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Coherent Calculus Course Design: Creating Faculty Buy-in for Student Success

Dr. Doug Bullock, Boise State University

Doug Bullock is an Associate Professor of Mathematics at Boise State University. His educational research interests include impacts of pedagogy on STEM student success and retention.

Dr. Janet Callahan, Boise State University

Janet Callahan is the Founding Associate Dean for the College of Engineering at Boise State University and a Professor in the Materials Science and Engineering Department. Dr. Callahan received her Ph.D. in Materials Science, her M.S. in Metallurgy and her B.S. in Chemical Engineering from the University of Connecticut. Her educational research interests include freshmen engineering programs, math success, K-12 STEM curriculum and accreditation, and retention and recruitment of STEM majors.

Susan E. Shadle Ph.D., Boise State University

Susan E. Shadle, Ph.D. is the founding Director of The Center for Teaching and Learning at Boise State and Professor of Chemistry and Biochemistry. Susan has served on the National POGIL (Process Oriented Guided Inquiry Learning) Steering Committee and as the POGIL Project's Scholarship of Teaching and Learning (SoTL) coordinator. Her scholarly interests are focused on inquiry based learning and other active learning pedagogies, faculty development, and institutional change in Higher Education.

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Abstract

This paper recounts the process used and results achieved as first-semester Calculus at Boise State University was transformed over a period of approximately 16 months from a collection of independent, uncoordinated, personalized sections, into a single coherent multi-section course. During the process of this transformation, section size and the instructor pool remained relatively constant; however, profound changes were made across all sections in terms of pedagogy, homework, timing of course content, grade computation and exam content.

The motivation for focusing on Calculus I arose from a five-year National Science Foundation Science Talent Expansion Program grant that was awarded in 2010 to a multi-disciplinary team that spanned engineering, mathematics and science. A major grant objective was to raise first-semester, full-time retention of students in STEM majors. The projects supported several year-long faculty learning communities (FLCs) of about 10 instructors each. With significant involvement from mathematics faculty, the first two FLCs prepared the ground for pedagogical reform of calculus. In 2013-14, a final FLC was created with the express purpose of implementing consistent, student-learning focused strategies across several section of calculus.

The specific approach used to design a coherent calculus course was tied to a decision made by the FLC to use identical homework assignments, with common due dates and times. The FLC structure facilitated buy-in and rapid communication and feedback between instructors, who as they came to agreement on the exact homework exercises, also came to agreement on learning goals and content for each individual lesson. Although there was no explicit attempt to have all instructors adopt the same pedagogy or classroom practices, because FLC discussions frequently turned to pedagogy, all members of the FLC chose to adopt a similar pedagogical approach which included devoting class time to solving problems, working in small groups, facilitated by the lead instructor and a learning assistant. In subsequent semesters, all calculus instructors have opted in to the common, coherent approach to the course (except for those teaching online or honors sections).

Pass and withdrawal rates pre and post implementation reveal an increase in pass rate of 13.4% and a drop in withdrawal rate of 3.9% as a result of the project. Results from anonymous faculty surveys show that faculty in the project changed their teaching practices in Calculus, that they observed positive effects of this in their classrooms, that they took advantage of the FLC to learn from their colleagues and that their experiences with Calculus will have spillover impacts in their other classes. Results from student surveys show, among other things, that students were aware of the pedagogical difference in terms of their classroom experience, with some expressing discomfort in terms of working in groups to solve problems in class and not receiving a traditional lecture experience and others reporting group work as a valuable aspect.

Introduction: Why Design *Coherent Calculus*?

Over the past six years, STEM enrollment at Boise State University grew from 2,421 to 3,778, representing more than half of the university's undergraduate enrollment growth over that time. This growth exposed three major problems that had been lurking in the Calculus sequence.

First, there was a lack of alignment of content, despite the presence of a guiding master syllabus and a common textbook. Second, there was a lack of alignment in terms of assessment. Pass rates varied widely from instructor to instructor, creating a strong sense in the minds of students and faculty in other departments that success in calculus was dependent on luck of enrollment: "Who you took" mattered more than "What you learned." Third, the average pass rates were quite low. As a reference point, the average pass rate across the 2005-2006 academic year for Calculus I was approximately 51%.[1]

Calculus I at Boise State University serves a wide range of students. For most, the course is a gateway requirement for their degree. Much of the content in the typical Calculus I offering was selected and focused toward mathematicians, rather than selected for relevance to the study of engineering or science. Too often, and for too many, Calculus functioned as an artificial barrier to progress, resulting in dissatisfaction among constituent departments and their students. These are not unique to Boise State University. Calculus as a barrier and its apparent lack of relevance are well known and longstanding problems. Potential solutions have been identified at many other institutions. Our efforts at reform were heavily influenced by a successful first-year engineering program at Wright State University[2] and informed by research summarized by Bressoud, et. al.[3]

Boise State University's efforts have been successful because we identified and capitalized on two important sources of momentum: 1) efforts to reframe calculus content and 2) faculty development supporting calculus instructors. In 2010 we were awarded a National Science Foundation Science Talent Expansion Program grant, specifically aimed at increasing STEM graduates by improving first-time, full-time student retention. One of the elements of the project was the support of three, year-long, STEM-specific faculty learning communities (FLCs) (e.g. see Cox, 2001).[4] Based on interest from numerous math faculty, coupled with Calculus I leadership by one of the co-PIs on the grant, the latter two FLCs became exclusively focused on Calculus. These FLCs were connected to work done by one calculus instructor to reframe his calculus content toward that needed by future engineers and scientists.

This manuscript first describes the activities that led to the creation of Coherent Calculus at Boise State University. This is followed by presentation of the impact of the reformed calculus on students, student success, the faculty involved, and campus culture in general.

