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Coordinating STEM Core Courses for Student Success

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Abstract: Research indicates multi-section coordination improves the academic performance of students in STEM education. This paper describes the process of coordination in Precalculus, Calculus 1, and Calculus 2 courses undertaken by a large department that grew from the merger of two institutions through a pilot program, and a project grant. Components introduced in the project courses are documented, including collaborative problem-solving sessions, student learning assistants, Q&A sessions, and additional technology resources. Preliminary data is provided on the impacts of the initiative on student success. The study findings provide a template for coordination, faculty buy-in, and increased student engagement at similar institutions undergoing consolidations or implementing initiatives in core courses. Finally, this work provides proof-of-concept for coordination at a large minority-serving institution.

Keywords: Coordination, Active learning, Collaborative problem-solving sessions, Precalculus, Calculus, STEM Education, Merger

1 INTRODUCTION

Coordination is a common practice at established universities with large multi-section courses. The literature provides several reasons why large and small academic institutions coordinate their courses. One reason is the large variation in the types of instructors (such as graduate students, adjuncts, tenure-track or tenured faculty) teaching core courses resulting in varying emphasis over a range of topics [13]. In addition, course coordination for multi-section classes is a documented effective practice, increasing measures of student success and ensuring an equitable experience for students [5, 7, 10, 14]. Coordination, especially in the early phases, is challenging in departments that have a history of independence. Such was the case with the University of Texas Rio Grande Valley which resulted from the consolidation of two universities that merged two mathematics departments into one. Such consolidations are widespread, with nearly 40 U.S, public college mergers between 2000 and 2017 [1]. This current paper serves as a case study of the process of coordination in Precalculus, Calculus 1, and Calculus 2 (P2C2) courses at a large minority-serving institution resulting from consolidation of two formerly distinct institutions. Increasing student success in P2C2 courses is important as they predict success and retention in subsequent courses and college persistence, which is particularly important to retain STEM majors [4, 6]. Documentation of the change processes undertaken to coordinate will help similar institutions with disparate pedagogical cultures unify their efforts to maximize student success. The paper is written from the perspective of the author team who were among the leaders in local coordination efforts.

2 HISTORY OF THE INSTITUTION

The University of Texas Rio Grande Valley (UTRGV) opened in 2015 through the consolidation of the University of Texas-Brownsville and the University of Texas-Pan American, whose present campuses are 55 miles apart. Fall 2018 data shows student enrollment at approximately 29,000 students of which 88% are of Latino descent, 55% are first-generation college students, and 60% are Pell grant eligible.

As a result of the merger, two mathematics departments became one, although still distributed on two separate campuses. Consequently, new opportunities and challenges arose, especially the coordination of core courses. For example, each campus continued their own curricula practices. One campus was closely coordinated and continued its practice of coordination in core courses with common textbooks, syllabi and a weekly schedule of topics to cover along with a dedicated course coordinator who coordinated homework sets, quizzes, and exams. On the second campus, coordination in core courses was limited to a common textbook and a common final exam. The campuses had little in common and were using different textbooks. The initial challenges included adopting common materials, agreeing to a unified curriculum, and instituting common interventions. Coordination was of utmost importance to provide equity and similar standards for students on both campuses to minimize expenses (such as the purchase of textbooks) for students who repeated the course on various campuses. Despite the multiple reasons for coordination, convincing faculty to collaborate and increase student engagement meant changing years of tradition and overcoming long-term instructor attachments to particular resources and approaches.

3 COORDINATION PROCESS

3.1 Initial Coordination

Starting in fall 2015, the first semester of unification, the department recognized that faculty on different campuses were covering different topics in core courses with varying emphasis. A major contributing factor was the use of different textbooks and other learning resources each campus had previously adopted. This resulted in a fragmented approach, inconsistent learning assessments, and widely disparate grade distributions.

Initial coordination consisted in the adoption of common textbooks, syllabi and uniform content coverage in core courses across campuses. Committees were formed in spring 2016 to discuss these issues, and a great deal of departmental discussion ensued thereafter each semester. Although the initial coordination efforts led to some collaboration across campuses, it would not be until two to three years later that the department would finalize common resource adoptions.

