

A Case Study of Change in the Teaching and Learning of Precalculus to Calculus 2: What We're Doing With What We Have

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Abstract: This article presents a case study that details the successes and lessons learned by faculty and administrators at San Diego State University (SDSU) who are in the process of implementing a substantial improvement to the Precalculus to Calculus 2 (P2C2) sequence. Improvement efforts have been informed by national studies of successful programs and center on the department as the primary agent of change. The majority of the article will discuss the particular changes that are being enacted at SDSU, with special attention to how they came to be as they are, how they are being implemented, and how we have identified and addressed salient concerns during the process. We conclude with how we intend to continue and expand our efforts to improve student success in introductory mathematics courses and a discussion of the lessons we have learned along the way.

Keywords: institutional change, precalculus, calculus, case study, coordination, professional development

Across the country, student success rates in introductory undergraduate mathematics classes are unacceptably low. This has a dramatic effect on the lives of hundreds of thousands of students each year, diverting them from opportunities to pursue STEM careers and leaving them discouraged (PCAST, 2012). However, recent work has shown that successful programs do exist. In their case studies of successful programs, Bressoud, Mesa and Rasmussen (2015) identified seven key features of successful programs that begin to paint a picture of the way forward. This article presents a case study that documents the successes and lessons learned by faculty and administrators at San Diego State University (SDSU) who are in the process of implementing all seven features to reform our Precalculus to Calculus 2 (P2C2) sequence.

We₊¹ have spent the last few years learning from successful programs and leveraging local opportunities to undertake a wide range of improvement efforts with the goal of improving student success rates, attitudes, and the depth of understanding of mathematics – all while working within the logistical constraints of a large, public university experiencing an ongoing budget crisis. It is our hope that others will be able to learn from our successes and struggles alike, and use our work as a jumping-off point to make changes at their own institutions.

To situate our process, we begin with a discussion of research on features of successful programs, and how we have used those features to frame our improvement efforts. We also discuss our particular context, our specific concerns, and the catalysts and fortuitous events that sparked our program of change. The majority of the article will discuss the particular changes that are being enacted at SDSU, with special attention to how they came to be, how they are being implemented, and how we have identified and addressed salient concerns during the process. We conclude with how we intend to continue and expand our efforts to improve student

¹ Because the authors of this article are also members of the department, the use of “we” can be ambiguous. To provide clarity, “we₊” with a plus sign subscript refers to the authors as well as other members of the department; “we” without a plus sign subscript refers to just the authors.

success in introductory mathematics courses and a discussion of the lessons we have learned along the way.

Framing for Change

As part of the ongoing nationwide efforts to understand and improve undergraduate calculus instruction, two National Science Foundation research projects conducted under the auspices of the Mathematical Association of America undertook national investigations of the subject. The first, *Characteristics of Successful Programs in College Calculus* (CSPCC), focused specifically on mainstream² Calculus I, and the second, *Progress through Calculus* (PtC) broadened the focus to include precalculus courses and the entire mainstream single-variable calculus (or P2C2) sequence. One of the major findings of the CSPCC project was a set of seven features (listed below) of successful programs at research universities, characteristics which inform the PtC project and our reform efforts at SDSU (Apkarian et al., 2016; Bressoud & Rasmussen, 2015).

1. Regular collection and use of local data to guide program modifications as part of continual improvement efforts
2. Effective procedures for placing students appropriately into their first P2C2 course (both initial placement and re-placing students after the term begins)
3. A coordination system for instruction that (a) makes use of a uniform textbook and assessments and (b) goes beyond uniform curricular elements to include regular P2C2 instructor meetings in development of de facto communities of practice.
4. Course content that challenges and engages students with mathematics
5. The use of student-centered pedagogies, including active learning strategies
6. Robust teaching development programs for teaching assistants
7. Proactive student support services (e.g., tutoring centers, services for first-generation students) that foster students' academic and social integration

An early finding of the PtC project is that these features are special, as posited by the CSPCC work – it is rare to find institutions with robust instantiations of any feature, and, as the PtC project has found, rarer still to find programs with multiple features (Apkarian et al., 2016). As of Spring 2014, SDSU's program was seriously lacking in each of these features. Instituting all seven of these features became a priority, and guided the development phase of the current ongoing change initiative. The decision to work toward all seven features at once necessitated careful planning. To help with this, we conceptualized the primary targets of improvement efforts tied to each of the seven features in terms of the following four levels: administration, department, course, and individual. The administration level involves collection and use of local data (targeting institutional data) and student support services (targeting institutional supports); the department level involves a coordination system (targeting horizontal coordination) and placement into the P2C2 sequence (targeting vertical coordination); the course level involves ensuring challenging, engaging courses (targeting content) and active learning strategies (targeting pedagogy); and the individual level involves teaching development programs (targeting faculty, instructors, and teaching assistants) and student support services (targeting students).

