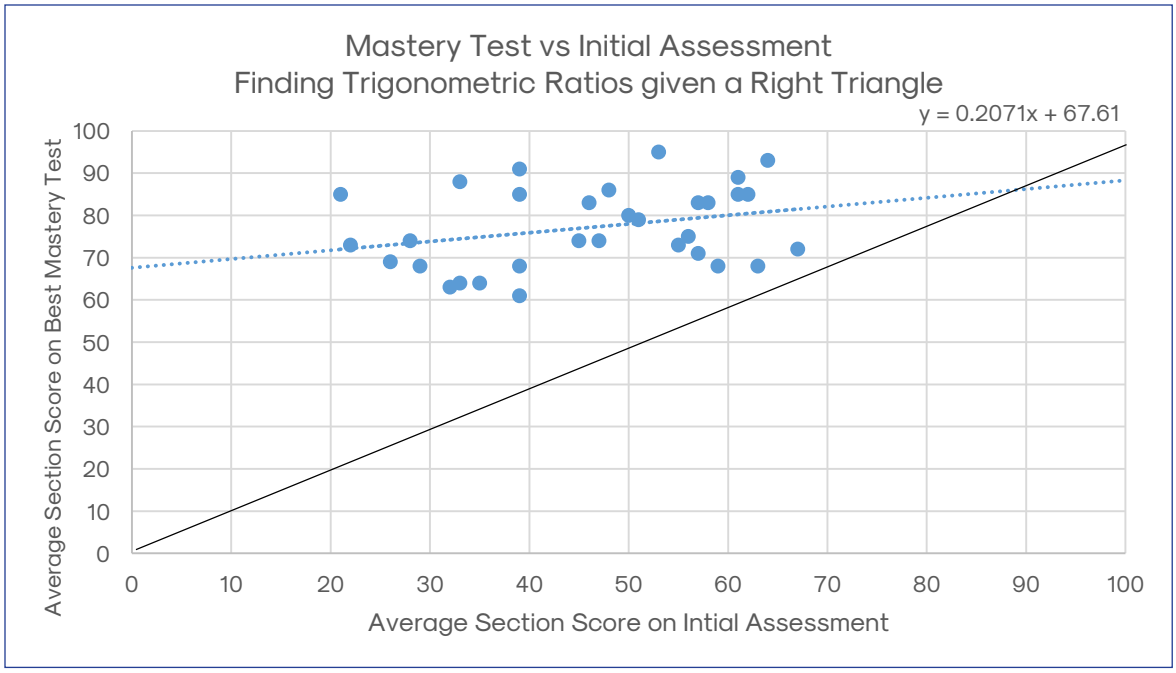
The students made progress with their prerequisite knowledge. We consider trigonometry, an especially weak area, as an example. In Figure 2, section averages are shown for three trigonometry topics (unit circle, right triangles, solving trigonometric equations) on the initial assessment and on the mastery test (best score) for all sections from Fall 2016 to Spring 2019. If section average performance stayed constant, then the best fit line would be y=x. In fact, all data shows that section performance increased from the initial assessment to the mastery test. This can be visualized by seeing how far each data point is above the line y=x. If all students mastered the topic, the best fit line would be y=100. This can be visualized by seeing how far each data point is below the line y=100. In fact, no section had 100% mastery of these topics. However, the students did increase their computational skills and understanding of prerequisite material.