Activities Leading to Coherent Calculus

The faculty member who emerged as the Calculus I project leader had been refining how he taught his section over approximately 10 semesters, guided by the principle that Calculus should have relevance for students in constituent departments. Between 2004 and 2012 he taught

Introduction to Engineering, had an engineering faculty member sit in on his calculus course,[5] participated heavily in developing ways for students to prepare themselves through on-line approaches and more. A revised Calculus I course emerged over time, with content reshaped to adhere to these principles:

- Whenever possible, students work with data sets and/or continuous models selected from actual physical, biological, financial or other applied models.
- Whenever possible, Calculus concepts are introduced and motivated by application to these models and data sets.
- Whenever possible, content is presented using notation, language and conventions of the disciplines from which the models are taken.
- As much as possible, content will be relevant, recognizable, and applicable in subsequent STEM coursework.
- All content will be accessible from an intuitive or practical viewpoint. In particular, the level of abstraction will be significantly less than typically found in Calculus I.

This approach stands in contrast to traditional calculus which is more abstract, more devoted to a formally rigorous foundation based on limits and continuity, and lightly dusted with applications. Thematically the revised Calculus I class is focused on three outcomes:

- Develop geometric and physical intuition for derivatives and integrals.
- Master the standard rules for symbolic computation of derivatives and some basic integrals.
- Apply both intuitive understanding and rules mastery to solve problems.

As the Calculus I faculty leader was reshaping the content he was also moving to a more active-learning pedagogy. The course design that eventually emerged had the following features:

- Many short homework assignments with immediate computer driven feedback/assessment, typically due on a two-day cycle.
- Each assignment designed along learning cycle principles to target one or two specific learning goals.
- The vast majority of class time devoted to students working in small groups on these homework assignments.
- In-class work facilitated by lead instructor and peer learning assistant.
- Additional and more involved weekly work with written feedback.

The redesigned course was effective, but it was only one section of approximately a dozen taught each semester. Its impact on student success was therefore muted, and, because it was limited to a single faculty member, any benefits were not institutionalized.

In parallel with this focus on calculus content, we had begun engaging STEM faculty to consider course design and evidence based instructional practices. This engagement was done primarily through a faculty learning communities (FLCs) strategy. An FLC is a type of community of practice in which a group of 8-10 faculty "engage in an active, collaborative, yearlong program with a curriculum about enhancing teaching and learning and with frequent seminars and activities that provide learning, development, the scholarship of teaching, and community building."[4, p. 8] As described in the literature, these groups generally draw faculty from multiple disciplines. The underlying logic of using an FLC to promote faculty change is that "undergraduate instruction will be changed by groups of instructors who support and sustain each other's interest, learning, and reflection on their teaching."[6] Indeed, studies have shown that faculty participation in FLCs increases interest in the teaching process, enhances understanding and influence of the scholarship of teaching and learning, increases reflective practice, and promotes exploration of new teaching strategies.[7-13]

The Center for Teaching and Learning at Boise State University has had an FLC program since 2007. With the 2010 STEP grant funding, one STEM-focused FLC was launched in the 2010-2011 academic year. The next two, held in 2012-13 and in 2013-14 were focused on calculus only, as a result of intense interest by math faculty. The first calculus-focused FLC was different than other FLCs that had been supported and differed from FLCs described in the literature in important ways. Because it involved faculty from a single discipline focused on a single course, the line between individual course-based teaching projects and a collective effort to improve a multi-section course was blurred. This is reflected in the goal that participants crafted for themselves:

> The purpose of this FLC is to explore and experiment with strategies at both the individual and institutional level in order to make recommendations about:
>
> 1. practices that will substantively impact student learning and success in calculus
> 2. structures within which these practices can occur

Throughout the experience, the community held in tension the practice of a "traditional" FLC, in which the focus was on mutual support of individual projects and exploration, and that of a group focused on consensus-driven, deliverable changes to calculus. Teaching projects and pedagogical exploration were focused at the individual instructor/section level, with the FLC meetings spent discussing the projects and their ongoing results and assessment. At the same time, meetings enabled a collective exploration of course content (e.g., scope and emphasis of various calculus topics). Likewise, a decision was made in the second semester of the FLC to co-author three questions that could be placed on all final exams, creating an opportunity to "try on" and de-brief the practice of common exams across sections. The FLC also allowed the group to place their exploration in the context of STEM student success at the institutional level. Despite the goals the group set for itself, no clear recommendations for common practices or institutional structures emerged at the end of this FLC. However, the seeds for the next step, the collaborative creation of a coherent calculus course, coordinated across sections, were planted.

Creating Coherent Calculus

In the 2013-14 academic year these two paths converged. The FLC structure was used to bring together a group of Calculus instructors with the concrete goal of delivering a multi-section calculus course with agreed upon common materials. This group was led and facilitated by the instructor who had developed the revised calculus content and related pedagogy. His course materials formed the starting point for adoption of a consensually agreed upon course structure.

Recruitment for the Coherent Calculus FLC took place in October of 2013 via email to 18 instructors who were either scheduled for a section of Calculus I for spring 2014 or known to be otherwise interested in this or similar projects. Several had already participated in one of the previous STEM or Calculus FLCs. Participants were offered a course reduction or an additional stipend for participating and were expected to dedicate ~4-5 hours/week across 20 weeks of the project. The recruitment email stated the objective:

> *"[The project] is about designing a Calculus I course that can be adopted by a reasonably large number of instructors with a high level of coherence. Ideally this means that all sections assign the same homework, all sections use the same quizzes and other assessments, all sections take the same or similar exams, and --- most importantly --- all sections are focused on the same learning outcomes and are using similar methods (pedagogy) to get there. [It is] loosely defined … since no such course design yet exists."*

The recruitment email also detailed the expectations and commitments required of participants.