² “Mainstream” refers to courses that prepare students for continued study of mathematics, i.e. those in the prerequisite stream for linear algebra or differential equations.

Conceptualizing our improvement efforts into distinct levels is not a unique approach, and we were inspired in part by the framing Corbo and colleagues used to describe the efforts made at the University of Colorado, Boulder (Corbo, Reinholz, Dancy, Deetz, & Finkelstein, 2015). Each of these levels requires distinct approaches and management. Working with the administration requires framing and communicating change efforts with regard to institutional goals and strategic plans; the administration is also a key source of data and support. The department level is where broader coordination is key, both horizontal (within a given course across different instructors and over time) and vertical (entry to the program and through sequences of courses) – change efforts here must be framed in terms of departmental goals and desired outcomes. Each course requires a fine-grained approach to changing the curriculum and pedagogy, addressing specific students and outcomes. Finally, at the individual level, we take a sociological approach, considering how to improve buy-in from faculty and students alike by targeting attitudes and culture as well as behaviors.

Who We+ Are and Where We+ Started

We begin by explaining a bit about our institutional context, to give some perspective on where these efforts are taking place. SDSU is a large, public research university that is part of the California State University (CSU) system. In Fall 2015 there were 33,483 students, 29,234 of whom were undergraduates. Each year SDSU accepts approximately 5,000 first-time freshmen, the majority of whom come from public high schools in California. Some other facts about SDSU:

- SDSU is a Hispanic-Serving Institution
- 84% of full-time undergraduates qualify for some type of financial aid
- Around 10% of all bachelor's degrees awarded are in STEM fields
- Approximately 1500 freshmen take a mainstream P2C2 course each fall
- 32% of students graduate in 4 years; 66% graduate within 6 years
- Roughly 50% of the students in calculus are engineering majors; 25% are science majors; 10% are mathematics or statistics majors, and the remainder are from a variety of majors; Precalculus has a larger proportion of non-STEM majors than the other two courses.

The Department of Mathematics and Statistics at SDSU has three divisions: mathematics and its applications, statistics, and mathematics education. The department consists of 17 applied and pure mathematicians (3 in partial retirement), 7 statisticians, and 6 mathematics educators. Historically some tensions have existed, including friction between divisions, disagreements among the math faculty about traditional versus more applied and computational approaches, and competition among faculty from different subject areas in mathematics. Despite this, the department has been able to offer a relatively standard set of bachelor's and master's degrees in the mathematical sciences, as well as doctoral degrees in mathematics education and computational statistics. Due to continued budget constraints, there are only two long-term lecturers and few part-time lecturers. In a typical semester, roughly half of the P2C2 courses are taught by tenured or tenure track faculty.

We now turn to the state of affairs regarding the seven features at SDSU prior to our improvement efforts. Data about grade distributions and teaching evaluations were regularly collected and considered by administrators but the department did not regularly review results or use them to monitor the quality of the program. Certainly there was an awareness of low passing rates, but no investigation was taken to uncover particular reasons or patterns. Program-based

assessment efforts, mandated from the highest levels of administration, were also conducted, but most faculty viewed them as obligatory rather than helpful and changes to the programs were not widely considered. The placement exam was a static 40-question multiple choice test, no remediation was offered between retakes, no studies had been conducted to investigate its correlation with student success, and there were concerns that solutions were available to students.

None of the P2C2 courses had any course coordination – not even the textbook was consistent across sections. The rare instructor conversations about course delivery, pacing, assessments, learning goals, etc. happened only by chance. Course content was not uniform and was disconnected from applications in the sciences, even though the vast majority of our calculus students are not mathematics majors. Moreover, exams tended to emphasize computations and procedural fluency rather than conceptual understanding. Precalculus was taught in lecture format (50-150+ students) three times per week with no breakout sessions³. Calculus 1 and 2 was taught in large lectures (150+ students) that met three times a week, with smaller breakout sessions once per week led by graduate teaching assistants (GTAs). Lectures and breakout sections were largely if not entirely instructor-centered with little to no active learning. While each calculus GTA had four to six 40-student breakout sections that met once a week, they did not receive any formal teaching development, training, or mentoring.

While the university itself maintained many student support services (especially for students in underrepresented groups), none of these programs had strong connections with the mathematics department. For example, the university recently organized a few math Learning Communities that were led by peer teachers. Unfortunately, these undergraduate tutors had had no significant communication with mathematics instructors nor any training to ensure consistency or quality of teaching. The “tutoring center” was a very small room with a few tutors and some light faculty supervision. The lack of oversight and monitoring meant that there were significant disconnects between the tutors and courses. Moreover, the small size of the tutoring room meant that it was not a space where students could comfortably gather to socialize or study in groups, and no other space for that purpose existed.

What We+ Are Doing

The short story is that we+ changed *everything*. In this section, we describe the improvement efforts that are ongoing and how they came to be, based on the list of seven features of effective programs described earlier. We note that a somewhat informal P2C2 supervisory team consisting of a mathematics educator, the three new course coordinators (one of whom is the director of the Mathematics Learning Center), and the department chair communicates frequently to monitor the overall program, discuss complications as they arise, meet regularly with stakeholders at all levels, and generally guide the initiatives.