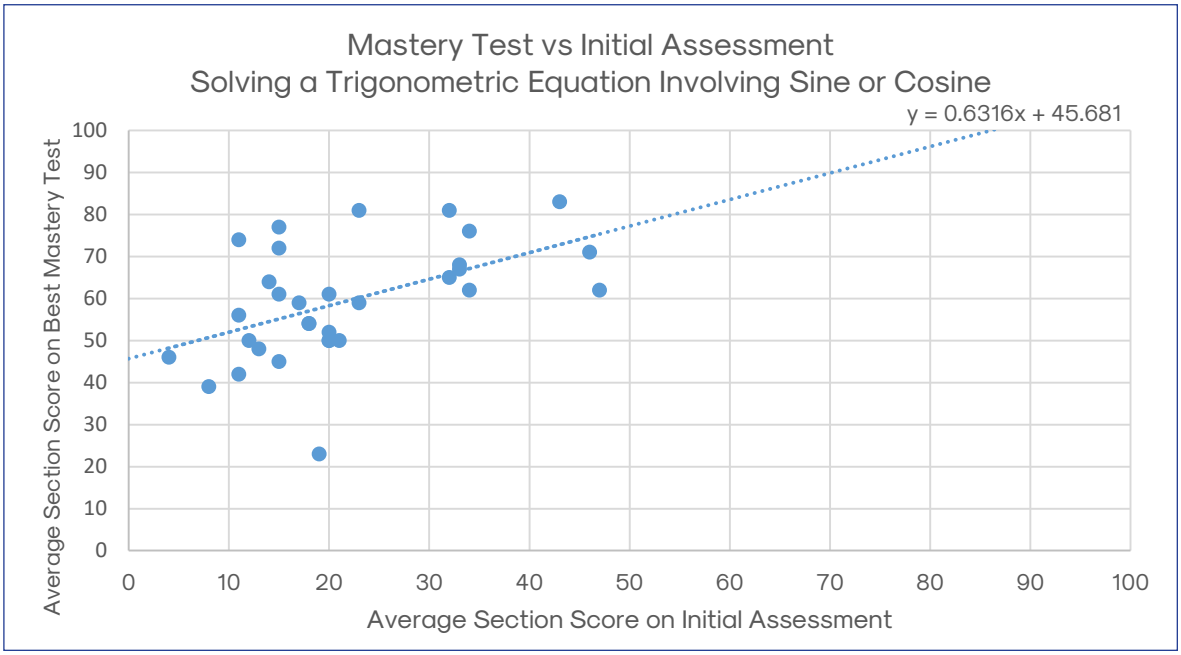
Figure 2. Scatter plot of section averages of initial assessment scores vs. best mastery scores for all sections between Fall 2016 and Spring 2019 for three trigonometric problems: coordinates of points on unit circle (top), trigonometric ratios in a right triangle (middle), and solving trigonometric equations involving sine or cosine in an interval (bottom). Each point represents a single section. The solid line is the linear regression line. Since all data points are between the dashed lines (y=x and y=100), section average scores improved from initial assessment to mastery test, but no section achieved complete mastery.

Figure 2

Scatter Plot of Section Averages of Initial Assessment Scores vs. Best Mastery Scores for All Sections Between Fall 2016 and Spring 2019 for Three Trigonometric Problems




Mastery Test vs Initial Assessment
Finding Trigonometric Ratios given a Right Triangle
y = 0.2071x + 67.61
Average Section Score on Best Mastery Test
Average Section Score on Intial Assessment
0
10
20
30
40
50
60
70
80
90
100