At the same time in spring 2016, a pilot program was being planned by the department chair. Low student success in the core courses of Calculus 1 and Calculus 2 led to the first coordination steps that actively solicited faculty volunteers from both campuses to participate in revamping these courses. Maximum enrollment in participating courses doubled from the department average of 30 to 60 to accommodate students at peak times. In fall 2016 six large sections of Calculus 1 classes piloted common interventions including collaborative problem-solving sessions where groups of students actively worked on problems assisted by instructors and undergraduate peer mentors. The pilot program was expanded in spring 2017 to two large Calculus 2 classes along with four large Calculus 1 classes. In addition, instructors agreed to have 80% commonality on syllabi grade distribution weights and assessments, common exams, comparable online homework and a common weekly list of topics to cover (but no common textbook). This uniformity was critical for the development of the weekly collaborative problem-solving session worksheets. Allowing a 20% leeway/margin served to provide instructors with autonomy with respect to pedagogical innovations and implementations; this autonomy would become important later to reach departmental consensus on some aspects of coordination. The pilot program continued in its second year (fall 2017 - spring 2018) with the same curricula implementations as before among the select faculty who volunteered each semester.

It was relatively easy to reach consensus with the small number of faculty who participated in the pilot program each semester. Since they had initially volunteered to be part of the pilot program, faculty buy-in for coordination of curricula materials was secured. Coordinators for each of the courses received one course release during the year given the small number of faculty participants.

3.2 Project Grant – Year 1

After two years of piloting collaborative problem-solving sessions and coordination in a subset of Calculus 1 and Calculus 2 classes, the department received a two-year Project grant to expand the pilot program beginning fall 2018. The grant precipitated the introduction of Precalculus classes to collaborative problem-solving sessions and coordination across the two campuses. A total of 8 Precalculus classes; 14 Calculus 1 classes, and 7 Calculus 2 classes participated in the project in the first year which amounted to 24%, 50%, and 35% of all Precalculus, Calculus 1, and Calculus 2 sections, respectively, in fall 2018 - spring 2019.

As in the past year, faculty volunteers were solicited to participate in the Project grant and instructors played a critical role in providing feedback on curricula materials. After having implemented the pilot program, the Project grant promoted an expansion to more classes and surprisingly, served as a springboard for the department to discuss coordination across all core courses, not just the P2C2 courses in the Project Grant.

At this early point, coordination discussions revolved about problem selection and content for common mid-term exams. Faculty would submit their previous exams and collaborate by email to create drafts of upcoming exams. Although faculty had up to a 20% margin to modify problems on mid-term exams, this rarely occurred as there were active email discussions regarding the problems and the content of the exams. In addition, with the absence of a common textbook, the flexibility led some instructors to experiment with various textbooks, including open educational resources, to decrease the burden of cost to students. This is an important consideration concerning equity since UTRGV spans two counties with poverty rates that are among the highest in the state.

In the same academic year, the department began discussion and voting on common textbooks in all core courses. Since instructional autonomy had been the norm in the department, many discussions occurred regarding academic freedom and its rightful place in teaching effectiveness and student success. The initial pass rate increases in participating Calculus 1 and Calculus 2 sections from fall 2015 to fall 2016 provided significant leverage for coordination and the adoption of a common textbook. Additional motivation for extending coordination to all core courses came from meetings with the Association of Public and Land-Grant Universities and consultants on student success from other institutions. These external observers pointed out that having common course resources is a minimum standard at similar institutions. Moreover, more robust coordination efforts at similar institutions have resulted in increased student success. Faculty and administrators became increasingly aware that the institution was distinguished by its lack of coordination. The feedback and corresponding literature on the impact of coordination was presented to faculty and upper administration. Strong support from college and university administrators along with faculty consensus about coordination culminated in a request from the department chair to all core course committees, including those outside of the Project grant, asking for a list of potential common textbooks. Faculty votes were conducted to determine the textbooks to be adopted. The extended period of discussion was concomitant with advances in high quality open education resources (OER) and led to the departmental adoption of OER textbooks in a number of multi-section core courses.