Local Data

We+ approached SDSU’s Enrollment Services and obtained all individual grades in all mathematics courses taken at SDSU between Fall 2010 and Spring 2015. Funding for a graduate student assistant to analyze the data was provided by the provost’s office (Spring 2015) and then the Dean of Undergraduate Studies (Fall 2015). Here we present a few key findings from the analysis: (a) typical pass rates for P2C2 courses ranged between 60 and 70%, and approximately 2/3 of these students continued on to the next course; (b) the proportion of students who started

³ From 2012-2014 Precalculus was taught entirely online. This format was ultimately rejected due to extremely low pass rates and considerable student complaints.

with Precalculus and passed Calculus 2 was roughly 17%, and fewer than 10% did so in three semesters; and (c) students who failed a P2C2 course were almost doomed: the proportion of students that received A's and B's on the second attempt was half that on the first attempt, and more than half of the students who received A's and B's on the second attempt failed the subsequent course.

This initial analysis made it clear that there was a tremendous waste of human potential as well as financial resources associated with students starting a STEM major with Precalculus. We+ had to invest in helping those students to succeed, as well as ensure good advising for those who need to find other directions. Perhaps the most significant outcome of the analysis was that it led to more refined questions that will guide future research: (1) How are different demographic groups succeeding (e.g., gender, ethnicity, major, commuter status,)? (2) Why do students leave the STEM pipeline, and where do they go? (3) What interventions are most successful in supporting struggling students? Continued cooperation with administration and attention to these data will allow us to gauge the health of our program and inform future programs – they provide us with a valuable benchmark to measure our improvement.

Placement

We+ began a transition to using the ALEKS® system for placement during the summer of 2015, and completed the transition as of the Winter 2016 term. Mathematics department policy now states that students wishing to take Calculus 1 must have (a) passed Precalculus (C or better); (b) have a qualifying score on the Calculus AP Exam (4+ on AB; 3+ on AB/BC); or (c) pass a proctored ALEKS assessment (78 or above). Each student pays a \$25 fee which gives access to learning modules as well as five assessments. The third and fifth assessments are proctored, with the others directing students to learning modules for remediation. Roughly 85% of incoming students attend an on-campus orientation during the summer, which provides an opportunity for them to take the proctored assessment.

We see a number of benefits with ALEKS assessment: the questions require numeric, symbolic, and graphical input, not just multiple choice; the questions are different each time a student takes an assessment; and the student has an opportunity to become accustomed to the system before taking a proctored test. In addition, the artificial intelligence probe and reporting of the precalculus knowledge space gives valuable information to both students and the department, and the integration of learning modules gives students an opportunity to work and improve whatever areas the system identifies as personal weaknesses. Implementing ALEKS required coordination with several institutional bodies, including the testing office, Enrollment Services, Advising, and the wider CSU system. It was a logistically challenging endeavor, but we hope that the improved system will see students placed more accurately into courses for which they are prepared, and their success will ease vertical coordination up and through the P2C2 sequence.

Coordination and Content

The burgeoning coordination system now in place is one of the initiatives we+ are proudest of because of the progress made and because it was initially one of the more daunting tasks. As noted, SDSU had no coordination of the P2C2 courses – not even a standard textbook. Each of the three courses now has a common syllabus, textbook⁴, online homework system, exams (midterms and final), lab activities, and a common grading scheme. Each course has a coordinator who is taking responsibility for the course as a whole for three years, including

⁴ We use the Stewart et al. series from Cengage for all three courses

organizing instructors and TAs and working with them to develop all course materials. The use of uniform course elements (horizontal coordination) allows us to ensure that students receive more consistent preparation for subsequent courses (allowing vertical coordination). It also allows for improved course content, as course design has become centralized. Instructors, coordinators, and the P2C2 supervisory committee are now able to join forces and ensure that content is not only consistent, but challenges students and engages them with the mathematics they are learning.

One of the early problems we+ encountered with the coordination initiative revolved round communication among the various instructors and coordinators. In particular, some instructors were not involved in the writing of the common exams. They felt unable to appropriately prepare students for those assessments, and students picked up on this. This came to light during the first semester of the initiative (through student complaints to the chair and student discussions in the math learning center), and communication increased in the second semester. Students' confidence in their instructors improved, and the levels and opportunities for communication and collaboration between instructors and coordinators continue to increase.

The uniform course elements have provided the basis for implementation of a crucial piece of a coordination system that goes beyond surface features such as textbooks and syllabi: regular instructor meetings (Rasmussen & Ellis, 2015). Instructors and TAs⁵ for P2C2 courses meet weekly with their course's coordinator to discuss course content, pacing, assessment, instructional approaches, as well as any emergent concerns. In addition, the P2C2 supervisory team meets regularly with instructors and TAs to ensure that the entire system of initiatives is well understood, that there is a sense of teamwork, and that lessons learned in one class are available to the others. We+ believe that these regular meetings are beginning to engender a sense of community in the department surrounding the P2C2 courses.