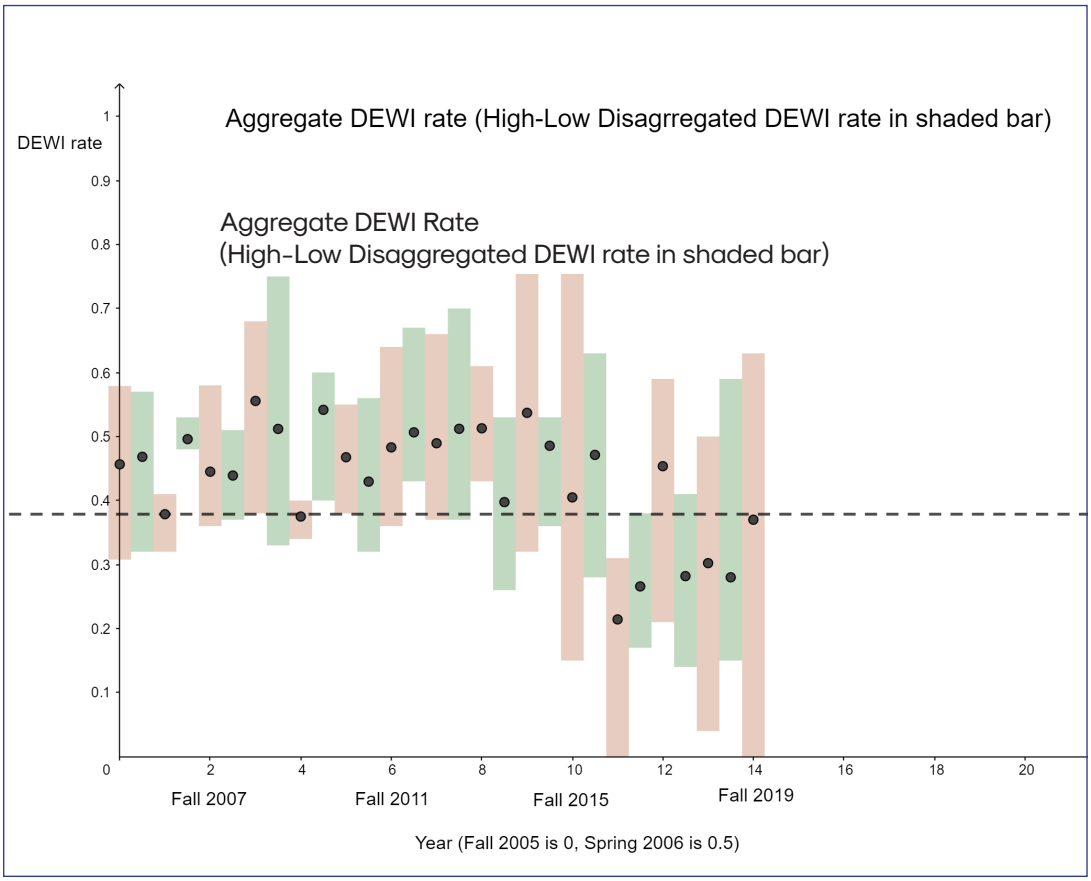

Mastery Test vs Initial Assessment
Solving a Trigonometric Equation Involving Sine or Cosine
y = 0.6316x + 45.681
Average Section Score on Best Mastery Test
Average Section Score on Initial Assessment
0
10
20
30
40
50
60
70
80
90
100

Student Success

The DEWI rate has improved. The DEWI rate for fall and spring semesters is shown in Figure 3. In most semesters since the redesign, the DEWI rate is lower than the lowest aggregate DEWI rate from the pre-coordination semesters.

Figure 3

DEWI Rates for Each Fall or Spring Semester Between Fall 2005-Fall 2019



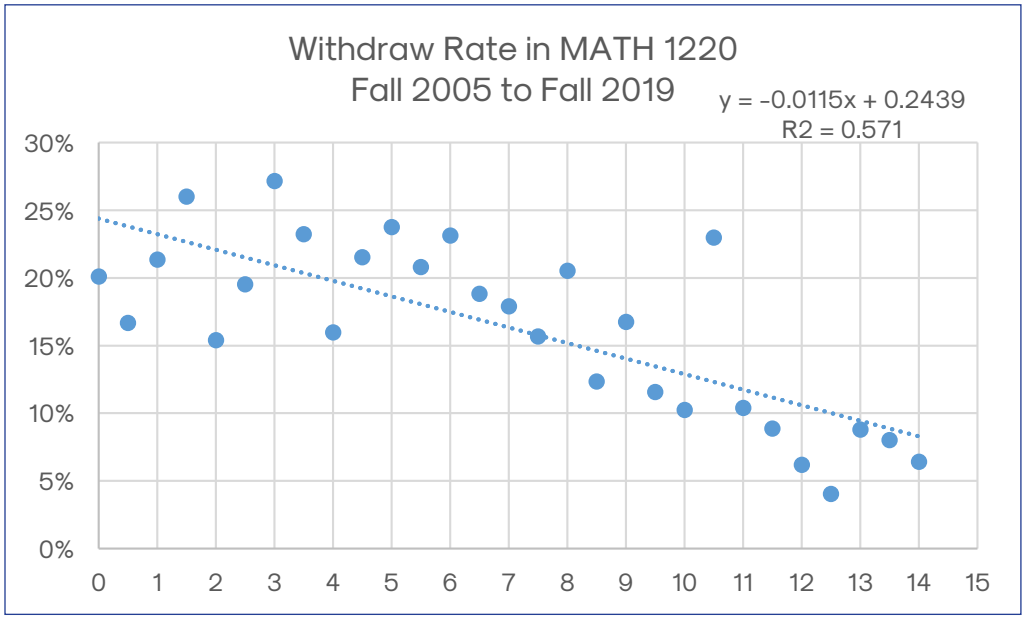
For each semester, the aggregate DEWI rates is depicted by a dot and the shaded bar shows spread across sections. Time is measured since Fall 2005: Fall 2005 is 0 and Spring 2006 is 0.5, etc. Course redesign began in year 10.5. The dotted horizontal line is the lowest aggregate DEWI rate from the pre-coordination semesters. In most semesters since the redesign, the aggregate DEWI rate has been lower than the lowest aggregate DEWI rate from before the redesign, but the variability between sections remains large. Adapted from "A Collaborative Approach to Coordinating Calculus 1 to Improve Student Outcomes" by Mingus and Koelling (2020).