In parallel with the above tasks, core course committees came up with coordination proposals that included a week-by-week schedule of topics, recommended courseware, recommendations for exam windows, and a common syllabus. As part of the syllabus, some committees agreed to have common weight distributions for all assessments while others continued the practice of having common weight distributions for some assessments but provided instructors with a 20% leeway for additional assessments. At the end of each semester, committees were asked to consider which recommendations to move forward with in the longer term and what changes should be made. This was done transparently in communication with department faculty.

Moreover, during this first year, an online survey was provided to instructors to gather ideas regarding coordination initiatives and to determine instructor support in teaching these coordinated classes. The survey was adaptive based on faculty responses. Those faculty who expressed interest in participating and leading coordination initiatives were asked to specify which course they wanted to focus on and their recommendations to increase student success. Faculty who did not express interest in participating were asked to list changes they would make to their courses in lieu of coordination with their colleagues and a list of expected outcomes of these changes. As part of the survey, all faculty were asked if they were interested in collaborating on grant proposals and initiatives to study the impact of coordinated innovations in core courses. Although not all faculty supported the coordination initiative, the meetings, communication, and collection of feedback contributed to the idea that collaborating on student success is the norm and an expectation in the department rather than a novelty.

3.3 Project Grant – Year 2

Throughout the pilot program and Year 1 of the Project grant, P2C2 course coordinators changed each academic year depending on the course schedule. To increase continuity in course coordination beginning in year 2 of the Project in fall 2019, P2C2 coordinators were asked to serve longer terms over at least 3 years and provided with teaching release each semester. Coordinators were selected through the course coordination online survey that was administered in spring 2019 as well as student feedback, student success metrics, and teaching narratives from annual evaluations. Coordinators were tasked with creating a week-by-week schedule of lecture topics for instructors to cover, midterm exams, weekly worksheets for the collaborative problem-solving sessions, and homework assignments. All core classes, Project and non-Project classes, were under the direction of the coordinators.

Despite enthusiasm for coordination, not all instructors agreed with the idea. In preparing the course schedule for fall 2019, rather than merely assigning faculty to teach classes, the department chair asked for volunteers to teach core classes that had a coordinated format. This was done to minimize dissatisfaction in teaching coordinated classes among instructors who opposed the idea. Hence the department chair went to great lengths to cultivate support for coordination.

3.4 Continuing Coordination and Progress

To maintain coordination momentum and amplify the impact of the Project grant, course coordinators for all core courses were tasked by the department chair to take incremental steps in implementing the following initiatives during fall 2019 - spring 2020 in collaboration with members of core course committees and their colleagues teaching the courses. Some of the initiatives cited below began in fall 2019 and others are in progress. We anticipate these initiatives will require refinements as improvements are made and instructors share best practices.

- **Revamping Courses:** Each committee was asked about changes, large and small, that can be recommended to increase student success. Recommendations were justified with data collected, discussions with colleagues, and comments from external observers.
- **Building Communities of Practice:** An important part of the initiative was to increase communication and discussion between instructors about student success and give feedback to instructors about their courses. Coordinators were asked to do this by holding regular professional development meetings for those teaching core courses**.**
- **Optimizing Curriculum:** For each of the core courses with a sequel, coordinators were asked to build a curriculum map connecting material needed in the subsequent courses with content in the core course. Core course committees used these to streamline the curricula and update recommendations for content coverage.
- **Coordinating Assessments:** Coordinators were encouraged to provide as much coordination on exams as possible. They wrote and distributed exam templates that faculty

adjusted and provided feedback on. Exams were aligned with the concepts in the week-by-week schedule and included several suggested problems for each concept.

- **Building a repository for new instructors and graduate teaching assistants:** For each lecture core course, coordinators were charged with producing an exemplary set of lecture notes and other course resources. The resources were consistent with the week-by-week schedule. The resources are available through a department repository to anyone teaching this course.

4 COMPONENTS OF COORDINATION IN THE PROJECT COURSES

In this section, the pedagogical features incorporated into the Project grant are discussed. This includes active learning strategies known to be effective in mathematics instruction [1, 8, 16]. The use of near peer guided practice in the project fits previously identified characteristics of successful Calculus programs [3]. The collaborative instructional elements introduced in the Project grant are particularly important for minority populations [15]. Details on four features implemented in the Project grant are discussed below. These are collaborative problem-solving sessions that include undergraduate Learning Assistants, Q&A sessions, a Calculus resource webpage and Desmos applets. In sections 5 and 6, preliminary data collection and analysis are provided comparing Project and non-Project courses.