If you participate in [the project] your duties would be:

- *Teach at least one section of [Calculus I] in the spring of 2014.*
- *As much as possible, conduct your section coherently with all the other participants in this project. The extent to which this is possible is highly dependent on the next bullet item.*
- *Join the course design and development team. The team will meet weekly, starting this semester and continuing until the end of Spring 2014. The team will be charged with designing, testing, and refining all of the homework and assessments that will eventually be the agreed upon course materials. It is expected that the course materials will be tested in your sections of Calculus I in the spring of 2014. The aim is to have something ready for potential broader use in the Fall of 2014.*

The invitation was extended to instructors of all ranks. Six made the full commitment to join the design team: one tenured math faculty member (project lead), three full time lecturers, and two adjunct faculty. Four others (2 tenured and 2 lecturers) participated in peripheral roles, providing occasional input or feedback. The core group of six instructors had been assigned to 8 of the 13 sections of Calculus I in the spring 2014 semester. The design team convened in November of 2013 to begin work.

The task for the FLC was to agree on as many elements as possible for a common course structure that would be rigorously defined and locked in for all sections. The FLC quickly arrived at consensus on some key structural elements. They agreed to adopt a common syllabus that locked in specifications on grading, weighting of homework, quizzes and exams, final letter grade cutoffs, and typical policies. More importantly, they agreed to two critical principles of the course design:

- All sections would use identical homework assignments, both daily computer graded work and weekly instructor graded work.
- All sections would use identical timing of homework. All dues dates were identical and synchronized to class start times for individual sections.

The agreement on homework and timing of due dates meant that the team would also be unified on the content and topics to be covered in every class session, because class sessions would necessarily be built around that day's homework.

They then began their most important task: agreeing on the exact homework exercises, and therefore the learning goals and content, for each individual lesson.

This was the critical element. The entire project is based on the principle that coherence and course coordination are best achieved by agreement on homework, which in turn creates a common understanding of the learning goals targeted by each homework assignment. The FLC took as a starting point the materials already developed by the project lead in previous semesters. These were debated, vetted, and revised as needed until the group was comfortable with the content. This level of detail was applied to the first five weeks of course material. At this point the group had to commit to the use of less carefully reviewed material, because the spring semester was about to start.

As a point of strategy, there was no explicit attempt to have all instructors adopt the same pedagogy or classroom practices. However, FLC discussions frequently turned to pedagogy, partly because the pre-existing course materials had been built with a particular model in mind but also due to professional interests of the FLC members. As implementation rolled out, all members of the FLC chose to adopt something similar to the model used by the lead instructor: class time devoted to solving problems, working in small groups, facilitated by lead instructor working with learning assistant (described earlier).

During the spring 2014 semester, while the FLC members were all teaching their courses, the weekly meetings continued. Approximately half of the time was spent on continuation of the process of examining and vetting remaining course material.   All remaining time was consumed by logistical issues and in discussions of how to create, deliver and grade exams.

Most homework was computer graded with no instructor input or feedback. However, each week there was one written assignment graded by hand. All of these assignments were identical for all sections, but each instructor graded these independently. There was much discussion about the value and costs of attempting a standardized rubric. It was judged that the benefits were not worth the time and work required to come to such detailed agreement. Instead, each instructor used these assignments to define the expectations for written work that would be applied on their exams.

Instructors created separate exams. However, each exam cycle included a full review of every exam by every other FLC member. This review, plus the common base of homework and learning goals, led to a reasonable amount of similarity among exams. Instructors then graded their own exams.

One of the project goals was to build a structure that could be scaled up in future semesters. For the fall 2014 semester four of the six design team members were assigned Calculus I sections by the department chair. All chose to continue using the material and continue working as a team to refine the course. In the weeks before the fall 2014 semester all other instructors assigned to a Calculus I course were offered the option of opting into the common course structure. The offer was made with no conditions – so an instructor could simply take all of the developed material and modify it to suit their tastes. What actually happened was that every instructor (except for online and honors sections) chose to adopt all of the prepared material, all of the structure in the common syllabus, and some form of the active learning pedagogy. There were no extra incentives for this, so their decisions were presumably made on the basis of perceived intrinsic value. The result was a team of 8 instructors for fall 2014, four with prior experience from the

FLC. The instructor pool was too large to have a regular common meeting, but the new instructors were able to find support and mentoring when needed by consulting with the returning instructors.

The Impact of Coherent Calculus

The impact of Coherent Calculus at Boise State University can be measured in several ways. Below we describe the impact of the project based on student success and from the perspective of students and faculty involved as seen from course instructor surveys completed by students and by surveys on the course completed by faculty who elected to participate in an anonymous survey. We also describe the impact on faculty and comment on the degree of institutionalization of the project. All data discussed below were collected and analyzed after the conclusion of the fall 2014 semester, so the described effects represent the impact of two semesters of Coherent Calculus.

Student Success as Measured by Course Grades

Figures 1 and 2 capture the effect of the project on Calculus I as seen by enrollment and final grades across all sections over time. Figure 1 details the portion of Calculus I enrollment that, over time, has been affected by the adoption of the new Calculus materials and pedagogy.