While the homogeneity across sections has improved from an instructional perspective, the variability in the progression rates has not diminished significantly. Some heterogeneity is expected due to factors beyond the instructor's or team's control (e.g. student cohorts, Honors College sections). Other sources of heterogeneity remain to be studied to determine if there is an underlying equity issue that should be addressed.

Although the withdraw rate prior to redesign was declining and has continued to decrease overall, the withdraw rate spiked during the first semester of the redesign as shown in Figure 4. This spike may be attributed to the timing of the initial assessment. During subsequent semesters, the team moved the

Figure 4

Aggregate Withdrawal Rates from Fall 2005 Semester to Spring 2019 Semester



Time is measured since Fall 2005: Fall 2005 is 0 and Spring 2006 is 0.5, etc. Course redesign began in year 10.5. Withdraw rates were declining before the redesign and continued to decline after the redesign. Adapted from "A Collaborative Approach to Coordinating Calculus 1 to Improve Student Outcomes" by T. Mingus and M. Koelling (2020).

CONTINUATION AND EXPANSION

Continuation in MATH 1220

The teaching team for MATH 1220 continues to coordinate, revise materials, and address new challenges, and the chair continues to assign a teaching team. The team has transitioned from using ALEKS for remediation to using WebAssign, and remediation methods will continue to evolve as the technology available and placement mechanisms change. The team has transitioned through three textbooks and will continue to evolve as student use of texts and online resources evolve. These adaptations have increased as the team has shifted learning from a face to face environment to online modalities in response to the COVID-19 pandemic.

Expansion into Other Courses

There has been an expansion of coordination. Since multi-section courses taught by faculty do not have a tradition of close coordination, the coordination of MATH 1220 was novel. Since similar issues to those in MATH 1220 were observed in MATH 1180 (precalculus) and MATH 1230 (calculus 2), features of this coordination were expanded into those courses through the efforts of original MATH 1220 team members.

In Spring 2018, precalculus was converted from a large lecture setting with multiple recitations to a multi-section course with a coordinator. This was enacted to better prepare students for calculus, accommodate a student-centered environment, and facilitate a more uniform approach and collaboration throughout all sections.

Since Spring 2018, there has been a deliberate and organized effort to increase collaboration among all precalculus instructors. The precalculus teaching team established a common set of goals for the course, course schedule for covering the topics, grading scheme and similar grading items. Weekly meetings were conducted throughout the semester: the team discussed a variety of teaching techniques and strategies for improving student success. These discussions centered on methods to improve student's conceptual understanding and ability for practical application. The team also developed uniform exams, quizzes and worksheets for all sections that balanced conceptual understanding and procedural fluency to prepare the students for calculus. There were also common grading rubrics for quizzes and exams.

There was a semester of increased coordination of MATH 1230 (second semester calculus). The instructors met on a weekly basis to discuss goals and instructional issues, and some instructors worked with learning assistants. A group of the MATH 1230 instructors worked closely together creating transparent writing assignments for the content to follow those in MATH 1220, and these assignments have been used by some faculty in later semesters.