4.1 Collaborative Problem-Solving Sessions

The primary mode for increasing active learning through the Project grant was the creation of weekly collaborative problem-solving sessions in which students work with faculty and peer guidance. Collaborative problem-solving sessions typically meet each Friday for 75 minutes in lieu of a traditional lecture period. In these sessions, students work in groups on worksheets pertaining to material covered earlier in the week with support from both the course instructor and embedded undergraduate Learning Assistants. Students are encouraged to discuss with each other or use their lecture notes/textbook or software such as Wolfram Alpha and Desmos, and other available resources. Exercises are meant to give students the opportunity to work on skills, practice communication skills in the use of mathematical terminology, and promote conceptual understanding. Worksheets are collected and graded as part of assessment that is incorporated in the students' overall course grade.

4.2 Learning Assistants

Learning Assistants (LAs) are undergraduate students who typically have completed advanced mathematics courses beyond Calculus and are identified by their previous course instructors as being strong academically with good interpersonal skills. The LAs main responsibility is to assist students in the collaborative problem-solving sessions to serve as peer assistants. In several instances, students who were enrolled in Project classes in previous semesters are hired as LAs, as they understand the structure of the sessions and the guidance that is provided to students. The target ratio of LAs to students is 1 to 20.

Learning Assistants are provided local training during the semester on how to effectively work with their peers, grade student work, and coordinate support sessions outside of class. Besides attending and helping students during the weekly collaborative problem-solving sessions, LAs also grade worksheets and provide Question & Answer (Q&A) sessions for all students outside of class.

4.3 Q&A Sessions

Beginning in spring 2019, Question and Answer (Q&A) sessions were implemented for Project courses to offer students with an all-in-one location to receive tutoring, get their questions answered, and work on online homework problems. In the Q&A sessions, LAs serve as peer leaders guiding students on homework problems and going over lecture materials and exam reviews. All sessions are held in the same computer lab to provide consistency for students and are scheduled throughout the weekdays. Each LA provides one weekly hour of assistance in the Q&A sessions. In spring 2019, this amounted to a total of 28 weekly hours provided by LAs.

4.4 Calculus Webpage and Desmos

As part of the Project, a Calculus webpage was created to provide a repository of resources to help both students and instructors in the Project and non-Project classes of Calculus 1. The webpage contains brief summaries of Calculus topics along with links to Desmos applets to aid instructors in teaching course content and integrating visualization of concepts with graph interpretations. Figure 1 shows a screenshot of the webpage where the lower left images within the boxes indicate the implementation of a Desmos applet.