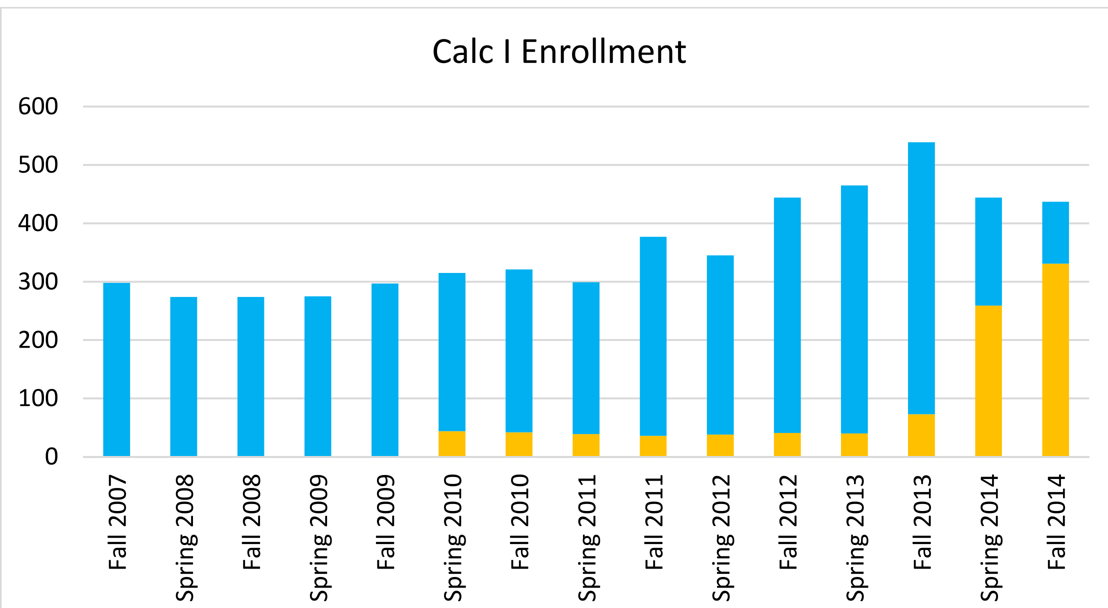

Figure 1: Total student enrollment in Calculus I (blue) and students enrolled in coordinated Calculus I (yellow).

Figure 2, using the same time axis, shows the university-wide pass rate in Calculus I, (number of A, B, C grades divided by total 10th day enrollment.) The results show a clear correlation between the implementation of Coherent Calculus across multiple sections (beginning in Spring 2014) and improved pass rates in the course.

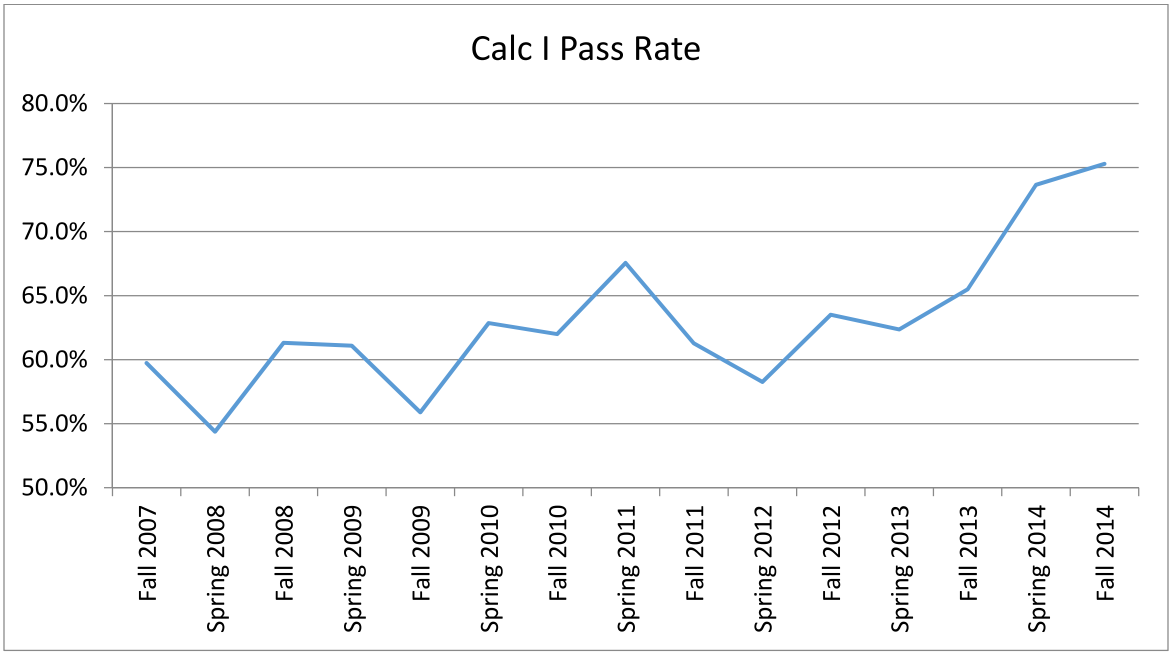

Figure 2: Pass rate in Calculus I as a function of time, spring and fall semester.

In order to further drill into student grades, an examination of course grades across six semesters was conducted. This included four semesters prior to the beginning of the project and two following the formal course coordination. Across the ten faculty who participated, six had taught Calculus I both before and after the transition, see Table 1.

The following observations are noted from this data. First, five out of six instructors showed marked increases in pass rate. The pass rate across all six instructors increased from a weighted average of 60.5% to 73.9%. Of particular note: the percentage of students earning A and B grades increased from 34.4% to 48.6%, an increase of 14.2%. Finally, the withdrawal rate decreased markedly, from 4.7% to 0.8%, a drop of 3.9%. Put in student numbers, for these 590 students following the transition, 23 more students persevered to complete the course with a passing grade than might have otherwise, and 84 more students received grades of A or B.

Table 1: Student grades awarded in Math 170 before and after the transition, by instructor.

Before the transition, four semesters

Instructor	N	A	B	C	DF	W	CW	%AB	%ABC	%W	%W+CW
1	192	44	50	52	40	5	1	49.0%	76.0%	2.6%	3.1%
2	39	5	9	11	11	2	1	35.9%	64.1%	5.1%	7.7%
3	168	8	22	62	57	12	7	17.9%	54.8%	7.1%	11.3%
4	215	27	43	42	93	7	3	32.6%	52.1%	3.3%	4.7%
5	78	17	11	13	32	3	2	35.9%	52.6%	3.8%	6.4%
6	115	18	24	30	31	9	3	36.5%	62.6%	7.8%	10.4%
Total	**807**	**119**	**159**	**210**	**264**	**38**	**17**	**34.4%**	**60.5%**	**4.7%**	**6.8%**