Impact on Progression through Calculus Sequence

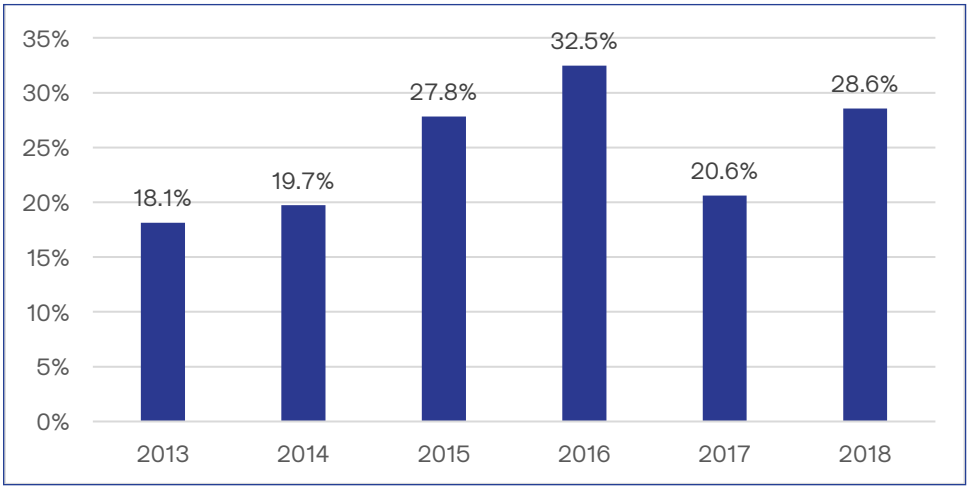
Changes in MATH 1220 affect subsequent courses. The following analysis looks at student progression from MATH 1220, taken in a fall semester, to MATH 1230 in the subsequent spring semester. We study cumulative progression eligibility percent (CPE), the percent of students who earned a grade in MATH 1220 that achieve a grade in MATH 1230 that makes them eligible for MATH 2720 (vector calculus). This analysis begins with the 2013-2014 academic year and ends with 2018-2019 . Figure 5 (top) shows the CPE. These percentages are relatively stable and show a slight upward trend. The best CPE occurred in the academic year 2016-2017 when the initial collaborative teaching team that had taught together in Spring 2016 continued working together for the next academic year. The dip in the CPE occurred in the 2017-2018 academic year, the first semester new members were incorporated into the team. The process of reconciling standards and renegotiating norms resulted in a lack of timely communication of instructor expectations to the students. Mechanisms to improve this communication between the students and instructors were created and implemented in the subsequent academic year. The CPE rebounded in the 2018-2019 academic year.

Figure 5 shows details of student progression. The percent of students who earned a grade in MATH 1220 is shown in the first row . The percent of students eligible to take MATH 1230 is shown in the second row . The percentage of students who earned a grade in MATH 1230 is shown in the third row. About ⅕ to ⅓ of students in MATH 1220 have majors that do not require MATH 1230. Thus, there is a natural decline in the number of students in the second semesters of calculus, so we expect a smaller percentage of students eligible for MATH 1230 actually completing it because many do not take the course. The percentage of students eligible to take MATH 2720 is shown in the fourth row. Combining these percentages, the CPE shown in the fifth row is obtained.

To study if the decreased DEWI rates were a result of degradation of course standards, we can look at these progression rates. The rates have not changed significantly. The CPE has trended slightly upward overall. This suggests that students are adequately prepared for the subsequent course, and the standards have been maintained.

Figure 5

Cumulative Percent Eligibility for 2720 AY 2013-2014 to 2018-2019



	Academic Year					
	2013	2014	2015	2016	2017	2018
Earned Grade in 1220	82.4%	82.8%	89.8%	89.6%	93.8%	92.3%
Eligible for 1230	66.7%	56.0%	66.3%	87.7%	58.2%	75.6%
Earn Grade in 1230	56.6%	53.2%	56.6%	60.3%	54.7%	49.6%
Eligible for 2720	58.3%	80.0%	82.6%	68.5%	69.0%	82.5%
Cumulative Eligibility for 2720	18.1%	19.7%	27.8%	32.5%	20.6%	28.6%

Figure 5 illustrates the cumulative percent eligibility (CPE) for MATH 2720 of those students who earned a grade in MATH 1220 (top) and details of CPE computation (bottom). CPE is computed by multiplying fractions of students who complete MATH 1220, of students who are eligible for MATH 1230, of students who earn a grade in MATH 1230, and of students who are eligible for MATH 2720. The fraction of students who earn a grade in MATH 1230 is low as expected, some students are not required to take MATH 1230. CPE has not dropped, suggesting standards were not lowered in course redesign.

COORDINATION AND INSTRUCTOR DEVELOPMENT

Coordination and communication about course priorities and expectations among instructors has created a more equitable learning environment for the students. The process of creating common assessments has helped faculty articulate their course goals and their expectations regarding student performance. Once these are articulated, instructors can communicate them to their students. Early and frequent communication of expectations is especially important for at-risk students who may have less academic capital than their peers and require more supportive educational environments.

LESSONS LEARNED AND POTENTIAL IMPLICATIONS

Issue 1 (student preparation): We have been able to help students acknowledge gaps in their preparation. Mastery tests have given the students a goal: learn the foundational material to pass the test. Just-in-time homework assignments are useful for some students. Using the complete remediation path available from ALEKS proved to require too much time for most students. Future work could involve helping students find more time efficient ways to remediate core prerequisite knowledge.