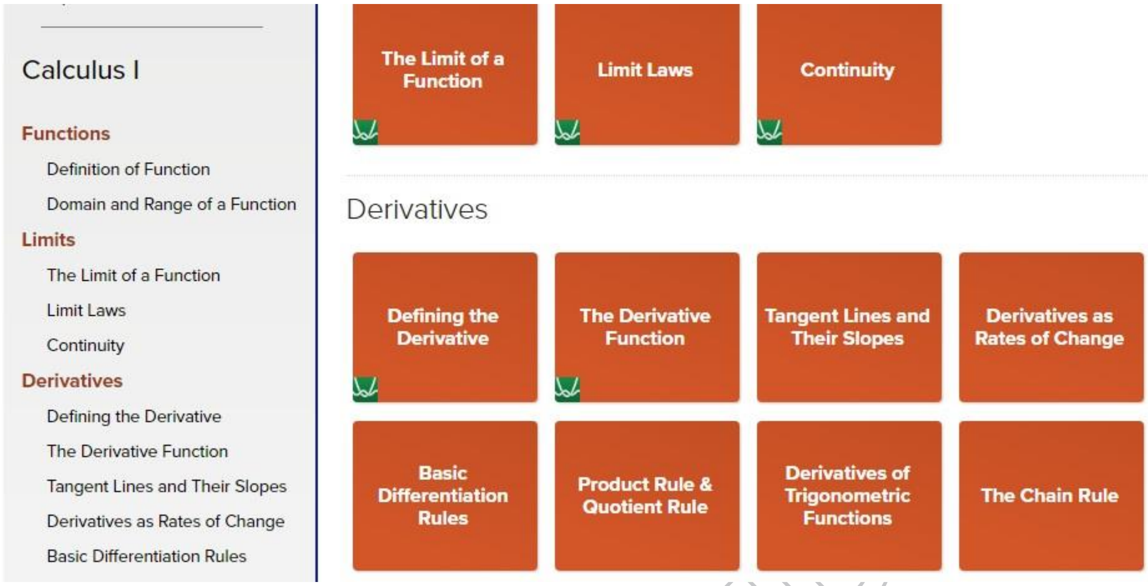


Figure 1. Calculus Webpage.
https://www.utrgv.edu/cstem/utrgv-calculus/

Students are encouraged to download the free Desmos app to their cellphones or to access the webpage to follow instruction during class lecture and hence to better understand the meaning of concepts. To cement individual student use of Desmos, worksheets in the collaborative problem-solving sessions require the use of Desmos to confirm understanding and explore concepts. For example, in graphing curves in Desmos, students can obtain an initial interpretation regarding the positive, negative, or zero value of a derivative at a point and confirm their response with the computed derivative at the point under consideration.

5 METHODS

5.1 Target Population

To analyze initial impacts of student success initiatives, preliminary data is presented. Historically, each P2C2 course has had enrollments of 400-500 students. The average class size in each course is typically around 30, although due to space availability some classes have been increased to 120 students. Table 1 shows the number of Project and non-Project sections taught during fall 2018 and spring 2019.

Semester	Fall 2018			Spring 2019		
Class	Precalculus	Calculus 1	Calculus 2	Precalculus	Calculus 1	Calculus 2
Project	2	5	3	6	9	4
non-Project	17	9	7	9	5	6

Table 1. Number of Project and non-Project sections in 2018-2019.

The instructors who volunteered to participate in the Project agreed to follow the course syllabus proposed by the course coordinator, to cover a common scope and sequence of topics, give common mid-term exams and final exams, hold collaborative problem-solving sessions, and use common weights for determining course grades. Each instructor was responsible for grading and evaluating his/her own students and for assigning course grades. During fall 2018 and spring 2019, a total of 16 distinct instructors participated in the project, with some teaching multiple classes: five taught Precalculus, eight taught Calculus 1, and six taught Calculus 2.

5.2 Data Collection and Data Analysis

Data collection consisted of graded materials and an informal instructor survey. Course grades and pass rates were collected through the university's reporting system for fall 2018 and spring 2019. Final exam scores were collected from four non-Project sections as well as all Project sections that incorporated a common final exam. Student pass rates and final exam scores were compared with Project courses and with non-Project courses. Pass rate comparisons were done by descriptive statistics, and final exam score comparisons by one-tailed two sample *t*-tests. The informal instructor survey inquired into instructors' attitudes toward instructional strategies by eliciting instructors' self-reports.

6 PRELIMINARY STUDY RESULTS

Due to the limitations involved in making dichotomous conclusions based on *p*-values [9], we conducted significance tests at various significance levels: $\alpha = 0.10, 0.05, 0.01$ and 0.001.

6.1. Comparison Between Project and non-Project Sections

To test the effectiveness of the Project course interventions as a whole, we compared pass rates (percentage of students receiving a course grade of C or higher) of students in Project sections and in non-Project sections of P2C2 courses in fall 2018 - spring 2019. As Figure 2 shows, Project sections of Precalculus and Calculus 1 had higher pass rates than did non-Project sections, while Project sections of Calculus 2 had lower pass rates than did non-Project sections. This contradictory outcome in Calculus 2 may be attributed to a number of factors: small number of Project sections in Calculus 2, instructional characteristics of the instructors, and class size.