After the transition, two semesters

Instructor	N	A	B	C	DF	W	CW	%AB	%ABC	%W	%W+CW
1	97	23	31	27	13	1	2	55.7%	83.5%	1.0%	3.1%
2	34	9	5	14	6	0	0	41.2%	82.4%	0.0%	0.0%
3	64	6	21	19	17	0	1	42.2%	71.9%	0.0%	1.6%
4	38	9	11	4	13	1	0	52.6%	63.2%	2.6%	2.6%
5	141	25	44	31	40	0	1	48.9%	70.9%	0.0%	0.7%
6	33	7	5	5	12	1	3	36.4%	51.5%	3.0%	12.1%
Total	**590**	**119**	**168**	**149**	**140**	**5**	**9**	**48.6%**	**73.9%**	**0.8%**	**2.4%**

Student Perspectives

After two semesters of implementation, participating faculty were invited as part of this study to share their student end-of-course evaluation results (see Appendix A for details). Of particular interest were comparisons of comments pre and post-implementation of Coherent Calculus. Of the ten instructors who participated in the Calculus project, four had no record of teaching calculus prior to their participation. Of the remaining six, three elected to have their comments included as part of the analysis for this project. For these three instructors, all had taught at least one semester of Calculus prior to the project, and two of the three had taught the Coherent Calculus course for two semesters. Fall 2014 (second semester after the project began in spring of 2013) to Fall 2012 or Fall 2013 comparisons were made.

An analysis was conducted, using four of the end-of-course evaluation questions. Q1: Tell us about this course. What aspects of the course were most valuable? Q2: Tell us about this course. What barriers to learning, if any, did you experience in this course? Q3: Course Items. What suggestions do you have for improving the course? The last question analyzed was: Q4: What other comments, if any, do you have about the instructor, this course, or about this survey?

We were particularly interested in comments that would elucidate student responses to the significant changes in the course with respect to content focus and pedagogy. A thematic analysis revealed students comments in the following categories: WebAssign/homework, Pedagogy, Teacher, Learning Assistants, Exams, and Textbooks.

The overwhelming majority of comments centered around pedagogy. For most students, the opportunity to work in groups in a math class was quite different from what they would have experienced in the past. For example, while pedagogy was not mentioned in pre-Q1 responses, it was mentioned multiple times for two of the three instructors in post-Q1 (What was the most valuable aspect of the course). One student indicated: "Being led to connections of big ideas rather than told what they were…i.e. the instructor asked questions that would lead students to their own conclusions." Another mentioned: "Building understanding of larger concepts by gradually adding together many smaller concepts." Many others, for two instructors, described group work as being a valuable aspect (post): "I really learned the value of teamwork. I worked hard to get a good grade in class, but I wouldn't have done nearly as well as I did if it wasn't for the people I sat with and worked with everyday." Not surprisingly, many students also put comments about pedagogy under post Q2, barriers to learning experienced in the course. These all had a similar theme, describing discomfort with not being taught, or getting direct answers to questions. For example, "At times I felt like I wasn't being taught, I was just told to read the notes and learning goals." Or, "The instructor didn't really teach…it seemed like we taught ourselves." And, "A barrier I noticed was lack of time spent on actually learning the material…it seems that we spent most time just doing homework in class." One was particularly blunt: "I hate the workshop theory, let teachers lecture and pass on what they know. Quit asking students to "discover" the concepts." Some students were self-aware in terms of their own comfort level: "Sometimes I was frustrated that we didn't lecture longer rather than doing homework, but as the semester continued I kind of got used to it." The quantity of students who commented positively on pedagogy (post) (15) was approximately the same as those who commented negatively on pedagogy (post) (16).

Pedagogy emerged again in terms of suggestions for improving the course (post-Q3) – a few students expressed a desire to have more lecture and less learning on their own: "Instruct the material in class instead of making the students figure it out on their own time." It was also mentioned by a few students in terms of post-Q4 which asked for any other comments: "This is the second time I've taken calculus and it was a lot easier to understand because of the way it was taught," and, "The whole concept of making the students figure it out on their own for this kind of class seems like it goes against the whole point of why we are taking this class and why I'm paying money for an instructor to teach the class when they don't actually teach the course material."

Only minor and typical comments were made about teachers (e.g. teacher availability, clarity, etc.), textbooks (waste of money, not used enough) and exams. One instructor received a few comments about their exams, with one student suggesting they use the standard ones from the department – indicating an awareness of students across sections that such an option was available.

WebAssign/homework was the only other significant emergent theme from student comments. Many students had been exposed to ALEKS, an online learning tool that provides very articulated example problems, and expressed a wish for WebAssign to include examples of how problems are worked, for example, "It does not adequately assist students in learning. There is no immediate feedback when doing assignments other than a right or wrong answer. This makes it very difficult to understand what you have done wrong." Complaints about WebAssign were numerous (N=13). One student however, remarked (post): "The homework was strangely satisfying and helped a lot with understanding topics."

These comments suggest that many students were aware of the pedagogical difference in terms of their classroom experience. That so many students remarked on pedagogy indeed indicates a significant shift had taken place. It is not uncommon for there to be resistance from students when there is a significant change in pedagogy from lecture format to a format where students are active in the classroom.[14-16] In the future, faculty in the project could be better supported to help students transition to this more active learning environment.

Interestingly, the analysis of course evaluations did not reveal any comments which indicate that students noticed or appreciated the shift in content focus. This is likely because most students didn't have any basis for comparison; they didn't know how it had been different before. It is also the case that the shift in content focus was eclipsed by the shift in pedagogy for most students in the course.

Faculty Perspectives

After two semesters of implementation, the effectiveness of the project from the perspective of the faculty involved was assessed as part of this study using a five-question survey conducted at the end of the fall 2014 semester (see Appendix A for details). The survey was distributed to the nine faculty members who participated in the Coherent Calculus project in fall 2013, spring 2014 and fall 2014. The lead faculty member was left out of this survey. Eight of the nine responded. The survey asked about participant motivation, whether and how participation changed their teaching practices, participant's opinions about student engagement, and what benefits there may have been to participating in the project. Most of the questions were open-ended so as to capture instructor perceptions without influencing their responses. The relevant survey questions are included in Appendix A.