A final note about the coordination system we are working to implement at SDSU: it interacts with other initiatives described in subsequent paragraphs. In particular, we+ have new active learning labs that are part of the coordinated courses – their content is created and managed through course coordinators. These labs are run by the TAs, and their increased role informed the structure and content of the TA programs. The coordination system also interacts with our new mathematics learning center – the tutors and TAs who work there can more easily keep abreast of course content and pacing. It also provides students with additional support from their peers, as having uniform course elements means that friends and dorm mates in different sections can more easily work together. By reducing barriers to collaboration, this coordination system may foster a sense of community among P2C2 students as well as instructors.

Active Learning Labs

Implementing active learning strategies is challenging for instructors who lack experience with group work and student discussions, particularly in large classes. We+ were cautious about making too aggressive a move to active learning without enough experience to ensure good quality. Our solution was the addition of a “lab” to Calculus 1 and 2, which we use as an active learning breakout session. This extra contact hour was achieved through some administrative sleight-of-hand: one unit of the four credit calculus courses was recoded as an “activity” which carries two hours of contact per unit. Thus each week there are now three hours of lecture with

⁵ We+ use TAs to refer to both the graduate teaching assistants (GTAs) working with Calculus 1 and 2 and the undergraduate instructional student assistants (ISAs) working in Precalculus unless a distinction is required.

100-160 students, and two one-hour breakout sections with a GTA. One section meeting is fairly traditional problem solving and one is an active learning lab.

The changes to Precalculus were slightly different because it is only a three-unit course. Instead of three lectures per week, students now attend two weekly lectures and one active learning lab period taught by an undergraduate instructional student assistant (ISA). In addition, at least one of the instructors is including pair and small group work during regular course meetings by making use of ISAs as in-class Learning Assistants. This model will expand to the other sections in the coming years.

The department chair worked with a university-level task force on class size to reduce the number of students in breakout sections from 40 to 30 students, a more manageable number for new TAs implementing active learning. The course coordinators worked hard to develop rich, group-worthy tasks that students would be unlikely to complete individually (in the time allotted), but that could be managed in guided groups. We+ aimed to develop tasks such as those described by Hsu, Kysh, and Resek (2007), which have a low-floor and a high-ceiling and engage student interest.

The first iteration of lab activities had some problems. Some students perceived the labs as unrelated to the assessments, some labs were too computational, some too complex, and some too simple. To address student perceptions, the coordinators added exam questions related to and explicitly including concepts from most of the labs. To address the content level concerns, a team of six TAs (two from each course) and all three coordinators is currently working to improve the lab activities. This work was made possible by funding from the Provost. As well as developing more precise content, the team is working to increase the consistency of presentation, connectedness to important concepts, and implementation instructions. We+ hope that these labs will provide experienced instructors with an introduction to active learning principles, which may eventually spill over into regular course meetings. At the moment, however, we are focused on providing students with the benefits active learning provides (Freeman et al., 2014) and exposing them to content that is challenging and engaging.

TA Professional Development

Our initiatives have meant an increased role for TAs in the P2C2 sequence. In addition to leading traditional problem-solving breakout sessions, they must also spend time in the new learning center and manage weekly active learning labs. These labs are the focal point of our work to include active learning, and so it was critical to develop a high quality training program for student instructors. The first formal TA teaching preparation workshop took place over three days before the Fall 2015 semester. The focus of this workshop was to introduce student-centered approaches to teaching and present rationales for the effectiveness of this approach. Topics included ways to facilitate group work, lead whole class discussions, promote participation, and attend to a range of student needs (e.g., the difficulty of the high school to college transition). Two follow-up workshops were held during each of the following semesters that provided further strategies for promoting student engagement in whole-class discussions and designing activities with high cognitive demand (Hsu, et al., 2007; Stein, Grover, & Henningsen, 1996), and managing behavioral issues.

We adopted a Lead TA model in Calculus 1 and 2, based on one of the TA professional development models detailed by Ellis (2015). Each Lead TA is in charge of their own two sections, but is also tasked with supervising the other TAs, helping with logistics, and facilitating communication between TAs and course coordinators. As appropriate, Lead TAs will continue in their role for the duration of their time at SDSU, and work with the next generation of lead TAs

before they graduate. Theoretically, these would be students who have had prior experience with active learning and other topics from the preparation workshop. However, in practice, such students are difficult to find. We+ thus selected students who had prior teaching experience and were open to the ideas of active learning. While the Lead TA program was initiated in Calculus 1 and 2, its success has motivated its extension to Precalculus.