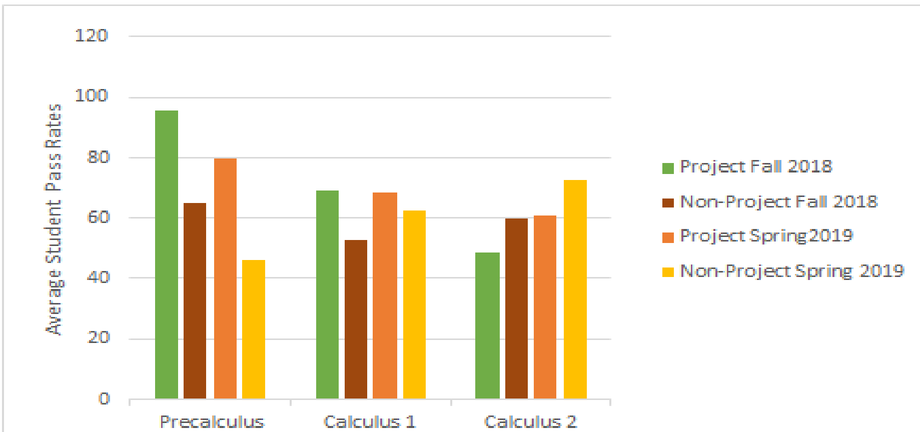


Figure 2. Pass rate comparison between Project and non-Project.

Next, one-tailed two-sample *t*-tests were conducted on the final exam scores of the Project sections and the non-Project sections of Precalculus and Calculus 1 which all used a common final exam. The test outcomes for Precalculus and Calculus 1 are summarized in Table 2.

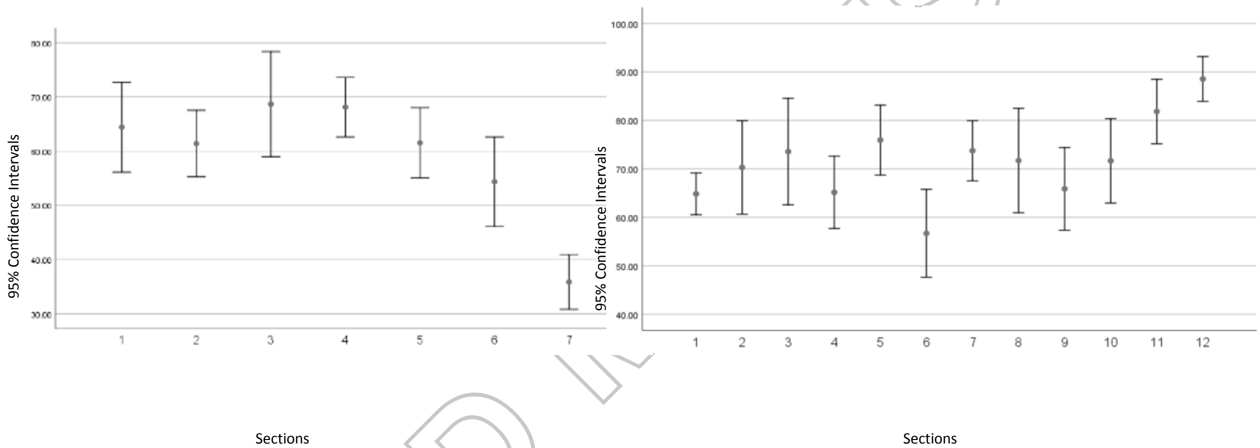
Courses (*p*-value)	**Precalculus** (0.11)		**Calculus 1** (0.08)	
Course type (sample size)	Project (n =230)	non-Project (n =425)	Project (n =294)	non-Project (n =158)
Mean (SD)	67.3 (24.3)	65.8 (25.8)	74.4 (20.7)	72.2 (22.0)

Table 2. Final exam mean scores of Project vs non-Project courses.

For Calculus 1, the effectiveness of Project intervention (p = 0.08) is significant at α = 0.10. For Precalculus, the effectiveness of the intervention (p = 0.11) is not significant at α = 0.10; nevertheless, its near-significance suggests that it is worth investigating the pedagogical characteristics of the Project courses in Precalculus.