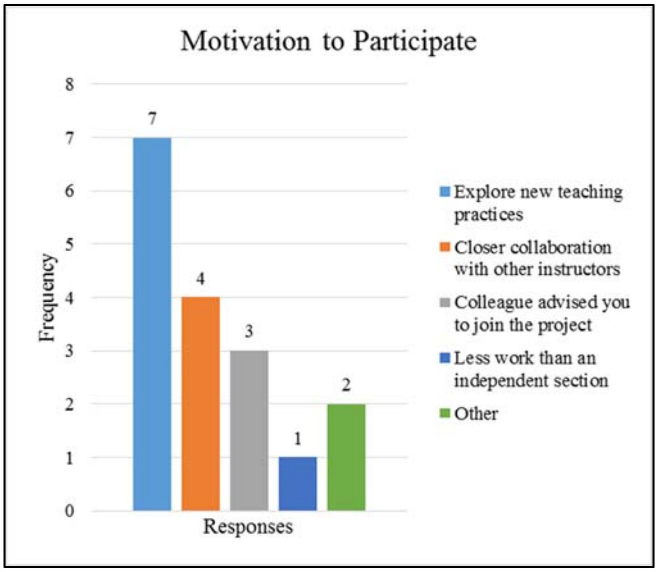

Figure 3: Instructor's motivation to participate in coordinated calculus project.

Instructors were asked, **"What motivated you to participate in the coordinated calculus project? Select all that apply. Select all that apply."** Results are shown in Figure 3. Most participants were motivated by an interest in exploring new teaching practices. Approximately half the participants were motivated by factors that related to connections with colleagues. Two colleagues indicated “other” responses: one deemed it politically wise to join, and one replaced an instructor who had originally been in the project.

When asked, **“Did your participation in this project change your teaching practices in any significant way?”** seven out of eight respondents indicated that it had. For respondents who answered “yes,” they were asked, **“Please describe at least one feature of your teaching practice that is different as a result of your participation.”** Six responded that they spent less time lecturing, with students spending time in class working on material on their own, e.g.: “Giving time in class for students to do more work and less just watching me do problems.” One commented here about increased student engagement: “The collaboration opened up different ways to present the same material. The major effect is that more students are staying engaged in the class. I started with 26 students and 25 took the last exam. I expect all 25-26 to participate in the final exam.”

Importantly, the impact on pedagogy appears to extend beyond Calculus I, Figure 4. When asked if participation impacted teaching practice in other courses, five instructors selected “As a result of the project, I have considered changes to my practices in other classes” and two faculty indicated “As a result of the project I have implemented changes in other classes.” Only one respondent indicated that “Any changes were restricted to the Calculus course taught as part of the project. I have not changed my practices in other classes.”

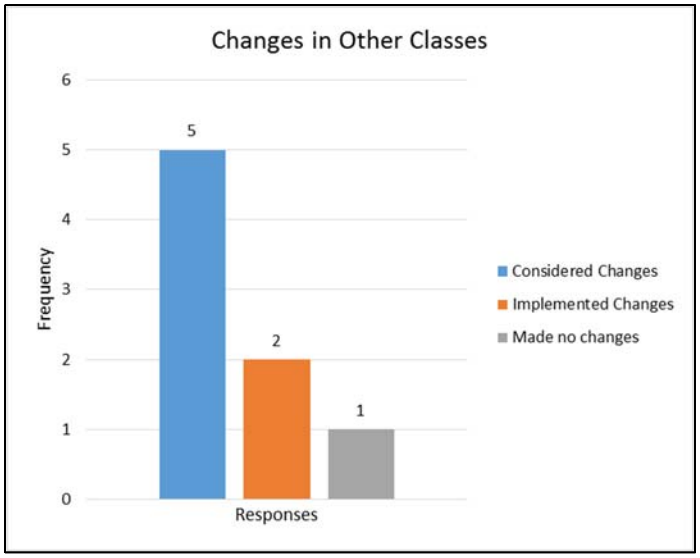

Figure 4: How has participation in the Calculus I project influenced your teaching practices in other courses?

The next question asked, **“In your opinion, was student engagement significantly different in your Calculus course, compared to your overall impression of student engagement in other courses you have taught?”** Five out of eight respondents affirmed a significant difference. The follow on question asked **“Please describe at least one thing that was different.”** Two instructors commented on aspects related to attendance: “Since work was being done in class I had better attendance because students saw a direct impact in attending class,” and “This was different in the past where students didn’t engage in classroom lectures, ask questions and eventually stopped showing up in class.” Three respondents discussed aspects associated with working in class. One remarked, “By working in groups the students were able to discuss freely the concepts and algebraic simplifications. When they do it, they remember it. If I do it on the board, they have not gone through the whole thought process and often get lost.” Another indicated: “They are actively working, not just trying to pay attention.”

Finally, "Some of the groups of students spent more class time reasoning through the material rather than listening and taking notes."

Taken as a whole these survey responses indicate that faculty in the project changed their teaching practices in Calculus, that they observed positive effects of this in their classrooms, that they took advantage of the FLC to learn from their colleagues, and that their experience with Calculus will have spillover impacts in their other classes. These conclusions are reinforced by one last survey question.

The last survey question inquired, "Were there any other benefits to participating in the calculus project?" All eight respondents answered in the affirmative and described these benefits, which are summarized in Table 2.