Aside from continuing negotiations about workload, the new TA programs have been implemented fairly smoothly. One concern has been the ad-hoc nature of support following the intensive three-day program prior to the semester. In our first year support was provided somewhat informally – weekly meetings of TAs and coordinators, observations and debriefings with Lead TAs, and discussions at the Mathematics Learning Center. Beginning in the 2016-17 academic year we will implement a 3-credit professional development course with bi-weekly meetings specifically designed to provide continued support for TAs.

Learning Center

A new Mathematics Learning Center (MLC) has been created at SDSU, and it has been another success. Not only does it mark a vast improvement from the previous tiny, uninviting room of tutors, but we have seen a real impact on students' success rates in the target courses and have received lots of positive feedback. The creation of the MLC⁶ was an explicit part of the university's strategic plan, but the development and management of the center has been organized almost entirely from within the department. A tenured mathematics education professor was named as the director for the center, and she brings knowledge of the mathematics education literature as well as a collegial relationship with P2C2 coordinators and instructors.

All TAs (except Lead TAs) are expected to spend four of their working hours in the MLC each week, working with students from any P2C2 course. This has not been universally welcomed – while some TAs believe this helps them understand the P2C2 pipeline and better help all their students, others view it as a waste of time and an undue burden. We+ are negotiating a solution, but feel that having them work in the MLC contributes to their professional development. For example, while working in the MLC TAs learn more about common student misconceptions across the P2C2 sequence and how to respond to particular comments or complaints. Such conversations are also useful ways to inform the director of the center to the need for certain resources for tutors or particular issues that need to be relayed to instructors. Finally, the TAs' presence in the MLC helps integrate the center's activities with what is happening in the P2C2 courses, providing even greater coherence.

The MLC supports P2C2 students in multiple ways. It functions as a tutoring center where students receive academic support, a supervised area where students can make up missed exams, a central location for holding math club meetings and help sessions, and an impromptu inviting space where students feel comfortable gathering. All of this fosters the social and academic integration Tinto proposed as important for students' identities and success (Tinto, 2004).

How We+ Got Started

But how did all this come to pass? In this section we consider the series of factors and events that created an environment in which our large-scale change initiative was possible. We begin with a short discussion of relevant programs and systems, followed by the many opportunities we+ took advantage of, and how it all came together.

Local Network

⁶ The physical space is actually the “Mathematics and Statistics Learning Center,” and provides support for multiple content areas. Here we focus on the center as it relates to P2C2 courses.

We begin with an acknowledgment of the complexity of institutions of higher education, and how this complexity makes change difficult. In order to initiate change, we needed to ascertain what institutional (and extra-institutional) programs were necessary to work and communicate with. In Figure 1 below, we highlight this network. The outer ring identifies the seven features of successful programs that frame our efforts (Bressoud, Mesa, & Rasmussen, 2015). The inner ring of ovals identifies existing administrative programs, divisions, and systems that were identified as relevant to those features. Curved arrows connect each oval to the feature(s) which they most directly controlled or had stake in. At the center is the department, which reflects our view that the department must be at the core of any change initiative. Each arrow from the department to an oval indicates a channel of communication that was opened or strengthened, and which provided the basis for cooperation and collaboration. We highlight this diagram, and these relationships, to impress upon the reader the importance of reaching out to work with others. Without these partnerships, it is difficult to see how this work would have come to fruition.