Issue 2 (student preparation for subsequent courses): We have been able to prepare our students to succeed in subsequent math courses at similar rates as before the redesign. Future work could include learning how to efficiently measure and track student success in subsequent math courses and tracking their progress through courses in partner disciplines.

Issue 3 (student success rates): We have been able to increase success rates and maintain the percentage of students successfully completing subsequent math courses. Further study is required to understand how high we can make the success rates in MATH 1220 without sacrificing student preparation for future courses or making the time commitment required for faculty onerous.

Issue 4 (variability of success rates across sections): Despite our attempts to provide an equitable learning environment for students of all sections through coordination of key class features, the coordination was not sufficient to decrease variability in class success rates.

Further Lessons about Coordination

Coordination by consensus is a continuous process that takes work to maintain. It is time consuming and requires active collaboration by team members. The department chair is essential in the assignment of team members who are willing to collaborate. With the addition of team members, the coordination must be renegotiated so that the new members can understand and embrace the collaboration. Ideally, members would share their own ideas and materials, understand the ideas and materials of others, improve the materials that are to be used, and apply the developed materials.

The work of developing common course priorities and expectations is messy. Teaching involves many choices, and instructors have different experiences and preferences they bring to the team. In addition, changes in textbook, text usage, homework systems, and/or content delivery add more variability. Changes force the team's expectations to evolve. Evolution does not always work perfectly. During semesters where multiple changes occur or communication is hampered, expectations are difficult to establish in a timely fashion. Transparency of objectives to instructors does not automatically yield transparency to students. As a result, communication to students is delayed making it more difficult for students to meet the newly formulated expectations. This can impact their performance in the class. Assignments and other messaging should help the students understand and accomplish major objectives. As changes are made, messaging to students should adapt as well.

When course priorities and expectations do not match in one semester, increased clarity is possible for future semesters. For example, common writing assignments were designed to make the goals and expectations of the course more transparent to the student (Winkelmes, 2019). The expectations on these assignments were parallel to instructor expectations on exams. Specific types of evidence were elicited from students to help them develop and rehearse their understanding of concepts in a non-high stakes setting. Students were given the opportunity to rewrite these assignments, and this process provided an important communication channel between the student and the instructor. As a result, the instructors could expect better use of evidence and mathematical notation in class and on exams.

Creating common assessments aided the articulation of priorities; this has been helpful as a way to include the ideas of team members. In the future, common assessment writing could be used for other courses and for the department as a whole.

Summary
Our implementation of collaborative coordination has increased success rates and continued to keep withdraw rates low. It improved the team's effort to prepare students for subsequent STEM courses and address variability in success rates across sections. This is work to tackle in the future.

REFERENCES

Bryk, A. S., Gomez, L., & Grunow, A. (2010). *Getting ideas into action: Building networked improvement communities in education.* Carnegie Foundation for the Advancement of Teaching. Retrieved from https://www.carnegiefoundation.org/wp-content/uploads/2014/09/brykgomez_building-nics-education.pdf.

Mingus, T. & Koelling, M. (2020). A collaborative approach to coordinating Calculus 1 to improve student outcomes. *PRIMUS*. https://doi.org/10.1080/10511970.2020.1772919

Winkelmes, M., Boyce, A. and Tapp, S. (Eds.) (2019). *Transparent design in higher education teaching and leadership: A guide to implementing the transparency framework institution-wide to improve learning and retention.* Stylus Publishing.

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[1] Most students must earn at least a grade of C in order to progress. Successful grades are A, BA, B, CB, and C; the success rate is the rate at which these grades are earned. Unsuccessful grades are DC, D, E, W, or I; the non-success rate is the rate at which these grades are earned. The non-success rate is called the DEWI rate.

[2] Assessment and LEarning in Knowledge Spaces (ALEKS) has adaptive online tutoring and assessment programs. We used Prep for Calculus with Limits.

[3] The last academic year after the redesign of MATH 1220 that is not impacted by the COVID-19 pandemic.

[4] The percentage of students who earned a grade in a course excludes students who earned an incomplete or withdrew from the course.

[5] The percentages of those eligible to progress to the next course are the number of students eligible to progress divided by the number of students who earned a grade.