Table 2: Other Benefits from Calculus Project

It showed not only a willingness to work together in a teaching community but an actual desire to share one's own thoughts about teaching calculus as well as listening to others. As a result all the participants were active in sharing their experience and improving the quality of their course.
It was helpful to have someone else's perspective on the tests that I had written. They were open to discussion and revision (for the better). Also helped me with my weakness of typos (form and from, sign and sing, etc).
Being able to bounce ideas off of other instructors and gain from each other's strengths.
Opportunity to see others' [instructors] assignments and how they approached course topics.
Better instructor interaction and student understanding.
Group protection from student complaints.
Better instructor interaction and student understanding.
I think that the students who really bought into the program were able to reason through test questions better. They were better able to detect when they were making mistakes and had some ideas on how to fix them.
Getting to know students on a more personal basis rather than just as a name...believe it helped with classroom interaction and participation.

Faculty Development and Institutionalization

The project had the specific goal of creating and delivering a multi-section course using common course materials. This was achieved. However, there were deeper institutional and faculty development goals, including the following

- Shift the teaching culture to be accepting of the trade-off of autonomy versus common course material and common grading standards.
- Shift the culture of practice from individual responsibility for single sections to team-based responsibility for a multi-section course.
- Create and sustain conditions for regular exchange of ideas and practices between instructors.
- Move faculty towards more active learning or student-centered pedagogy.

That we have moved toward the achievement of these goals is evidenced by the fact that in the two semesters following the project launch (fall 2014 and spring 2015) all Calculus I instructors have been invited to voluntarily join the team and to have their sections use common materials. So far 100% of instructors outside of online or honors calculus have opted in. Every new instructor has opted into every feature of the coherent course. Also, in the last two terms the common structure has moved to include some common exams in fall 2014, and entirely common exams in spring 2015.

Discussion and Summary

In summary, the project succeeded in creating a sustained culture of collaboration for the purpose of delivering Calculus I. It had significant impact on the pedagogy used in Calculus I and it had the spillover effect of shifting faculty teaching practices outside of Calculus I. The changes had a large effect on student success, including a profound impact on student success as measured by grades, as seen by an increase in pass rates, by an increase in the percentage of students receiving course grades of A and B, and by a decrease in withdrawal rates. The pedagogical emphasis on group work/collaboration, noted in student comments as being a "valuable aspect of the course," may have profound and long-term impact on student persistence and success in major, due to the increased student engagement with one another and a possible future outside-the-classroom effect on student behavior.[17, 18]

It demonstrated a viable path to course transformation that does not rely on a top down command structure. We could have designated someone to coordinate and manage the course. That person might have enforced a common syllabus and grading policy, chosen an appropriate content focus and trained faculty in a particular pedagogy with requirements for their implementation. This paper describes an alternative strategy of cultivation, support and collaboration. It begins with a decision to agree on the homework. Next comes agreement on and definition of the skills and objectives that the homework is designed to deliver. This in turn gives definition to exams, grading practices, standards and course level objectives. Consensus on the higher level aspects flowed readily from the initial decision to agree on the homework. The end result was a significantly changed course that was consensually agreed upon and rapidly adopted by essentially all instructors without any coercion.

Future Work

While we view the positive outcomes as strong indicators of success, we also recognize that we must continue to attend to the sustainability of the project. We have identified a second faculty member who will share managerial workload with the original project leader. Together they can support instructors who come into the project. Additionally, we will continue to provide faculty development both through the department and through the Center for Teaching and Learning to be sure faculty have what they need to teach the Coherent Calculus. This will allow us to help faculty address areas of concern such as the fraction of students who perceive it would be better to be lectured to during class.

The Calculus I project scaled up more quickly and achieved wider buy-in than was initially thought likely. While this is a clearly positive development, it means that Calculus II is now an urgent priority. The same project lead, working closely with one member of the FLC team, is currently launching a Calculus II project with the same general plan but an accelerated time line:

- Spring 2015: reframe and revise content.
- Fall 2015: form an FLC to review and revise content, creating buy-in along the way.
- Spring 2016: Launch a multi-section course.

Although the Calculus I project originated in a move away from the traditional course content, there is one clear advantage to the traditional content – when students move on the Calculus II their instructors will expect a traditional Calculus I background. While we are happy with the new Calculus I content as a self-contained course, there is a real possibility that it aligns poorly with the traditional Calculus II content that students encounter one semester later. We have recently begun building tools to measure the effects of Calculus I reform on Calculus II students, as well as other downstream courses. Future work will be informed by this data. This is likely to impact both the Calculus II content currently being built and to indicate areas where the Calculus I content can be strengthened. Finally, the coordinator and instructors of Calculus III and Differential Equations are becoming interested in the Calculus I and Calculus II projects, so there will be additional collaboration up and down the entire course sequence.

Awareness of the project has already spurred interest from those who teach outside the Calculus sequence. There are nascent efforts to apply the coordination model to Business Calculus and General Statistics. Two instructors of Linear Algebra have already run a course using common homework. And the group that oversees our multi-section Scientific Computing course is considering a similar approach. If successful, these efforts would achieve full coordination of the entire suite of service courses across every STEM or related discipline.

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References

1. Bullock, D., Callahan, J., Ban, Y., Ahlgren, A., Schrader, C. (2009). The implementation of an online mathematics placement exam and its effects on student success in precalculus and calculus, American Society for Engineering Education Annual Conference & Expo, AC 2009-1783.

2. N Klingbeil, A Bourne. A National Model for Engineering Mathematics Education: Longitudinal Impact at Wright State University. 200th Proceedings of ASEE Annual Conference & Expo (2013).

3. Bressoud, D., M. Carlson, J.M. Pearson, C. Rasmussen. 2012. Preliminary Results of the Study of Characteristics of Successful Program in College Calculus. 12th International Congress on Mathematics Education. Seoul, Korea, July 8-15 (2012).

4. Cox, M.D., & Richlin, L. (Eds.) (2004). *New directions for teaching and learning, No. 97. Building faculty learning communities*. San Francisco, CA: Jossey-Bass.

5. Callahan, J., Bullock, D., Chyung Y. (2012) "Both Sides of the Equation: Learner and Teacher," American Society for Engineering Education Annual Conference & Expo, San Antonio, TX, AC 2012-5051.