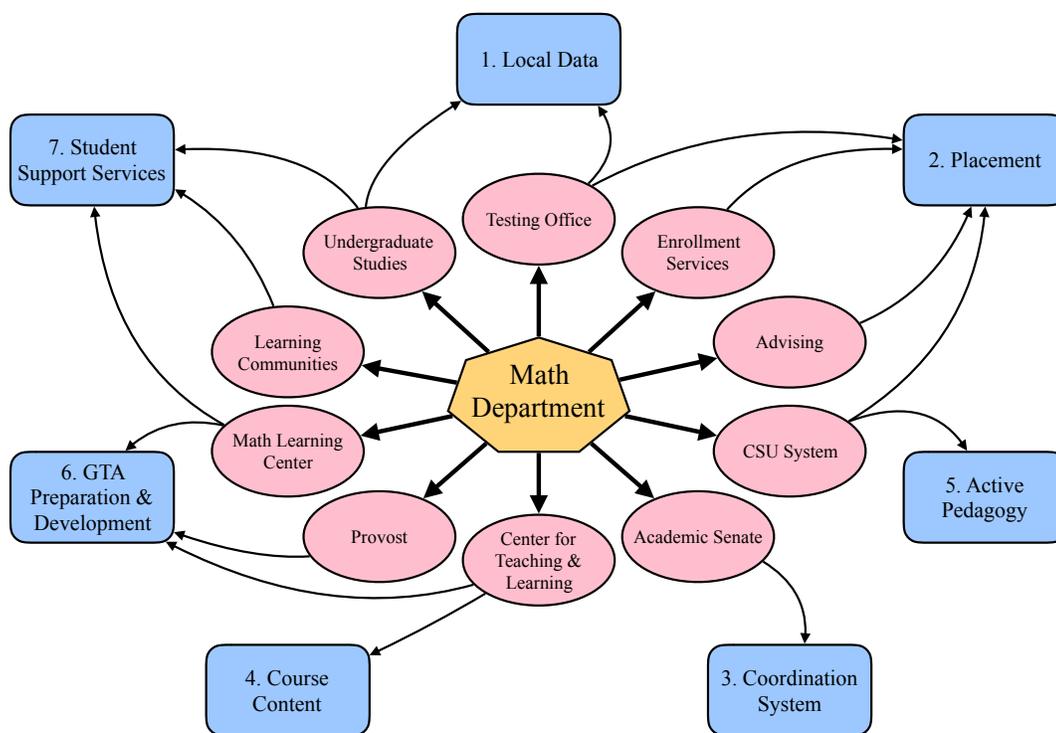


Figure 1. Significant communication channels between the department and various administrative programs.

Opportunities

At the institutional level a confluence of factors contributed to the initiation and development of our improvement efforts. First, in 2012-2014 the California State University system funded a number of “course redesign” efforts distributed to various campuses. Our department had two initiatives funded to support the use of ISAs, one in Precalculus and one in Calculus 1. These were the first two initiatives to use undergraduate ISAs in the history of our department.

Second, during this same time frame, SDSU adopted a new strategic plan entitled “Building on Success.” One of the explicit initiatives outlined to support student success called for the creation of a learning center for mathematics and statistics, our new MLC. The inclusion of an

MLC in the strategic plan meant that securing funding was less difficult than it might otherwise have been, and administrators were inclined to work with the department. The Dean of the College of Sciences (COS) insisted that the MLC be directed by the COS and led by the department, rather than relinquish control to a non-content specific office of the university. Administrative support was also key in securing the large, open space in the library that the MLC now occupies. Having administrators invested in the MLC also helps ensure its continued funding.

A third institutional-level change was the switch to using ALEKS for placement. This suggestion was actually initiated by an associate dean in the College of Science. This was coupled with concerns from the Testing Office that some students seemed to have access to the solutions to the existing placement exam. As noted earlier, although it seems easy to simply switch to a new assessment instrument, we found that required a great deal of the chair's time to communicate with the ALEKS Corporation, the Testing Office, the student advising apparatus, and the university technical team that deals with information flow between ALEKS and campus systems. The Associate Vice President for Academic Affairs and the Associate Dean provided vital support for the change.

Working with the university, the chair served on a task force created by the Academic Senate that was convened to assess the impact of large classes and seek some key points where class size reduction would have a significant payoff. The chair, with broad support from the department, proposed a relatively low-cost change: increase the number of TAs and decrease the number of students they taught per week so that they would come to know their students better. The Associate Vice President for Academic Affairs who served on the Senate Task Force eventually supported the proposal, so that, with the addition of the dean's approval, one-time funds of \$90,000 were allocated. This seemingly simple change has had significant positive ripple effects, and dovetailed well with the initiatives to increase TA professional development, infuse active learning into discussion sections, and improve students' transition to college by providing someone who knows their name and cares about their success.

At the department level, the wave of new faculty hired between 2014 and 2015 brought enthusiasm and energy to the department as well as new perspectives and experiences from other institutions. They expressed dismay at the low level of preparation of students entering upper division mathematics courses. There was particular surprise among these new members of the department at the lack of coordination of P2C2 courses in comparison to other institutions where they had worked. A more gradual shift in department culture was the general easing of historical conflicts and tensions, and the development of more respect for and willingness to work with mathematics educators.

Another crucial piece of the puzzle at the department level was that the new chair (a mathematician, appointed in 2014) made the improvement of lower division mathematics instruction his first priority. He was eager to work toward student success, to bring the different factions within the department together to address the issue, and to take advantage of all opportunities that presented themselves. It is critical to note that he was not an authoritative figure who ordered improvements, but rather a principled mediator who was respected and trusted by department members. When concerned parties (e.g., students; faculty; campus program directors) brought issues to his attention, he investigated them carefully and was genuinely upset with the overall situation and reputation of the P2C2 program. He brought mathematics educators and their expertise to bear on problems they had knowledge of, going a

long way toward healing the historical divide in the department and leveraging resources that had long been ignored or undervalued.

We+ have also benefitted from partnerships outside our institution. The department chair attended meetings of CSU chairs which led to increased cooperation with other institutions in the system. He and other leaders in the department began participating in national meetings related to education and developing new relationships with like-minded others. These include the AMS Committee on Education, the Transforming Post-Secondary Education meetings, and conferences sponsored by the CSPCC and PtC research projects. One particularly important connection comes from our association with the Mathematics Teacher Education Partnership (MTE-P), giving us access to a networked community of educational researchers working to improve mathematics teachers at the K-16 levels. Several members of our department, including the chair, are now involved in the Active Learning in Mathematics Research Action Cluster within MTE-P, and a new NSF project about institutional change. When our change initiatives were in their infancy, we+ were able to draw on this large network for ideas and advice about their design, and even to bring participants to SDSU to speak about their programs.