6.2. Instructional Characteristics of the Project Courses

Identifying Differences among Project Sections. Figure 3 presents 95% confidence intervals for the final exam mean scores from each of the seven Project sections of Precalculus (3.A) and the twelve Project sections of Calculus 1 (3.B). Figure 3.A shows that the final exam mean score of course sections 3 and 4 in Precalculus, taught by two different instructors, are higher than other scores. We note that one of the two instructors also taught sections 1 and 2, which also have relatively high scores. Figure 3.B shows that the performance of students in section 12 of Calculus 1 is significantly higher than many other sections. Section 11 was also taught by the same Calculus 1 instructor.



A: Precalculus B: Calculus 1

Figure 3. 95% Confidence intervals of student final exam mean scores in Project sections.

Identifying Effective Instructional Strategies. For further analysis of instructional strategies, two participant groups were created: Group 1 of the three instructors discussed above who had the highest final exam mean scores, and Group 2 of the remaining nine instructors. An informal survey administered to Project instructors suggested that more successful P2C2 instructors had certain instructional strategies in common. Group 1 opted to have students present solutions to problems on the board, implemented project-based learning approaches, gave daily quizzes, and gave entrance and exit questions in class. In addition, the survey suggested that faculty with increased student success measures emphasized more immediate low-stakes feedback than other instructors. These instructional strategies represent an active learning approach where students are encouraged to engage in classroom learning activities. This suggests that a closer study may reveal additional interventions that could be implemented to increase student success in P2C2 courses.

7 CONCLUSION

As part of the coordination effort to improve the efficacy of the gateway math courses for STEM majors and provide equity to students taking these courses, we developed and implemented coordinated initiatives for Precalculus, Calculus 1, and Calculus 2 (P2C2) courses. The process of coordinating core courses has been a challenge in our department given the merger of two campuses. Incremental steps have been initiated over the course of three years to achieve coordination in terms of common materials such as a syllabus, textbook, assessments and weight distributions, week-by-week schedule of topics to cover, mid-term exams, and a final exam. The incorporation of core course coordinators has also evolved through the process along with their responsibilities and tasks and long-term goals. Faculty buy-in was cultivated through a lengthy period of analysis and discussion. Our initiative to revamp courses starting with a small nucleus of motivated individuals teaching P2C2 courses grew into a healthy campaign involving faculty from all core courses in the department. We hope that documentation of our experience can assist departments in the process of course coordination and implementation of best practices. Our department's efforts in course coordination will continue to change as we make improvements, as the department implements new programs, and as we experiment with initiatives for student success.

In this study, we tested the effectiveness of the Project by considering student pass rates and exam scores. The comparison between Project and non-Project courses, both by student pass rates and by final exam mean scores, indicate that Precalculus and Calculus 1 students in Project classes outperformed their counterparts in non-Project classes. The overall pass rate in Calculus 2, however, shows the opposite. As course grades and pass rates for individual courses are instructor dependent, additional data such as student scores on a common final exam would be beneficial in either confirming or revising the comparison between Calculus 2 Project and non-Project courses. We note, however, that systemic changes to course instruction may cause an initial decrease in student achievement before seeing improvement [12], and this study is an impetus for further studies that identify factors that may be different in Calculus 2 instruction.

Although the study was empirical and the statistical significance was not large, the study outcomes suggests positive effects as shown in higher pass rates and higher final exam scores for students in the Project group in both Precalculus and Calculus 1. A further look into the strategies used by the instructors showed that strategies that maximize active learning were more preferred by successful instructors. The outcomes related to active learning align with the current recommendations of the National Council of Teachers of Mathematics [11] and the findings from Freeman et al.'s empirical study [8] on the effectiveness of active learning in STEM education. We hope the preliminary findings lay a foundation for further research on course coordination for core courses. This preliminary study focused on many potential factors such as a common syllabus, exams, weekly schedule of topics, and collaborative problem-solving sessions. It still remains to learn quantitatively which instructional strategies are appropriate to include in coordinating these courses and which learning activities serve as key factors for improving student learning, and to learn about challenges instructors face in implementing certain instructional strategies or activities in a uniform manner.

The study reported in this paper has some limitations. First, the project groups were not selected randomly, as instructors participated voluntarily. Second, instructional standards differed among sections, and the sample size was small; further research when more data become available will allow us to better understand the instructional strategies of more successful instructors. Third, this study is still on-going, and the preliminary data did not allow quantitative analysis of instructors' attitudes toward implementing instructional strategies.

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