6. Borrego, M. & Henderson, C. (2014) Increasing the use of evidence-based teaching in STEM higher education: A comparison of eight change strategies. *Journal of Engineering Education*. 103(2), 220-252.

7. Beach, A. L., & Cox, M. D. (2009). The impact of faculty learning communities on teaching and learning. *Learning Communities Journal*, *1* (1), 7-27.

8. Dees, D. M., Zavota, G., Emens, S., Harper, M., Kan, K. H., Niesz, T., Tu, T-H., Devine, M. A., & Hovhannisyan, G. (2009). Shifting professional identities: Reflections on a faculty learning community experience. *Learning Communities Journal*, *1* (2), 49-73.

9. Nadelson, L. S., Shadle, S. E., & Hettinger, J. (2013) A journey toward mastery teaching: STEM faculty engagement in a year long faculty learning community. *Learning Communities Journal, 5*, 97-122.

10. O'Meara, K. (2005).The Courage to be Experimental: How one faculty learning community influenced faculty teaching careers, understanding of how students learn and assessment. *Journal of Faculty Development, 20*(3), *153-160.*

11. O'Meara, K. (2007). Stepping Up: How one faculty learning community influenced faculty members' understanding and use of active learning methods and course design. *Journal on Excellence in College Teaching.* 18(2), 97-118

12. Smith, T. R., McGowan, J., Allen, A. R., Johnson, W. D.,II, Dickson, L. A., Jr., Najee-ullah, M. A., et al. (2008). Evaluating the impact of a faculty learning community on STEM teaching and learning. The Journal of Negro Education, 77(3), 203-226.

13. Sirum, K. & Madigan, D. (2010) Assessing how science faculty learning communities impact student learning. Biochemistry and Molecular Biology Education, 38, 193-202.

14. Michael, J. (2007). Faculty perceptions about barriers to active learning. College Teaching. 55(2), 42-47.

15. Henderson, C., Dancy, M.H. (2011) Increasing the Impact and Diffusion of STEM Education Innovations. A White Paper commissioned for the Characterizing the Impact and Diffusion of Engineering Education Innovations Forum. Retrieved from https://www.nae.edu/File.aspx?id=36304

16. Wright, E.L., & Sunal, D.W. (2004). Reform in undergraduate science classrooms. In D.W. Sunal, E.L. Wright, & J.B. Day (Eds.), Reform in undergraduate science teaching for the 21st century (pp. 33–52). Greenwich, CT: Information Age

17. Kogan, M. & Laursen, M.L. (2014) Assessing Long-Term Effects of Inquiry-Based Learning: A Case Study from College Mathematics. *Innovative Higher Education*, 39(3), 183-199

18. Springer, L., Stanne, M.E., Donovan, S.S. (1999) Effects of small-group learning on undergraduates in science, mathematics, engineering and technology: A metaanalysis. *Review of Educational Research.* 69(1), 21-51.

Appendix A:

A.1 [[http://hausdorff.boisestate.edu/14spring170/gen_syllabus.htm]]

Survey

Email 1: Script for email for recruitment of instructors:

You are being asked to participate in the following research study, "The Effectiveness of the Implementation of a Coordinated Calculus Course and its Impact," because you were part of the coordinated calculus project. Your feedback will be used at an aggregate level to evaluate the effectiveness of the implementation and its impact.

Participation is voluntary and anonymous. X and Y are the co and principal investigators on this project. Results will be aggregated and shared with the calculus course coordinator and the Director, Center for Teaching and Learning who have worked on the project and some of the results may be reported in a publication or to the National Science Foundation.

Because this study involves human subjects, informed consent is required. The first page of the survey contains an online consent form. Participating in the study should take approximately 30 minutes. The study has five questions, some of which are open response questions.

Go to Survey [hyperlink]

A.2 Faculty Participant Survey:

This survey has 5 questions, some of which are open response questions. It is expected to take approximately thirty minutes to complete.

1. What motivated you to participate in the coordinated calculus project? Select all that apply:

Less work compared to an independent section

Opportunity for closer collaboration with other instructors

Opportunity to explore new teaching practices

A colleague advised you to join the project.

Other: (written response)

2. Did your participation in this project change your teaching practices in any significant way? Yes/no

2a. (If yes from 2) Please describe at least one feature of your teaching practice that is different as a result of your participation.

2b. (If yes from 2) Please select the statement that you most agree with:

A. Any changes were restricted to the Calculus I course(s) I taught as part of the project. I have not changed my practices in other classes.

B. As a result of the project, I have considered changes to my practices in other classes.

C. As a result of the project, I have implemented changes in other classes.

3. In your opinion, was student engagement significantly different in your Calculus I course, compared to your overall impression of student engagement in other courses you have taught.   Yes/no

3a. (If yes to 3) Please describe at least one thing that was different.

5. Were there any other benefits to participating in the calculus project? Yes/no

5a. (If yes to 5) Please describe.

Thank you for participating in this survey.

A. 3: Email 2: Request to Instructors Regarding Course Evaluation Data:

To understand how student perceptions of the course may have changed as a result of the coordinated calculus project, we would like to access your course evaluation data for Math 170. This data would be accessed without needing your assistance, (other than your permission) and rendered anonymous so that no identifying comments or other features can permit identification of you as the instructor (e.g. if a student would write, “Dr. Jones speaks too softly,” we would replace that with “Instructor 1 speaks too softly.”) Please indicate what level of access to your course evaluation data you would permit by reply email (reply A, B, C or D).

A. No access to the course evaluation data collected for my course.

B. Access to numerical data for these four specific questions only:

1. The WebAssign homework was valuable to my learning.
2. The weekly written homework was valuable to my learning.
3. The in-class warm-up exercises were valuable to my learning.
4. Class time used for students working on problems was valuable to my learning.

C. Access to all numerical data, but not to student comments, from any semester going back three years.

D. Access to the all course evaluation data going back three years.