Calculus Task Force

One of the most important elements of our improvement process was the formation of the Calculus Task Force (CTF) in Spring 2015. The goal of the group was to assess the P2C2 program and determine how it might be revitalized within our particular institutional constraints. This group looked into mathematics education research and brought in speakers from some more successful institutions for inspiration and guidance. A key feature of the CTF was that, by design, it included faculty with diverse interests and spheres of influence in the department – some interested in making changes and some who were more skeptical – altogether five mathematicians, three mathematics education faculty, and two senior engineering faculty. The CTF compared our exams with those from other institutions, discussed programs at other institutions, and communicated informally with members of the department. Visitors from several universities with innovative programs (e.g., University of Arizona, University of Michigan, South Carolina University) gave colloquia talks and met with faculty to discuss their programs in depth. The CTF reviewed data about our program, developed initiatives to address our problem areas, and drafted proposals for consideration by the wider department.

The CTF was especially influential in implementing the coordination system. After agreeing to the extensive coordination plan and role of teaching assistants described earlier, they prepared proposals for consideration by the department. Concerns were raised about instructor autonomy and some faculty expressed resistance to participating in a coordinated course. These faculty were assuaged with assignments to other courses, thereby generally sidestepping the entire issue. The CTF also recognized that if exams were held in the evenings at a single time, instructors would actually gain several class periods for instruction, and used this argument to reduce resistance to the introduction of common exams. In the end the proposal was strongly supported by a majority of the department and the proposal was approved. Members of the faculty have expressed an appreciation for the task force, and in particular its composition, as building their confidence in the initiatives and ensuring their voices were heard.

Where We+ Are Going

While faculty in the department have many ideas for future work, we+ must continue to monitor the initiatives already in place and modify them as needed. This includes, first and foremost, listening to stakeholders – both students and instructors – and responding to their concerns and needs. We+ will continue to collect data about grade distributions and course-taking

patterns, with increased attention to following students through the P2C2 sequence and identifying bottlenecks that continue to thwart student success. We+ have begun this process by modifying course evaluations to include language of engagement and interest, and will use verified tools to measure student attitudes and dispositions towards the program (Bowers & Smith, 2016). This data will allow us to best design and implement initiatives and modifications, as well as make a case to the administration for continued support, financial and otherwise.

Based on existing feedback, we+ will be working hard to continue the integration process and ensure that our initiatives support one another. In particular this will involve integrating the lab activities more closely with the courses they are part of, and tweaking the teaching preparation program to address concerns and issues raised by the first crop of TAs teaching the active learning labs. The lab activities themselves will continue to be revised and improved iteratively in coordination with each course. We+ will also be working to make the TA professional development program as coordinated as possible, ensuring a consistent experience throughout TAs' teaching tenure. The MLC is developing ever more robust and worthwhile programs; in addition to walk-in tutoring, they are working to implement an online appointment system, online tutoring for students who commute, targeted workshops, and support for mathematical software (e.g., R, MATLAB).

The existing Compact Scholars program involves undergraduate students who are working to implement supplemental instruction (SI) based approaches to teaching the learning communities. These undergraduates are also required to attend lecture. In the Fall 2016 semester one of the Calculus instructors will leverage the presence of these SI leaders in the lectures by asking them to function as Learning Assistants, following the lead of Precalculus instructors.

There are also some brand new initiatives we will be working to implement. We+ hope to revitalize the CTF with new charges and undergo a similar process of innovation. One of their charges will be to target issues of equity in mathematics classrooms, furthering our institution's dedication to supporting students from underrepresented groups. We+ have begun to collect data about underrepresented students, but as yet do not have math-specific initiatives to increase the diversity of successful students.

A second charge for the CTF will be to make student-centered strategies part of every course meeting. Beginning with the P2C2 courses, we+ hope to make inroads into affecting the pedagogy in regular class meetings now that they are coordinated. This might include think-pair-share activities, the use of Learning Assistants, and/or peer assisted reflection activities (Reinholz, 2015) – low-level entries into student-centered pedagogy. We+ also intend to find ways of making the professional development programs open and accessible to all department instructors teaching all courses, in the hopes that they will begin to understand more about the teaching and learning of mathematics.

Alongside pedagogy, we+ will continue working on the content in our P2C2 courses. We+ intend to develop learning objectives as a department and work to (re)design our courses to ensure that opportunities to learn important content are present, explicit, and relevant to student needs. Another target is the creation of an additional support system for students who are “just” scraping by in calculus. Other institutions report success using a one-unit co-calculus course. This would provide instruction and support in pre-calculus topics concurrently with Calculus 1, enabling students to receive remediation without falling behind their graduation schedule in STEM majors.

We+ must also consider the sustainability of our efforts. This takes on two meanings: financial and social. The financial is obvious – we+ must justify continued expenditure to

administration, and find ways around “one-time” funding opportunities to ensure that our improvements remain part of the status quo, without breaking the bank. This includes determining the cost-effectiveness of our work for the institution, and providing clear descriptions of what their money is buying for students. The social sustainability is more complex. We+ are currently riding a wave of high spirits and the general attitude towards our work is positive – but we+ must work to make these initiatives part of the culture of the department. Doing a good job takes real work, and if faculty members’ dedication begins to waver there is the risk of a reversion to the old ways.

What We+ Have learned

This article concludes with some of the lesson learned through this process. Following a brief sampling of things that went well, and things that went not-so-well, we present a few recommendations for those seeking to improve the P2C2 sequence at their own institution.

We+ realize in retrospect that if we were to choose a single guiding principle for our process it would be taking a holistic approach. This refers not only to the number of initiatives tackled at once, but to the people and programs involved. The department received a great deal of support from a variety of administrators and administrative initiatives, so we benefited from attending to the university as a whole. All members of the department were consulted for input, and the CTF was chosen to be as representative as possible. This resulted in the departmental trust in the integrity of the process. The P2C2 program was treated as a whole, with the supervisory team meeting regularly and in constant informal contact to monitor the implementation, share lessons learned, and catch problems at an early stage. For each course, there was an effort to have the coordinator, the instructors, and the TAs work as a team, with (ideally) weekly meetings and regular contact. There is also a delicate power balance between the coordinator and the other instructors that must be managed with care, to ensure that the community of instructors is not fractured by hierarchy.

While taking a holistic approach to improving our program was a daunting task, in retrospect it was a huge advantage. It meant that all initiatives could be designed to work together from the beginning, ensuring greater coherence. It also meant that the changes were distributed and shared across levels, which required communication between many different people. Having clear, transparent communication between department leadership, faculty, instructors, administrators, TAs, etc. has also been incredibly helpful. The range of perspectives and experiences that were thus brought to bear on our problems smoothed and improved the design of most of our initiatives. It has also had the unexpected benefit of breaking down division walls and making the department a more comfortable place to be. Having regular and robust communication with administrators also helped the initiatives gain official support, which we+ were able to leverage to increase faculty buy-in. While we+ had top-level support for the initiatives, the changes themselves were not mandated from on high, only supported. The initiatives were developed from the “middle-out,” starting with a small group of department leaders, moving to “bottom-up” as more of the department became engaged. We find an adage from organizational behavior, “people support what they create,” resonates with the experiences at SDSU. In order to allow many people to participate in the creation of our initiatives, we+ found ways to compensate people for participating or buying-in (e.g., course releases for coordinators) to avoid asking people to do more with less. Finally, while we took on the whole system at once, we started with small goals and gentle steps that were easier for people to adopt and work with. These have already opened the door for larger and more comprehensive steps, and we intend to continue to follow the swell.

Based on some of our missteps, we have a few pieces of advice. The first is to include *all* instructors in decision-making and course development – particularly when it comes to exams. In not doing this (at first), students and instructors developed a certain level of resentment and disempowerment. With the increased opportunities for instructors to get involved in the coordination (under the leadership of the coordinators), this resentment has eased and the scenario is approaching that which we envisioned. More practical advice is to start thinking early on about how to schedule weekly or biweekly meetings (e.g., blocking a certain timeslot from having courses) to ensure that there are no major conflicts. This was a surprisingly challenging aspect of our work, and one which could have been easily avoided. Regarding data collection, again our advice is to plan early. Having a plan for what data to collect, and how, prior to the implementation of changes would have allowed for more responsive monitoring of our progress in the moment.

Now a few words about the implementation of change initiatives. While we, and others, tout the wisdom of bottom-up approaches to changes, it is important to have top-down support and interest in improvement to get things done. The crucial piece seems to be in-department leadership. Having a department chair who actively advocates for improvement and supports was critical for our success. In building an improvement effort “up and out,” a whole group of people need to be on board. Looking back at our work, none of this would have been possible without our department chair, our associate dean, and the faculty who agreed to coordinate courses. Our path has been smoothed by the presence of mathematics educators in our midst, but having respected faculty on board has been a major factor. Finally: communicate. Talk and listen to stakeholders at every stage of the process, and really listen. Don’t dismiss resisters out of hand, work to understand why they are concerned and what can be done to assuage their fears.

As a parting thought: communication and cooperation have been key in implementing initiatives at our institution. Partnerships developed within our institution, across the CSU system, and in national networks have been invaluable resources in developing, initiating, and modifying our change efforts. We+ have learned many lessons, but cannot impress upon the reader enough the importance of communication, cooperation, and collaboration. We hope that you will find a way to join us in our efforts to improve success in undergraduate mathematics across the nation. In the spirit of communication and cooperation – don’t hesitate to call on us.

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